June 2021

CREDIT SUISSE

Research Institute

The global food system: Identifying sustainable solutions

Thought leadership from Credit Suisse and the world's foremost experts

Introduction

In my new role as Chairman of Credit Suisse, I am delighted to introduce the first study from the Credit Suisse Research Institute under my tenure, with its accent firmly on sustainability.

Sustainability is, rightly so, a key component of Credit Suisse's strategy and culture, which importantly shapes solutions we provide for our clients.

"Investing with purpose" is the underlying theme of our recently published investment Supertrends. Aligned with such thinking, the Credit Suisse Research Institute has been tackling topics such as energy transition and the consequences of growing water scarcity in its recent studies. This report now throws a spotlight on the global food system.

I hope you find our insights in this study valuable and wish you a stimulating read.

António Horta-Osório
Chairman of the Board of Directors
Credit Suisse Group AG

Cover photo: Getty Images, Sompong Sriphet EyeEm; photo right: Getty Images, alvarez

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The investor view

This Credit Suisse Research Institute report on sustainable food provides a deep dive into the challenges associated with the need to make the global food supply system more sustainable. With the world's population set to increase to about ten billion by 2050, it is clear to me that a change in what we eat, how much we eat, and how we produce food is paramount. For businesses and investments, this will give rise to both opportunities and disruption.

Changing diets
Our health is the single biggest driver of human longevity and productivity, as well as total labor input. Or, as I like to put it, it is our most valuable asset. Yet the sad truth is that too many people, though aware that they may not live healthily, do not know how to begin the change. I have experienced first-hand the strong impact that a healthier diet can have by adhering to a few simple principles that are also highlighted in this report: avoid consuming sugary foods, processed foods, refined grains and trans fats, reduce consumption of meat and dairy, and increase the intake of vegetables, natural vegetable fats and fibers. Adherence to these principles has been a game-changer in terms of my overall well-being.

Applying these principles on a broad scale is arguably a substantial challenge given people's lifestyle and eating habits and requires being equipped and supported to do so. However, as this report outlines, it is a challenge that must be tackled given that the authors estimate the total cost of malnutrition to the global economy at USD 13.6 trillion annually.

Food and the sustainability revolution
Addressing the challenges of feeding the planet better and more sustainably first requires access to better dietary education. Importantly, it also means that healthy food must become more available and more affordable, as more than three billion people around the world are not even able to afford a healthy diet. For this to succeed, powerful lobbying groups must also be challenged, in my view.

Unhealthy diets and eating habits are the root cause of the unspoken pandemic of our day and age, leading to various chronic diseases that cause substantial human suffering and economic costs. I expect governments and regulators to focus on food and health to the same extent as on climate change, inevitably triggering a new major trend.

Sustainability, now much more than a buzzword for many sectors, is a risk that companies must adequately manage. And, as other sectors before it, the food industry is going to be increasingly scrutinized by investors, consumers and regulators, pushing it to focus more on sustainable food.

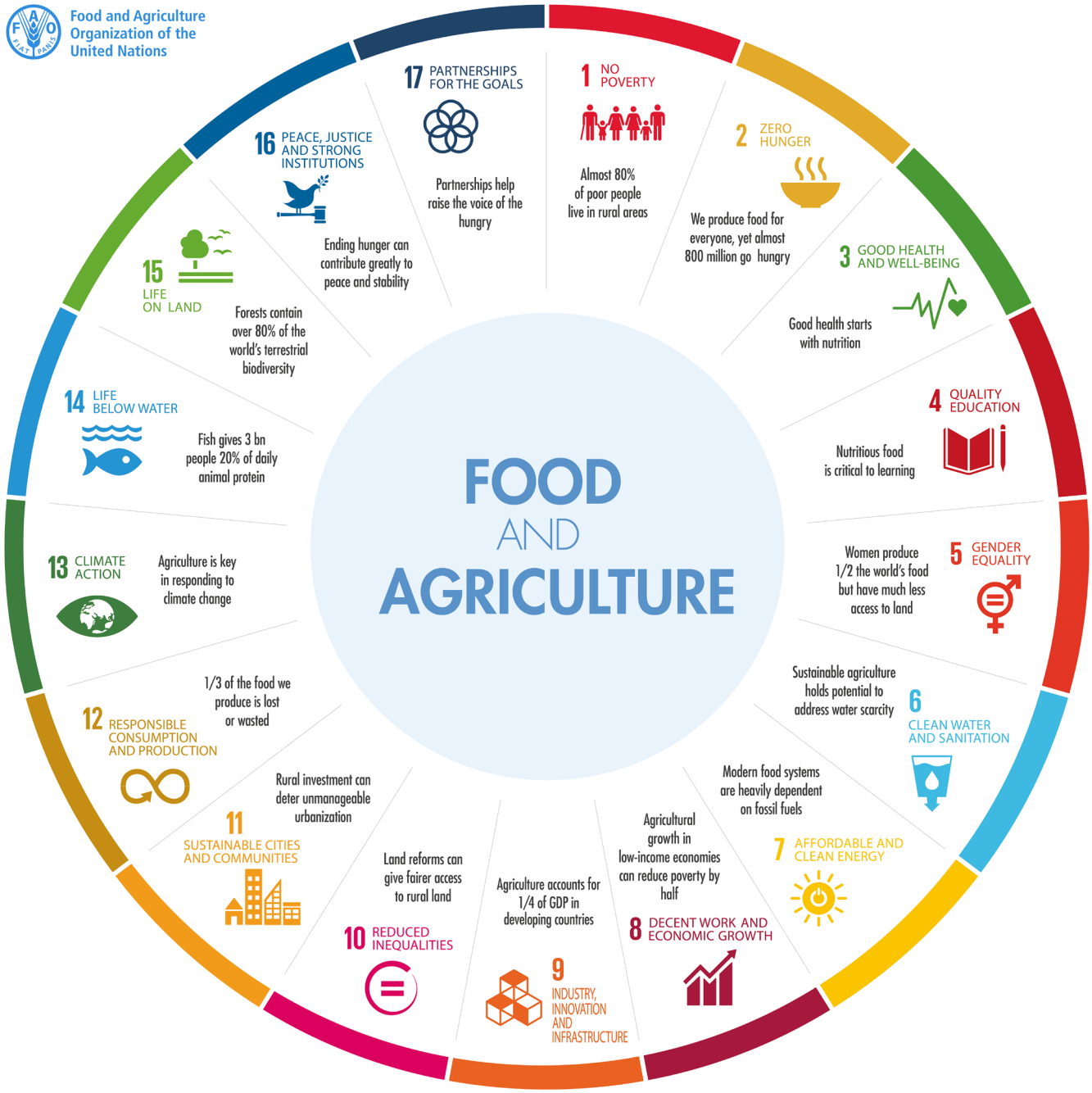
Digital agriculture and circular solutions to address food loss and waste
As this report highlights, there are likely beneficiaries, too, including technology companies providing "smart-agricultural" solutions, for example. Vertical farming could provide 80% of food demand in urban areas, while precision farming through the use of artificial intelligence, drones, autonomous machinery and smart irrigation systems could yield productivity increases of 70% by 2050. Companies that help address food waste and loss, for instance using circular-based solutions, are likely to multiply. Moreover, smart-packaging solutions are being developed that not only improve production yields, but also help reduce food loss and waste across the entire supply chain, from farm to home. The development and introduction of cooling and storage solutions would help extend the lifespan of food even more.

The role of investors
I am convinced that investors play a significant role in catalyzing these likely trends in how they deploy their capital. This report provides an important starting point and reference with regard to the different aspects that need to be considered. The rewards are ours to reap.

Michael Strobaek
Global Chief Investment Officer
Credit Suisse

The food system impacts all SDGs

The relevance of a sustainable food system to the UN Sustainable Development Goals



Source: The Food and Agriculture Organization of the United Nations (FAO)

The global food system covers all activities related to food production and consumption from "farm to fork." A sustainable food system is highly relevant in relation to the 17 Sustainable Development Goals as introduced by the United Nations in 2015. In fact, we agree with analysis done by the UN that all of its 17 SDGs benefit from a more sustainable food system. To put it another way, meeting the 2030 targets associated with the SDGs appears highly unlikely in our view unless action is taken to make the global food system more sustainable.

The double burden of malnutrition

A sustainable global food system benefits human health as well as the global ecosystem. However, this is far from the reality at present as almost 700 million people are undernourished, while at the same time around 1.8 billion people globally are overweight or obese. The need to change appears obvious to us as the impact of malnutrition alone costs the global economy USD 13.6 trillion annually.

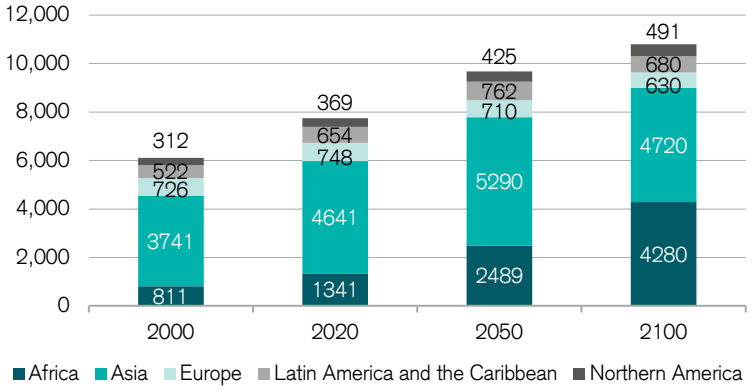
Demographics add pressure to the challenge

We will highlight the current reasons why a shift in food production and consumption toward a more sustainable system is needed; however, it is important to understand that, if unaddressed, these challenges will significantly worsen in the future, partly because of the potential demographic changes that the world is likely to experience this century.

Estimates from the United Nations indicate that the world's population may increase from around 7.8 billion this year to almost ten billion by 2050, and close to 11 billion by 2100. **Figure 1** shows how expected population growth is unevenly distributed around the world, with 93% of growth expected in the next three decades occurring in lesser-developed Africa (59%) and Asia (34%). The implications for food production cannot be overstated, in our view.

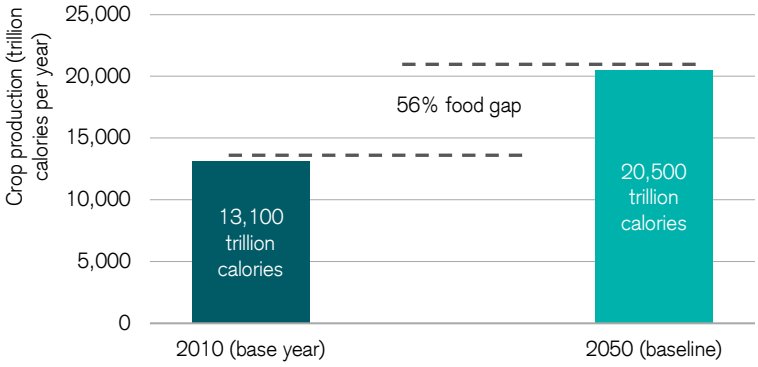
Estimates from the World Resource Institute (WRI) indicate that total food production (in terms of calories) needs to increase 56% between 2010 and 2050 in order to feed the expected population. We note, however, that these estimates are conservative given that they do not assume the calorie intake of consumers across developing countries will converge fully

Figure 1: Population growth estimates (m)



Source: United Nations, Credit Suisse Research

Figure 2: Total calorie consumption globally



Note: Includes all crops intended for direct human consumption, animal feed, industrial uses, seeds, and biofuels. Source: WRI analysis based on FAO (2019a); UNDESA (2017); and Alexandratos and Bruinsma (2012)

Table 1: Scenario for animal food intake by region, 2010–50

Region	Population (m)		Total animal-based foods				Ruminant meat (beef, sheep, goat)			
	2010	2050	kcal/ capita/day (2010)	kcal/ capita/day (2050)	% change per capita (2010–50)	% of global consumption – 2050	kcal/ capita/day (2010)	kcal/capita/ day (2050)	% change per capita (2010–50)	% of global consumption – 2050
European Union	528	528	772	858	11	10	68	71	4	7
USA and Canada	344	433	774	794	3	7	92	82	–10	6
Brazil	197	233	629	748	19	4	140	153	9	6
China	1,390	1,396	551	716	30	21	33	62	87	15
Former Soviet Union	288	298	575	704	22	4	93	119	28	6
OECD (other)	205	198	489	615	26	3	55	77	41	3
Latin America (excl. Brazil)	400	547	462	605	31	7	87	110	27	11
Asia (excl. China and India)	1,035	1,476	263	418	59	13	23	37	62	9
India	1,231	1,659	195	419	114	15	9	24	181	7
Middle East and North Africa	460	751	308	402	30	6	50	70	40	9
Sub-Saharan Africa	880	2,248	155	201	29	10	39	53	38	21
World	6,958	9,772	403	481	19	100	44	59	34	100

Note: Regions are listed in order of projected daily per capita consumption of total animal-based foods in 2050.
Source: GlobAgri-WRR model with source data from FAO (2019a); UNDESA (2017); FAO (2011c); and Alexandratos and Bruinsma (2012).

Figure 3: Undernourishment is worsening
Percentage (l.h.s.) and number (r.h.s.) of undernourished people in the world, 2005–19

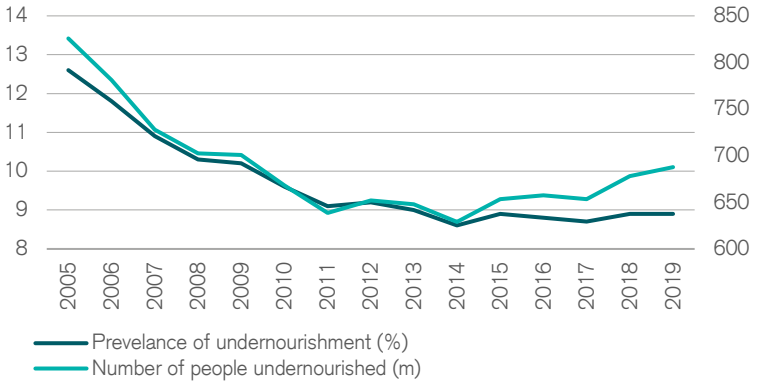
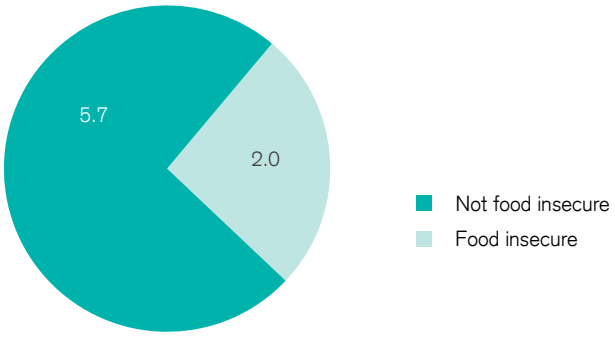


Figure 4: Two billion people globally face food insecurity
Number of people facing food insecurity, in billions, 2019



Source Figures 3 and 4: FAO, Credit Suisse Research

with that seen in developed markets (see **Table 1**). Full convergence could create a substantially larger food gap than the WRI's base case of an already challenging 56%. Later in this report, we provide our own estimates for food requirements if the convergence of diets and population growth were to occur.

Undernourishment

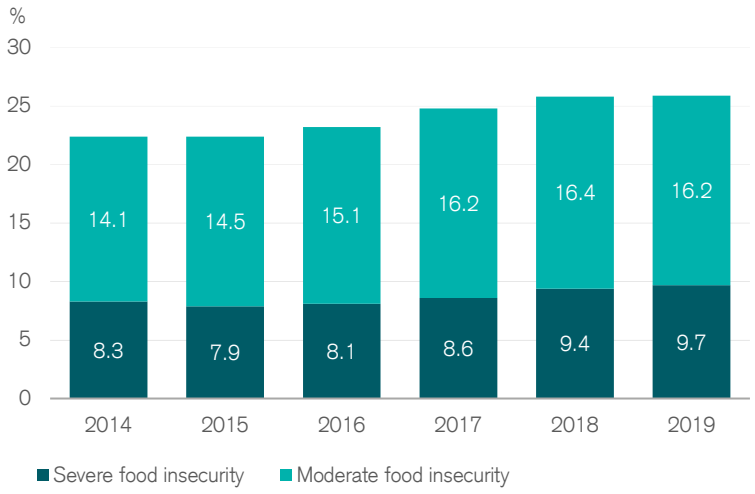
Undernourishment is a significant challenge for the world. The need of addressing this was recognized by the UN in 2015 when it introduced the 17 Sustainable Development Goals. Among them SDG1: No poverty, SDG2: Zero hunger and SDG3: Good health and well-being are all directly associated with the need to address undernourishment and food security more broadly.

However, progress to date has been poor. In fact, data from the FAO suggest that both the share of undernourished people globally as well as the absolute number has increased since the SDGs were introduced in 2015 (**Figure 3**). Data from the FAO also suggest that the increase since 2015 has been due to worsening conditions in Sub-Saharan Africa, Western Asia, Northern Africa, Latin America and the Caribbean. Furthermore, the FAO also estimates that the COVID-19 crisis may add

between 83 and 132 million people to the total number of undernourished worldwide in 2020 and that, if recent trends continue, the number of undernourished people would surpass 840 million by 2030.

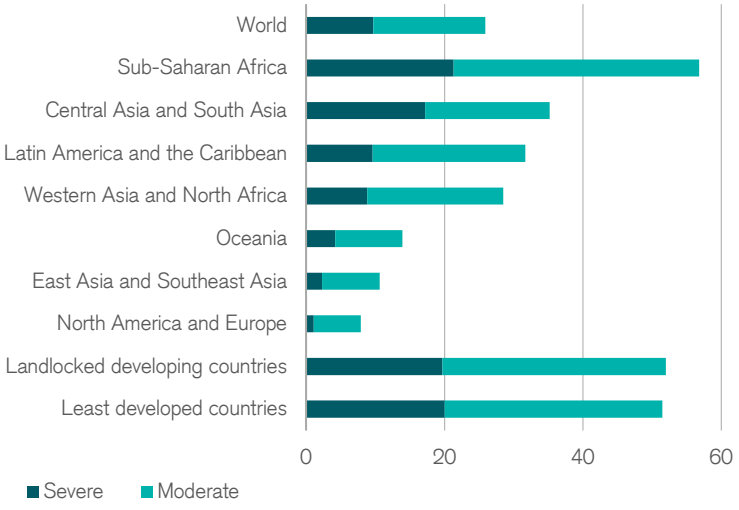
Undernourishment is related to a number of factors, one of which is connected to food insecurity. The lack of access to (healthy) food is a clear headwind for addressing undernourishment. Progress in reducing food insecurity has been slow to even negative during the past few years. Data from the FAO suggest that 25.9% of the world's population faced moderate or severe food insecurity in 2019. This share is up from 22.4% in 2015 (**Figure 5**). On a regional basis, we find that almost 60% of people living in Sub-Saharan Africa are facing food insecurity (**Figure 6**).

Figure 5: World population facing food insecurity
Share of world population facing food insecurity, in %, 2014–19



Source; FAO, Credit Suisse Research

Figure 6: Food insecurity by region
Prevalence of severe and moderate food insecurity by region in 2019 (%)



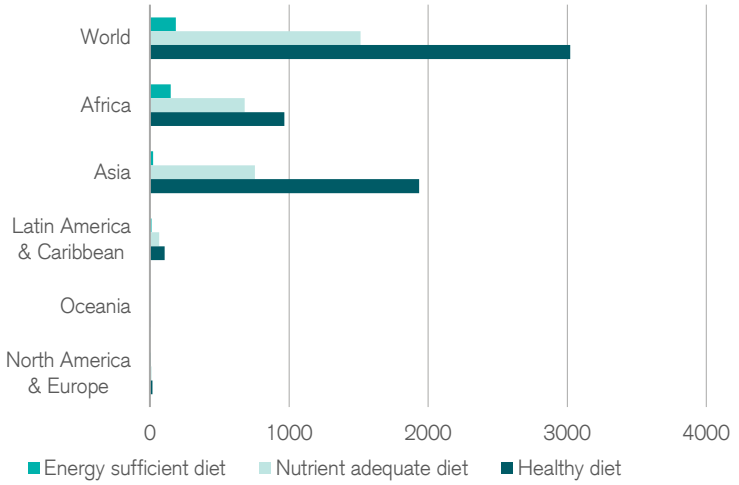
Source; FAO, Credit Suisse Research

> “Progress in reducing food insecurity has been slow to even negative

In addition to a lack of access to food, we find that consumers across lesser-developed countries and regions face additional challenges. First, we note that consumers across lower-income regions do not have the same food available to them as consumers across wealthier regions. Second, and partly related, is the fact that not all consumers have the financial means to afford a healthy diet. In fact, research suggests that more than three billion people around the world were not able to afford a healthy diet in 2017.

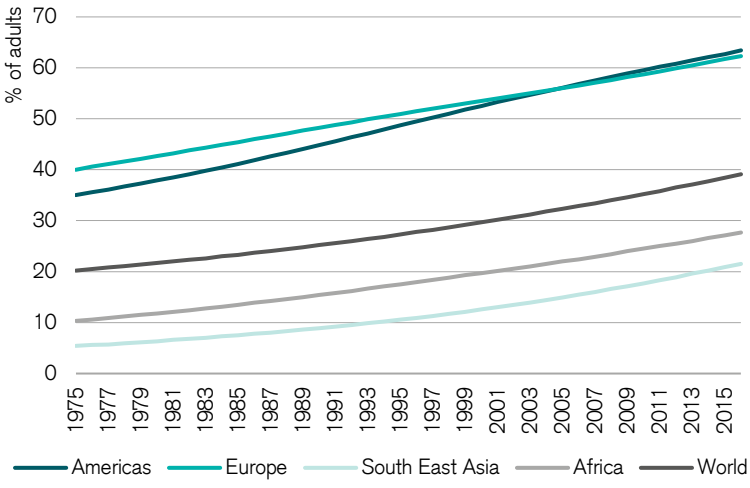
More than 1.5 billion people were unable to afford a diet that was adequate from a nutrition standpoint (**Figure 7**). Addressing the food challenge across developing countries therefore not only requires an increase in overall food production, but also importantly needs to ensure that the right food is available at affordable prices globally.

Figure 7: Food affordability
Number of people who cannot afford a healthy diet, in millions, 2017



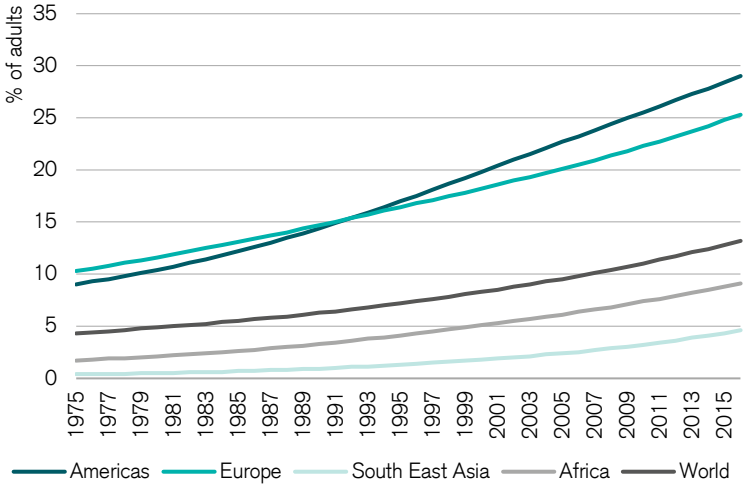
Source: Herforth, A., Bai, Y., Venkat, A., Mahrt, K., Ebel, A. & Masters, W.A. 2020. "Cost and affordability of healthy diets across and within countries"

Figure 8: 40% of world population considered overweight
Share of adults that are overweight (BMI ≥ 25), in %



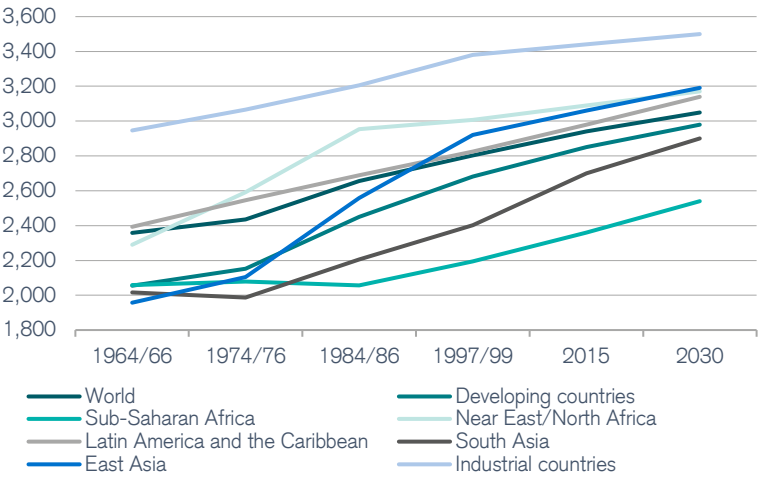
Source: WHO, Credit Suisse Research

Figure 9: Global share of obese adults almost tripled since 1975
Share of adults that are obese (BMI ≥ 30), in %



Source: WHO, Credit Suisse Research

Figure 10: Average daily calorie intake only below required level in Sub-Saharan Africa
Average daily calorie intake per person, in kcal



Source: FAO

Overweight and obesity

Undernourishment is not the only reason why a change toward a more sustainable food system is required, in our view. The growing number of people globally who are either overweight or obese presents additional challenges. However, these challenges can be met if the world switches toward more sustainable and healthy food production and consumption. To put the growing concerns related to overweight and obesity into context, we note that the share of the global population considered to be overweight doubled between 1975 and 2016 to close to 40% (**Figure 8**). Even more worrying is the rise in the number of people who are obese. The share of the global population that has a Body Mass Index (BMI) of 30 or higher has risen almost threefold since 1975 to almost 15% in 2016 (**Figure 9**). We will discuss the implications associated with malnutrition in terms of health and economic costs later in this report.

> “Even more worrying is the rise in the number of people who are obese

Causes of malnutrition

The rise in the number of people that are overweight or obese is due to a combination of factors.

How much we eat is an issue

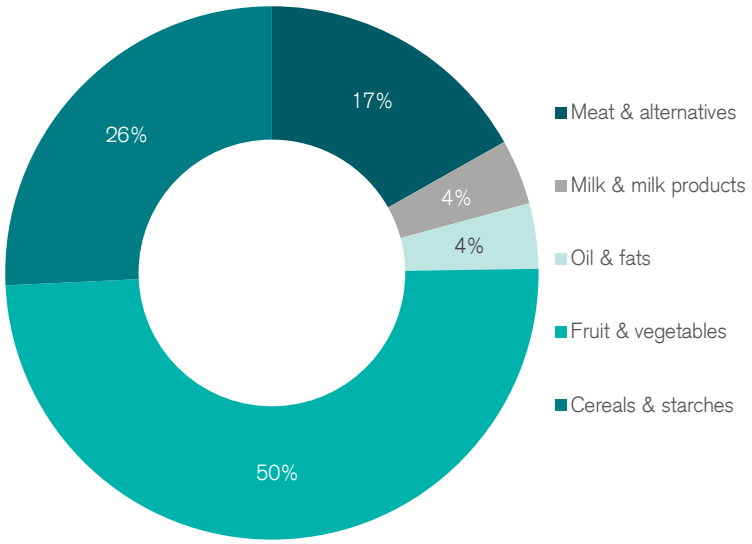
While greater urbanization and less physically active lifestyles suggest that people need less food to “fuel their engines,” the opposite has happened. Average calorie intake per person has increased globally over the past few decades as can be seen in **Figure 10**. Estimates from the FAO indicate that the rising intake of calories is not just a developed-country phenomenon, but effectively extends to all regions. It has been estimated that the required average daily energy intake per person can be 2,100 kcal assuming a BMI target of 22 kg/m2. Some of the more prominent studies on healthy diets such as the EAT-Lancet study from 2019 assume an average required energy intake of

2,500 kcal/day. Based on that assumption **Figure 10** shows that, except for Sub-Saharan Africa, consumers in all other regions in the world already consume more calories per day than the required daily energy intake.

What we eat is an issue

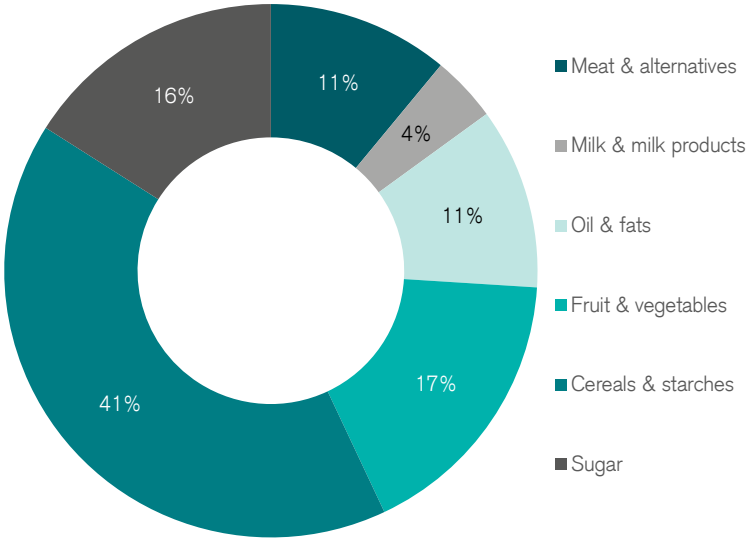
Creating a more sustainable food system not only means that people who eat too much should reduce their intake. Of equal importance is to address what people eat. Health professionals often note that consumers eat too much unhealthy high-calorie processed food and too little healthy nutritious organic food. We address this topic in more detail later in this report, but note here that what we eat is not necessarily what we should eat (see **Figures 11 and 12**). For example, a healthy balanced diet suggests that 50% of our daily intake should be made up of fruit and vegetables; however, young people in Europe do not reach half of that amount. Some of our previous research at the Credit Suisse Research Institute supports the academic view on desired food consumption as it highlighted the need to reduce sugar intake (see "Sugar: Consumption at a crossroad").

Figure 11: What should we eat?
Harvard's healthy eating plate model



Source: Harvard University, KB, KC (2018)

Figure 12: What adolescents in Europe eat (2011)



Source: Dethelm, Jankovic et al (2011) "Food intake of European adolescents"

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Studies have shown that obesity and food insecurity often go hand in hand

Poverty and lack of education matter too

Poverty and lack of education are two of the root causes of malnutrition even in wealthy and developed nations. Studies have shown that obesity and food insecurity often go hand in hand. In the United States, for instance, some 10.5% of all households were food insecure in 2019, having insufficient money or other resources for food. In that year, the US Supplemental Nutrition Assistance Program (SNAP), the country's most important food assistance program, reached 38 million

people – food assistance has become a way of supplementing low wages or making up for insufficient unemployment benefits.

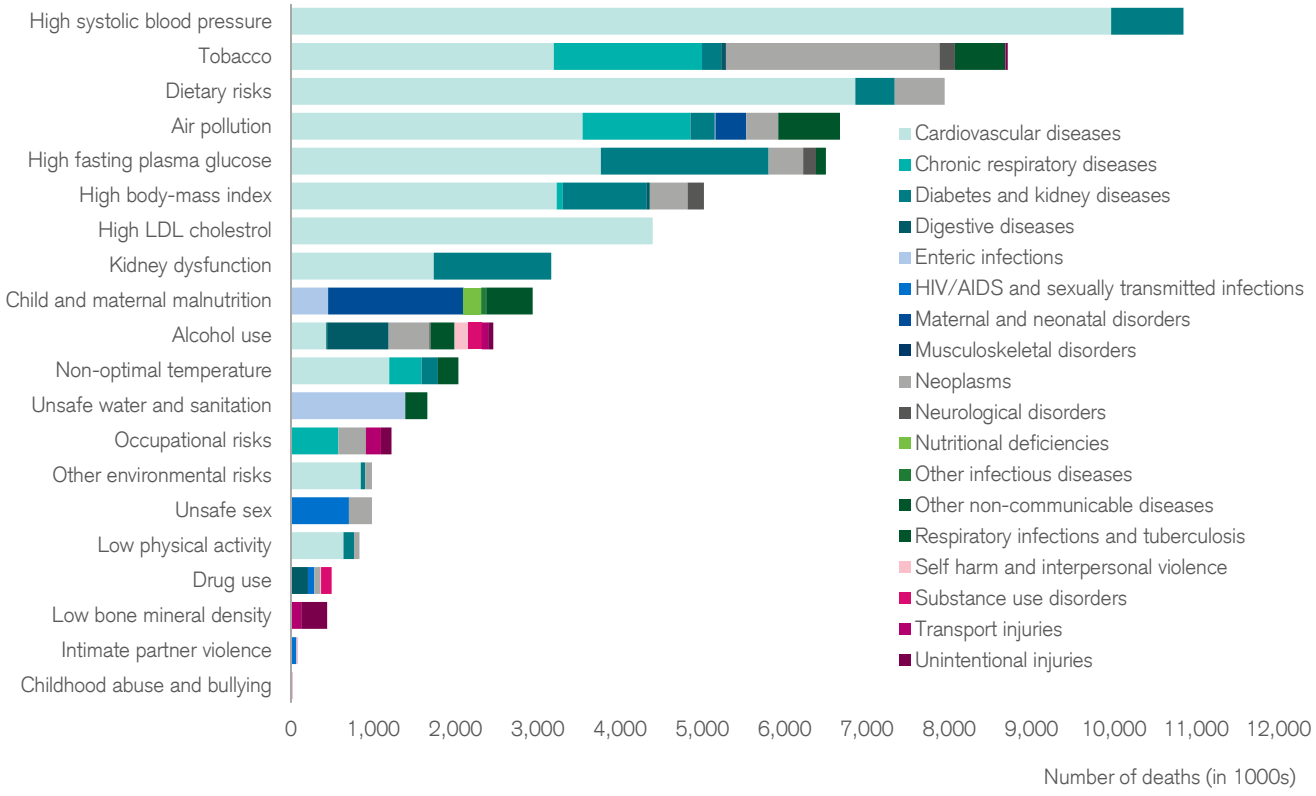
Dave and Kelly (2012) find further evidence that higher unemployment rates are associated with lower consumption of fruit and vegetables, and higher consumption of unhealthy foods such as snacks and fast food. However, unemployment is not the only issue. Many poor Americans have a job, but their wages are too low for their families to live comfortably. They often have long working hours and are therefore forced to eat what is convenient along the way. Adding to the problem, they mostly lack the know-how necessary to eat healthily on little money. Many of the USA's working poor (people who spend 27 weeks or more in a year either working or looking for work, but whose incomes fall below the poverty level) are low-educated, which often correlates with a higher prevalence of obesity (Ogden et al. (2017)).

For many poor households, the extra weight resulting from an unhealthy diet is collateral damage – an unintended side effect of hunger itself (McMillan (2014)). Over the past decade, food insecurity in the United States has been declining. However, the ongoing COVID-19 pandemic, which has shed light on the economic and social struggles of America's poor, may bring this trend to a halt.

Health implications associated with malnutrition

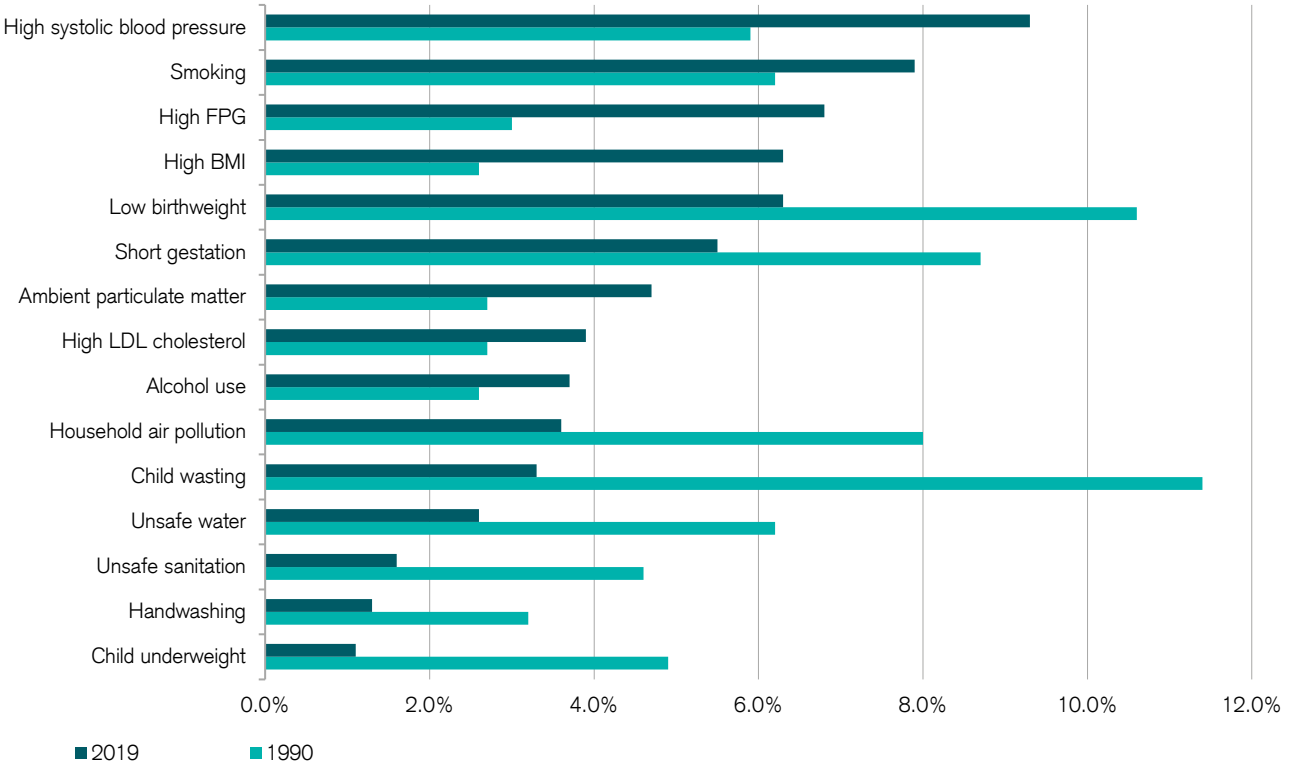
The health implications of an increasingly large portion of the nation that is overweight or obese is another factor that cannot be overestimated in our view. For example, the Global Burden of Disease Study 2019 (GBD 2019) estimated years of life lost (YLL) associated with 87 risk factors and combinations of risk factors. The study's conclusions suggested that many of the factors that have shown an increase in risk exposure between 1990 and 2019 are metabolic risks including high fasting plasma glucose (FPG), which is often an indicator of diabetes, high LDL cholesterol and a high body mass index (BMI). The risk factors that contributed most to YLL and that are increasing by more than 1% per annum in 2019 were FPG and a high BMI. The study estimated that around 35 million years of life were lost in 2019 due to metabolic risks, largely due to a combination of eating too much, eating the wrong food and not exercising enough.

Figure 13: Key leading risk factors attributable to deaths
Global attributable deaths from Level 2 risk factors in 2019



Source: "Global burden of 87 risk factors in 204 countries and territories, 1990–2019; a systematic analysis for the Global Burden of Disease Study 2019," GBD 2019 Risk Factors Collaborators, Credit Suisse Research

Figure 14: Leading risk factors by percentage of disability-adjusted life years lost



Source: "Global burden of 87 risk factors in 204 countries and territories, 1990–2019; a systematic analysis for the Global Burden of Disease Study 2019," GBD 2019 Risk Factors Collaborators, Credit Suisse Research

In **Figure 13**, we show the leading risk factors as identified by the GBD 2019. **Figure 14** shows the share of life years lost that, according to the GBD 2019 analysis, can be attributed to various risk factors and how this has changed from data collected in 1990. The metabolic-related factors dominate and have increased very substantially since 1990.

In 2017, collaborators with the GBD 2019 released an article in which they estimated that, on average, more than 20% of total deaths among adults aged 25 and older can be attributed to dietary risks.

The economic cost of malnutrition

Both undernourishment and overweight or obesity have negative economic consequences. As part of our report, we have estimated the annual cost of malnutrition. Undernutrition has severe consequences for economic productivity and ultimately economic development. Undernourished adults have lower stamina and subsequently lower work output. While this productivity loss may manifest very quickly in lower incomes and eventually in lower affordability of healthy diets, there is also an indirect impact of undernourishment on human capital that may take years to emerge: poor nutrition during infancy affects cognitive skills and impedes school achievement, with long-term effects on labor-market prospects later in life.

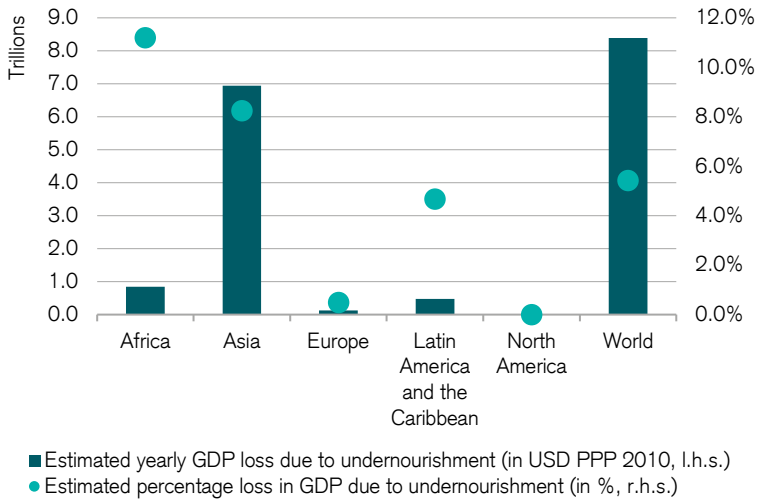
> "Undernutrition has severe consequences for economic productivity and ultimately economic development

There is thus a two-way link between nutrition and income. Low-income families have less variation in their diet. Moreover, lower income is associated with worse sanitation and health, such that there is a higher loss of nutrients associated with infection. Last but not least, less maternal education (associated with lower income) leads to less-favorable infant feeding practices and mothers who are less able to obtain care for themselves during pregnancy (Horton and Steckel (2013)).

It is not just undernourishment that causes enormous economic costs. So do overweight and obesity. The impacts on population health also translate into an increase in health expenditure. Nortoft et al. (2018) found that obese people have higher healthcare resource utilization rates than individuals with normal weight, resulting in considerable excess healthcare costs. Bad eating habits also affect the labor market: overweight and obesity reduce the employment rate, increase absenteeism (absence from work, sick leave) and "presenteeism" (reduction in productivity while at work), and are also one reason why people retire earlier (Fitzgerald et al. (2016), Kudel et al. (2018)). As a result, the global workforce and total work output are reduced, generating additional economic costs.

Finally, malnutrition not only impacts people's health, but also the health of the planet and therefore causes costs for the whole of society.

Figure 15: Undernourishment causes yearly economic costs of almost USD 7 trillion in Asia alone
Estimated yearly GDP loss due to undernourishment, average 2020–35



Source: Credit Suisse analyses based on Horton and Steckel (2013)

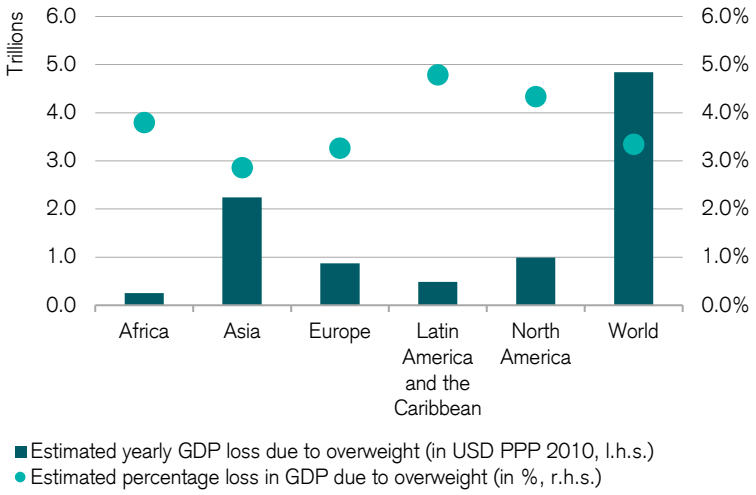
The FAO has stated that the total financial cost associated with the "double burden of malnutrition" can be estimated at about 5% of GDP. This estimate was partly based on 2010 data and did not provide a fully comprehensive global estimate for the overall economic losses associated with all types of malnutrition and related diseases, in our view. In this report, we attempt to fill this gap, drawing on the available literature about the implications of malnutrition for the economy and the environment. For a better understanding of the contributing factors, we have disaggregated the total costs of malnutrition into three components: the economic costs of undernutrition, the economic costs of overweight and obesity, and the social costs in conjunction with a higher carbon footprint. We explain our methodology in greater detail in Appendix 1 of this report.

"The FAO has stated that the total financial cost associated with the "double burden of malnutrition" can be estimated at about 5% of GDP

According to our estimates, malnutrition in all its forms may impose an average yearly cost of USD 13.6 trillion (in USD PPP 2010) to the global economy over the period 2020–35. The biggest contributor to these costs is undernourishment at approximately USD 8.4 trillion worldwide, with Asia alone recording a yearly loss of almost USD 7 trillion due to undernourishment (**Figure 15**). While in Europe and North America undernourishment is a negligible problem, it is a major obstacle for the development of African countries, on average causing a yearly loss in GDP of 11.2% in 2020–35.

Overweight is a burden for both the developing and developed world

Figure 16: Overweight is a major problem in both developed and developing countries
Estimated yearly GDP loss due to overweight, average 2020–35



Source: Credit Suisse analyses based on Cecchini and Vuik (2019)

Unlike undernourishment, which mostly concerns poor countries, overweight is a burden for both the developing and developed world. We estimate that overweight costs the global community USD 4.8 trillion each year, with the highest percentage of losses recorded in Latin America and the Caribbean (–4.8%) and North America (–4.3%, **Figure 16**). On a country level and in absolute terms, the highest losses due to overweight are documented in the United States (USD 922 billion), followed by China, India and Brazil.

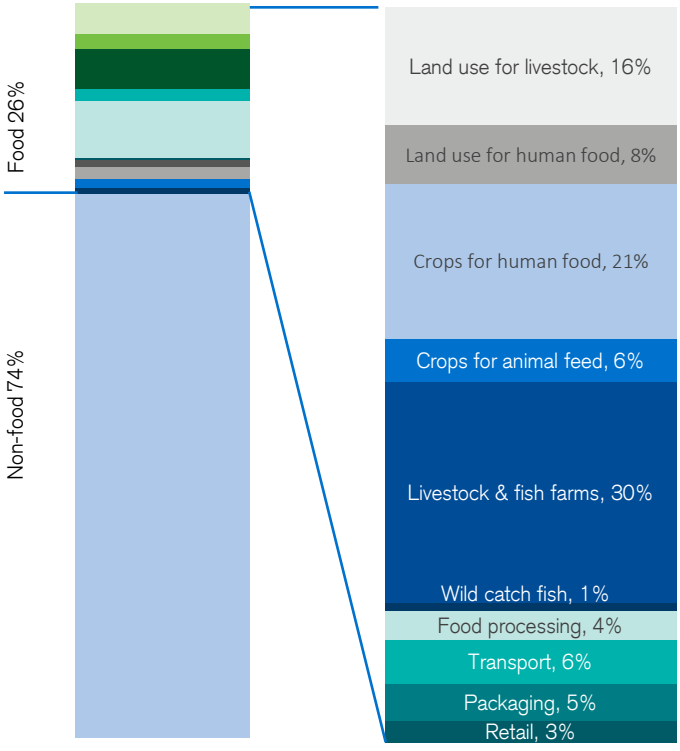
Moreover, malnutrition in all its forms may result in extra emissions of approximately 1,762 megatons of CO2 equivalents per year globally. Putting a price tag on these extra CO2 emissions of USD 186.8 per ton of CO2 equivalents results in additional yearly costs of USD 329.1 billion between 2020 and 2035 (in 2010 US dollars).

Photo: Credit Suisse

The environmental impact of food

Malnutrition is not the only reason why the global food system needs to change. Food production and consumption already contribute well over 20% to global greenhouse gas emissions and account for more than 90% of the world's freshwater consumption. After reviewing the environmental footprint of all major food groups, we conclude that the current situation is likely to worsen significantly unless action is taken. The likely growth in the world's population to around ten billion people by 2050 coupled with a further shift in diets, especially across the growing emerging middle class, could increase emissions by a further 46%, while demand for agricultural land could increase by 49%.

Figure 1: Food-related GHG emissions by source globally



Source: Poore and Nemecek (2018), Credit Suisse Research

The carbon footprint of the global food system

The global food supply chain plays a significant role in the climate change debate given that estimates put the share of greenhouse gas (GHG) emissions generated by the entire food system at well over 20% (**Figure 1**). Various reports have assessed which activities are mostly responsible for these emissions. Work from Poore and Nemecek in 2018 showed that, on a global level, more than 50% of emissions generated by the food system was related to livestock, either through land use, animal feed, land conversions or methane production. Their analysis also showed that roughly 15% of food-related emissions were generated by activities after the production phase, including processing, transport, packaging and retail.

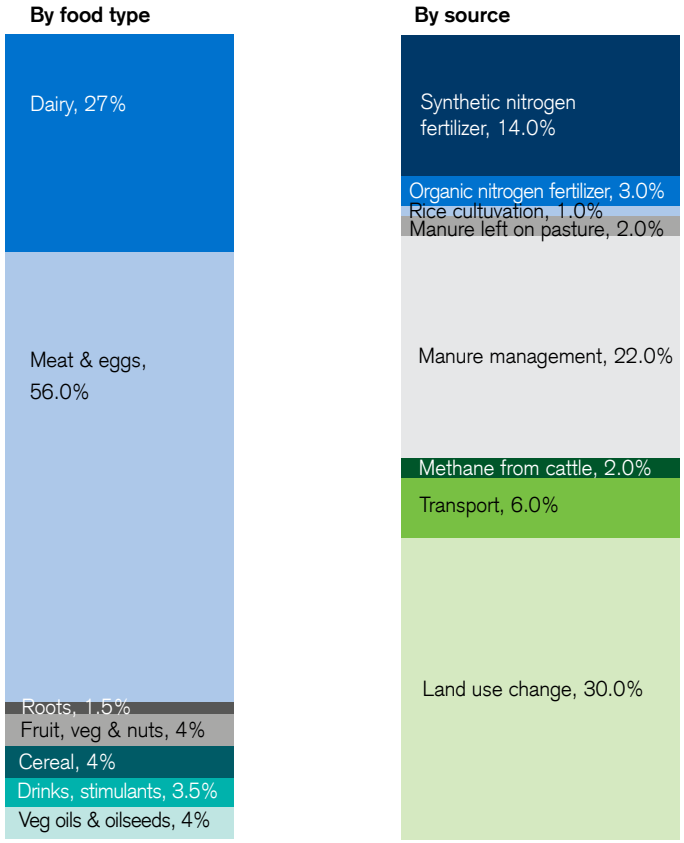
Work from Sandstrom et al. in 2018 reviewing food-related emissions in the EU (**Figure 2**) suggested that more than 80% of food emissions could be traced back to the production of animal-related food such as meat, dairy and eggs.

Analysis of emission generation by individual food types clearly suggests that beef-related products are most intense from a GHG perspective (**Figure 3**). The main reason is that beef production requires a lot of land and generates high levels of methane. Other food products that are emission-intense include dark chocolate (mainly due to the change in land use) and coffee (land conversion). Products that appear most aligned with climate-change targets from a GHG-emission perspective are plant-based, including fruit, vegetables and nuts. The need to reduce GHG emissions in order to meet long-term climate-change targets thus suggests that a reduction in meat consumption should be a key priority.

Water intensity of the global food system

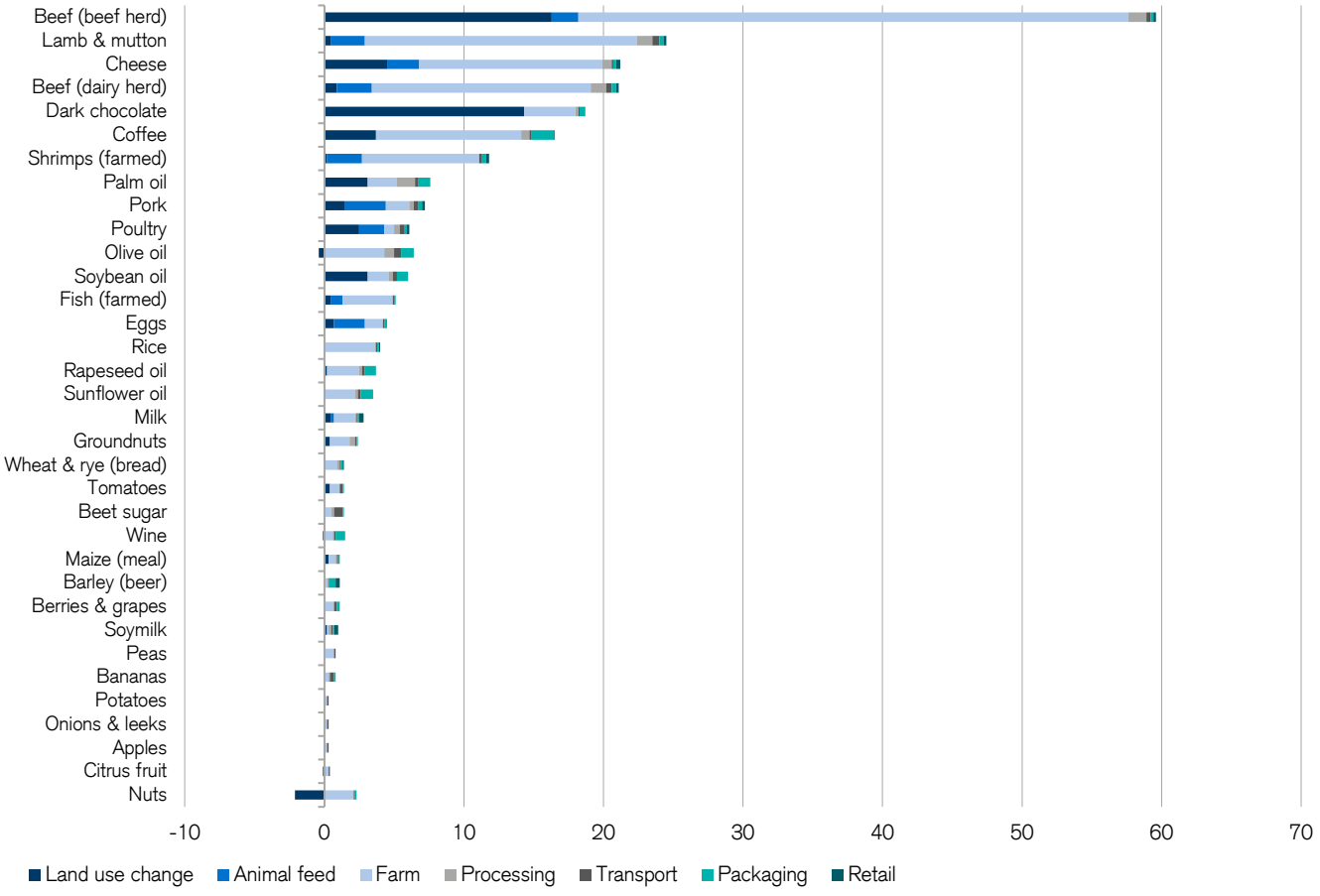
The footprint of the current food system not only consists of GHG emissions. Another significant factor is that food production can be very water intense. Over 90% of global annual freshwater consumption is currently driven by agricultural production, which also accounts for close to 70% of total freshwater withdrawal (**Figure 4**). This is a serious problem as water stress is a significant issue for most regions globally,

Figure 2: Food-related GHG emissions by food type and source in the EU



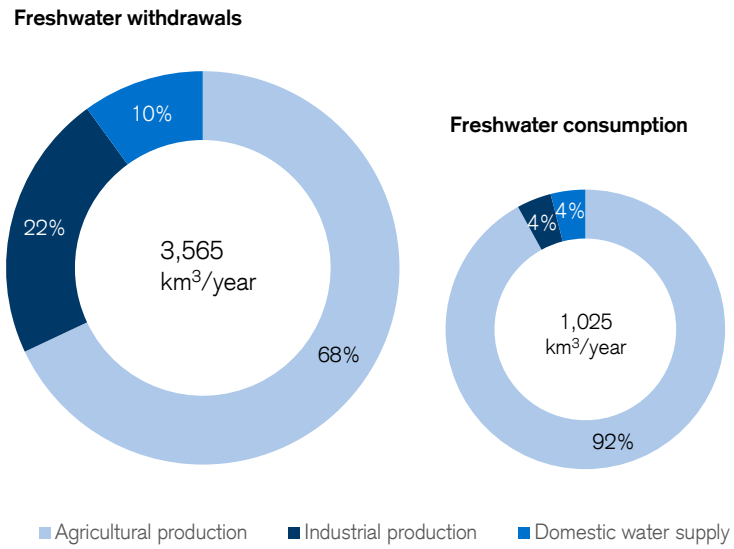
Source: Sandstrom et al (2018), Credit Suisse Research

Figure 3: GHG emissions by food type and broken down by source (kg CO2 equivalent per kg of product)



Source: Poore and Nemecek (2018), Credit Suisse Research

Figure 4: Agriculture is a key driver of water scarcity



Note: Figures measure only "blue water" demand and do not consider rainfed agriculture ("green water"). Consumption figures are averaged for the years 1996–2005; withdrawal figures are for the year 2000. Source: Hoekstra and Mekonnen (2012) (consumption); OECD (2012) output from IMAGE model (withdrawals)

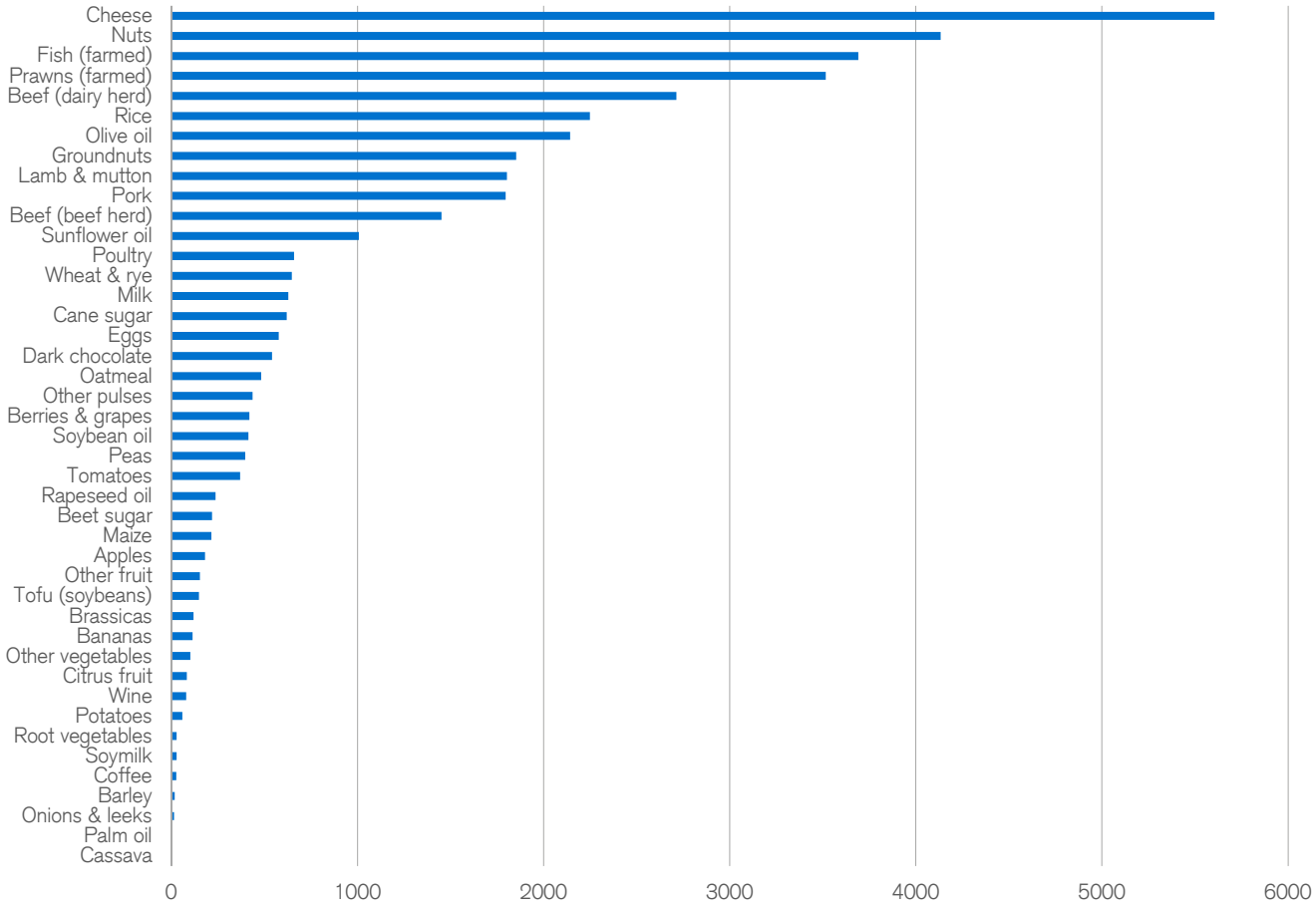
especially developing ones. Without changes to the food system, we see food-induced water stress worsening for two reasons:

- First, we note that the World Bank estimates the global population will reach close to ten billion people by 2050, which will increase total water demand as well.
- Second, we believe that per-capita food consumption is likely to increase due to the expanding middle class across emerging markets, which in turn increases water demand (see also **Figure 14**).

These two factors combined not only put significant further pressure on food-related GHG emissions, but will also increase agriculture-related water consumption unless changes are made to what we eat, how much we eat and how it is produced.

A review of water intensity by food product yields similar conclusions to those drawn from our assessment in relation to GHG emissions. Meat production requires some of the highest freshwater consumption per calorie of product. Interestingly, however, and indicative of the fact that solving the sustainable food question is not as easy as switching to a full non-meat diet is the fact that nut and fish production are also very water intense (**Figure 5**).

Figure 5: Water footprint per kilogram of food product



Source: Poore and Nemecek (2018)

The impact of food production on land use

The fact that the current food system forms a crucial element of the climate change agenda is not only driven by the emissions generated by food production and consumption or the water usage associated with it. The amount of land that is needed for the production of food is equally relevant. Data from the FAO indicate that 71% of the world's land mass is habitable, which equates to around 104 million km^2. Of this, roughly 50% is already used for agriculture, with 77% of that used for keeping livestock. The question is whether the continued increase in food demand driven by rising middle-class incomes across emerging markets or population growth might require an amount of agricultural land that is simply not available.

The expansion of arable land historically…

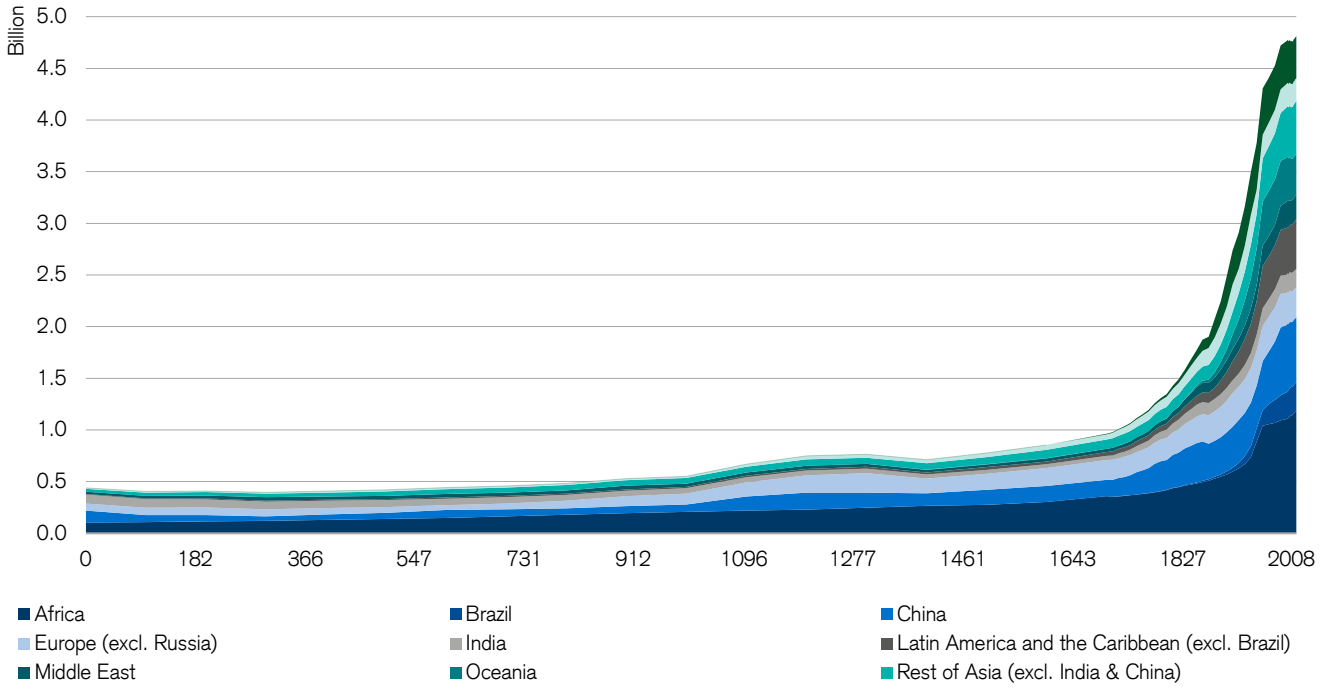
Some might argue that the potential increase in agricultural land needed to meet future food demand should not be impossible given how successful we have been in increasing arable land mass historically. For example, data from the Historical Database of the Global Environment show that the amount of agricultural land globally has increased from around 0.5 billion hectares in the year zero to close to five billion hectares in 2016 (**Figure 6**). Since 1900, the expansion of agricultural land has been particularly strong in Asia (+167%) and Latin America (+210%). In Africa, the total amount of agricultural land has doubled since 1900.

…might not continue

The fact that the total amount of agricultural land has increased during the past few hundred years has helped in meeting the growth in food demand seen during that period. However, we are not convinced that growth in arable land mass will be sufficient to meet the potential growth in food demand going forward. Two observations are worth making here:

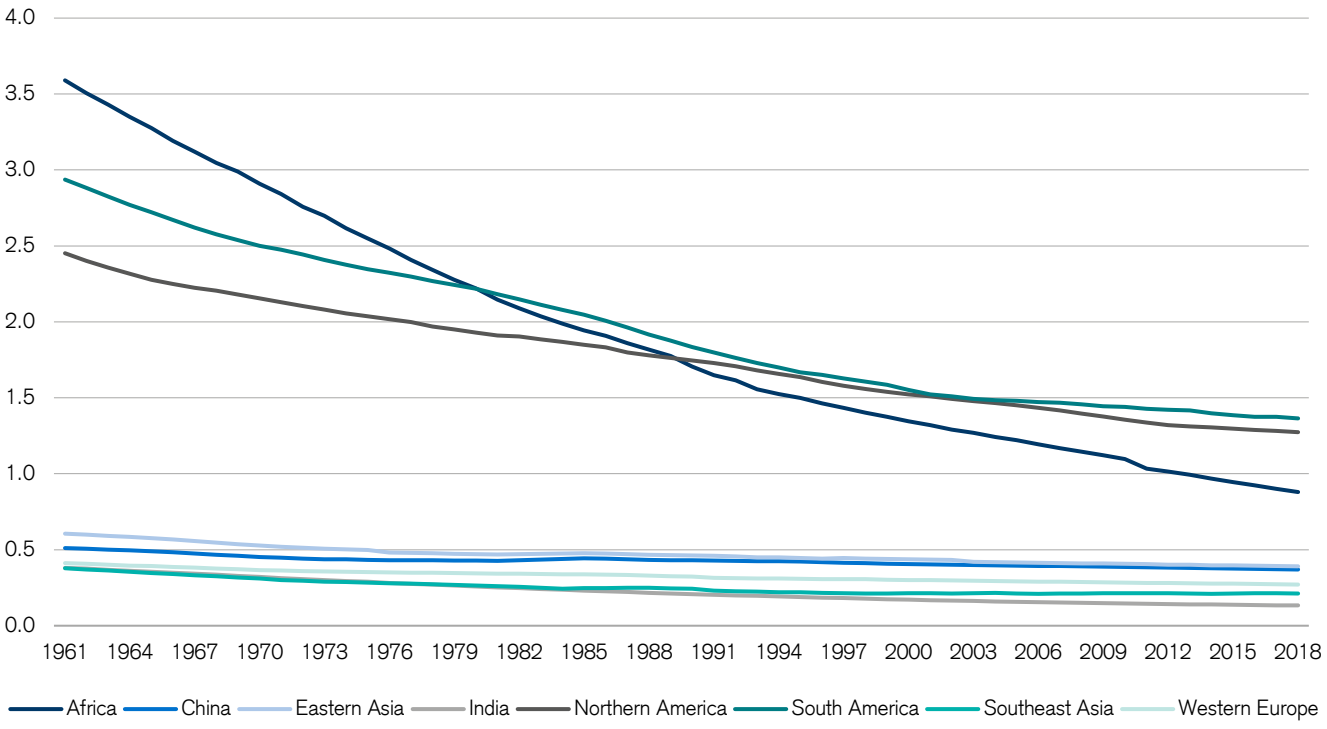
- First, it is important to note that, despite the growth in total arable land during the past few hundred years, the amount of agricultural land available per capita has actually declined. Over the past 50 years, the reduction in land available per person has been strongest in Africa and South America (**Figure 7**).
- Second, we note that the growth in agricultural land seen to date has come at the cost of greater deforestation. Data from Globalforestwatch suggest that annual tree loss cover has increased from around 14 million hectares in 2001 to around 25 million hectares in 2019 (**Figure 8**). The FAO indicates that some 420 million hectares of forest has been lost since 1990, which is the same as roughly eight times the size of France or 50% of the USA. Deforestation not only releases stored carbon dioxide, but also reduces the ability to capture future carbon releases. Furthermore, it contributes to a loss in biodiversity and puts pressure on soil quality, which in turn is seen as contributing to the risk of drought and floods.

Figure 6: Total agricultural land use over time (billion hectares)



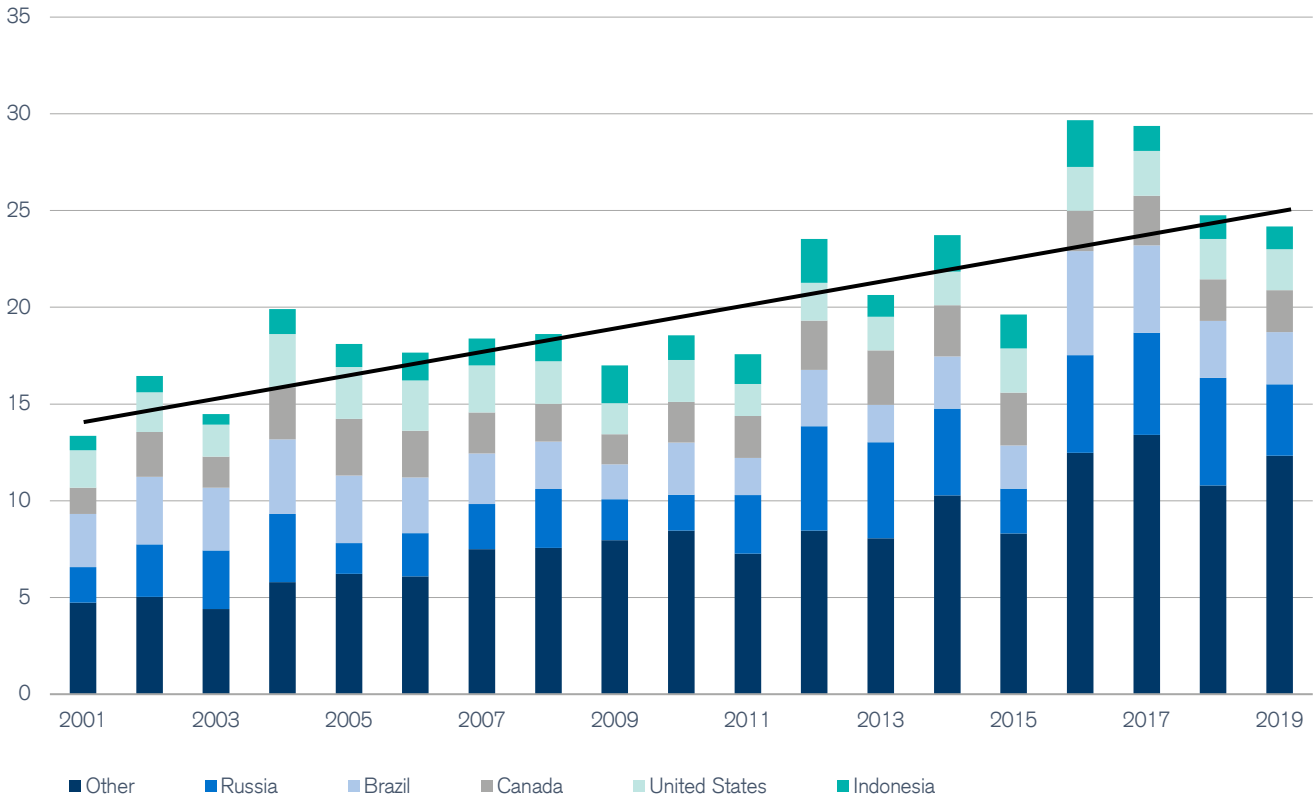
Source: HYDE, 2017

Figure 7: Agricultural land per capita (hectares)



Source: FAO, Credit Suisse Research

Figure 8: Annual tree cover loss (million hectares)

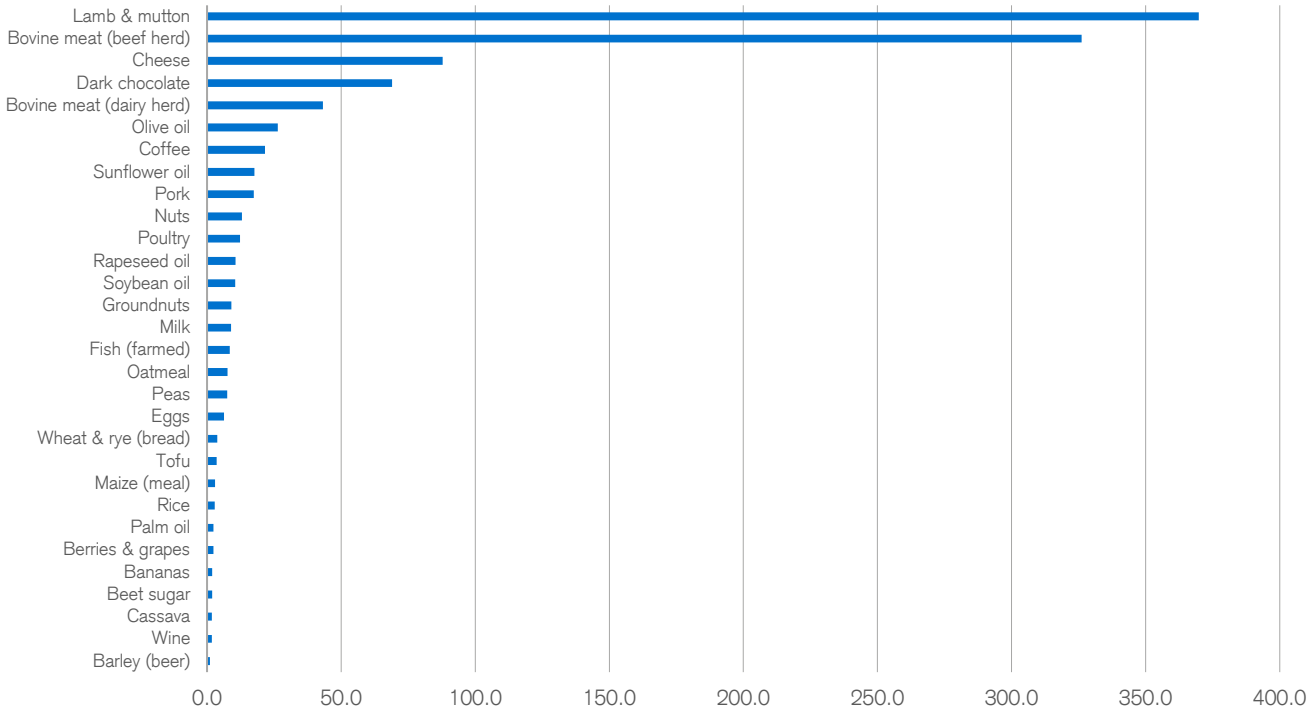


Source: Globalforestwatch.org, Credit Suisse Research

The strong decline in agricultural land available per capita in some of the lesser-developed regions and the need to limit deforestation suggest that a "business-as-usual" approach where simply more land is used for agricultural purposes is unlikely to be successful in improving the sustainability of the world's food system. We see two potential solutions here:

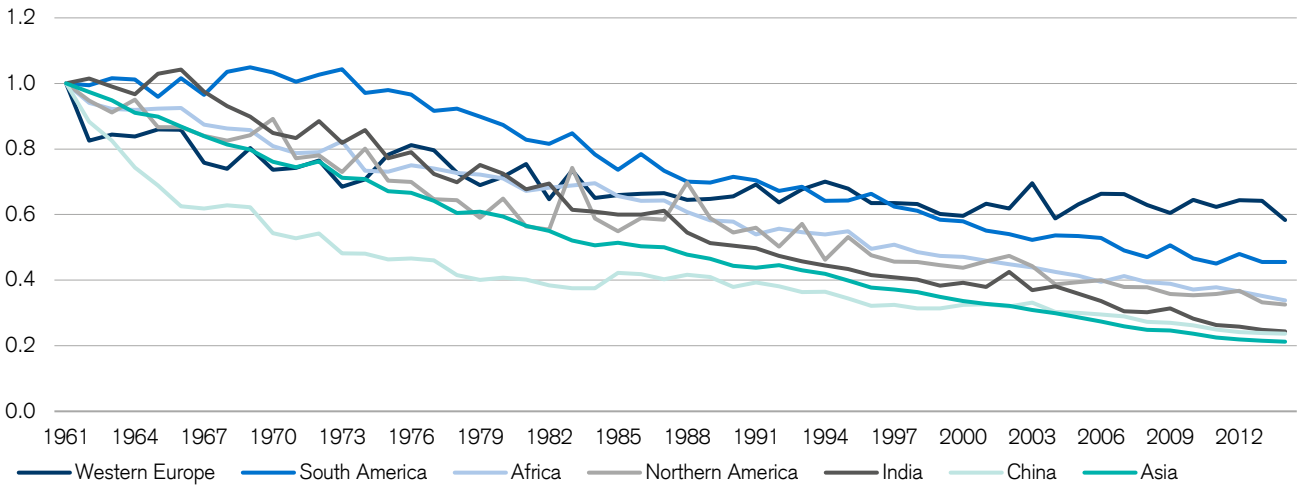
- First, we note that the land footprint differs between food groups (**Figure 9**). In other words, one can reduce agricultural land demand by shifting diets toward a mix of products with a lower land use requirement per kilogram of product. The previously mentioned research by Poore and Nemecek has indicated that, once again, a move away from a meat-based diet toward a plant-based diet would be helpful here as well.
- Second, and importantly, significant progress in productivity has been achieved during the past 50 years. Data from the FAO indicate that the amount of arable land needed to produce a fixed number of crops has declined very significantly between 1961 and 2014 (**Figure 10**). Later in this report, we will highlight a number of technologies that we believe should help to achieve further gains in agricultural productivity and in turn help reduce the need for more agricultural land.

Figure 9: Land use (m^2) per kilogram of produced product



Source: Poore and Nemecek (2018)

Figure 10: Arable land needed per unit of crop production



Source: FAO, Credit Suisse Research

Table 1: Environmental intensity of individual food groups

	Average rank	Land use m2/kg	Emissions GHG kg CO2eq/kg	Emissions Acidifying g SO2eq/kg	Emissions Eutrophying g PO43-eq/kg	Freshwater withdrawals l/kg
Root vegetables	3	1	2	2	4	7
Soymilk	5	6	10	1	2	6
Onions & leeks	5	3	6	5	9	3
Apples	6	5	2	4	3	16
Citrus fruit	6	8	1	7	5	10
Cassava	6	13	14	3	1	1
Other vegetables	7	2	8	10	6	11
Potatoes	8	9	5	6	11	8
Barley (beer)	9	11	13	11	7	4
Brassicas	10	4	7	13	14	13
Other fruit	11	10	12	8	8	15
Bananas	11	15	9	9	10	12
Wine	14	12	18	19	13	9
Maize (meal)	16	20	17	16	12	17
Beet sugar	17	14	20	18	15	18
Berries & grapes	18	17	15	17	16	23
Tofu	18	22	24	12	17	14
Tomatoes	18	7	21	22	19	20
Peas	18	25	10	14	20	21
Palm oil	20	18	33	23	22	2
Wheat & rye (bread)	21	23	16	20	18	30
Oatmeal	22	26	22	15	23	25
Cane sugar	24	16	25	24	26	28
Milk	25	28	23	25	21	29
Other pulses	26	34	18	26	27	24
Soybean oil	26	30	32	21	24	22
Nuts	27	33	2	32	28	42
Rapeseed oil	27	31	28	30	29	19
Groundnuts	29	29	26	27	25	36
Rice	29	19	29	28	31	38
Eggs	29	24	30	34	30	27
Coffee	31	37	39	36	39	5
Sunflower oil	32	36	27	29	34	32
Poultry meat	33	32	34	37	33	31
Olive oil	34	38	31	31	32	37
Dark chocolate	35	40	42	33	36	26
Crustaceans (farmed)	35	21	38	38	40	40
Pork	36	35	35	40	35	34
Fish (farmed)	36	27	36	35	41	41
Lamb & mutton	39	43	41	39	37	35
Cheese	40	41	37	41	38	43
Bovine meat (beef herd)	40	42	43	42	42	33
Bovine meat (dairy herd)	41	39	40	43	43	39

Source: Poore and Nemecek (2018), Credit Suisse Research

Food's future environmental footprint

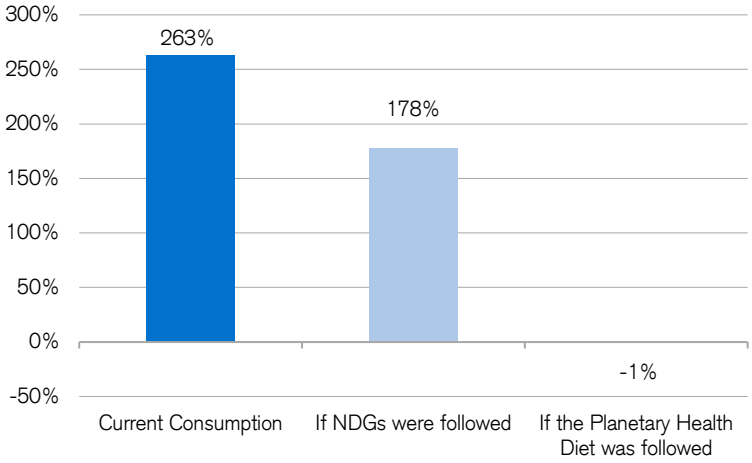
As the previous section indicates, different food groups have different environmental footprints, including land use requirements, fresh water needs and emission intensity. With the population growth that the world is likely to experience during the next few decades, the question is therefore what types of food the world should be focusing upon to balance feeding a growing global population with the need to minimize the environmental impact.

In **Table 1**, we rank a range of food products based on their environmental intensity. The table clearly suggests that animal-based protein scores worst across all five categories considered. It requires the most land and water per kilogram of any product and generates the most GHG emissions as well as acidifying and eutrophying pollutants, which originate primarily from anthropogenic emissions of sulfur dioxide, nitrogen oxides and ammonia. On the other hand, vegetables, fruits and wheat have the lowest environmental impact.

Two products are worth highlighting here. First, we note that rice is among the less-environmentally friendly food products. This is relevant, especially given the role that rice plays in Asian diets. Second, as mentioned earlier, while scoring well on GHG intensity, we find that the production and consumption of nuts ranks poorly in regard to all other factors. Therefore, a complete switch away from animal-based to plant-based foods might not have as much of a positive environmental impact if nuts were to represent a significant portion of a plant-based diet. Various academic papers have made projections related to future food consumption and what this could mean for GHG emissions. For example, Springmann et al. estimated last year that future food consumption would be 2.6 times the maximum sustainable level if current consumption patterns did not change (**Figure 11**). Analysis by the World Resources Institute suggests that emissions associated with food production alone could rise by 66% between 2010 and 2050 (**Figure 12**).

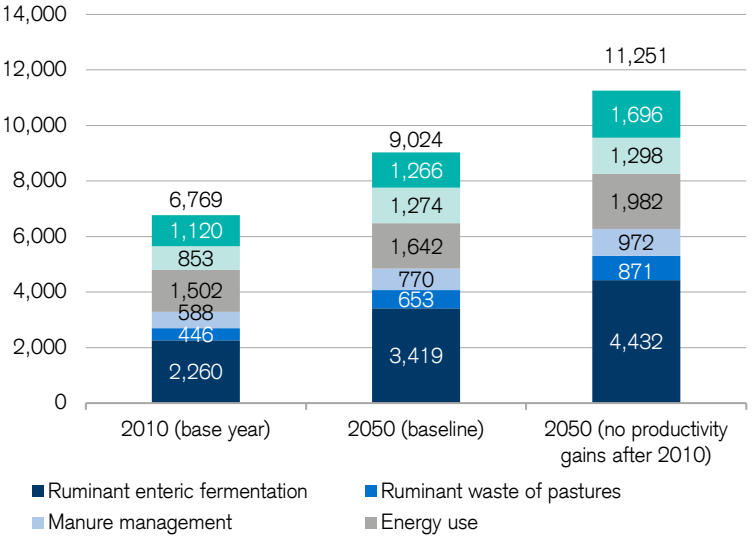
However, Springmann's analysis also showed that the potential negative impact from the global food system in a no-change scenario is not restricted to GHG emissions alone. A no-change scenario suggests that the use of nitrogen and phosphorus may rise by more than 50%, which would likely result in greater contamination of soil and waterways. Furthermore, such a scenario would increase blue water use (i.e. freshwater excluding rain water) by 65%, whereas the amount of land needed for crops would increase by 67% (**Figure 13**).

Figure 11: Projected food-related GHG emissions if G20 consumption patterns are adopted globally



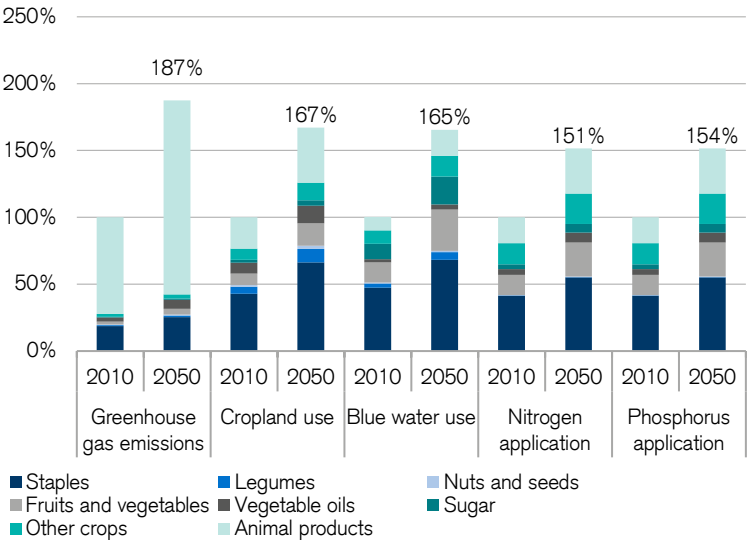
Source: Springmann et al (2020)

Figure 12: Agricultural production emissions could reach 9–11 gigatons/year by 2050



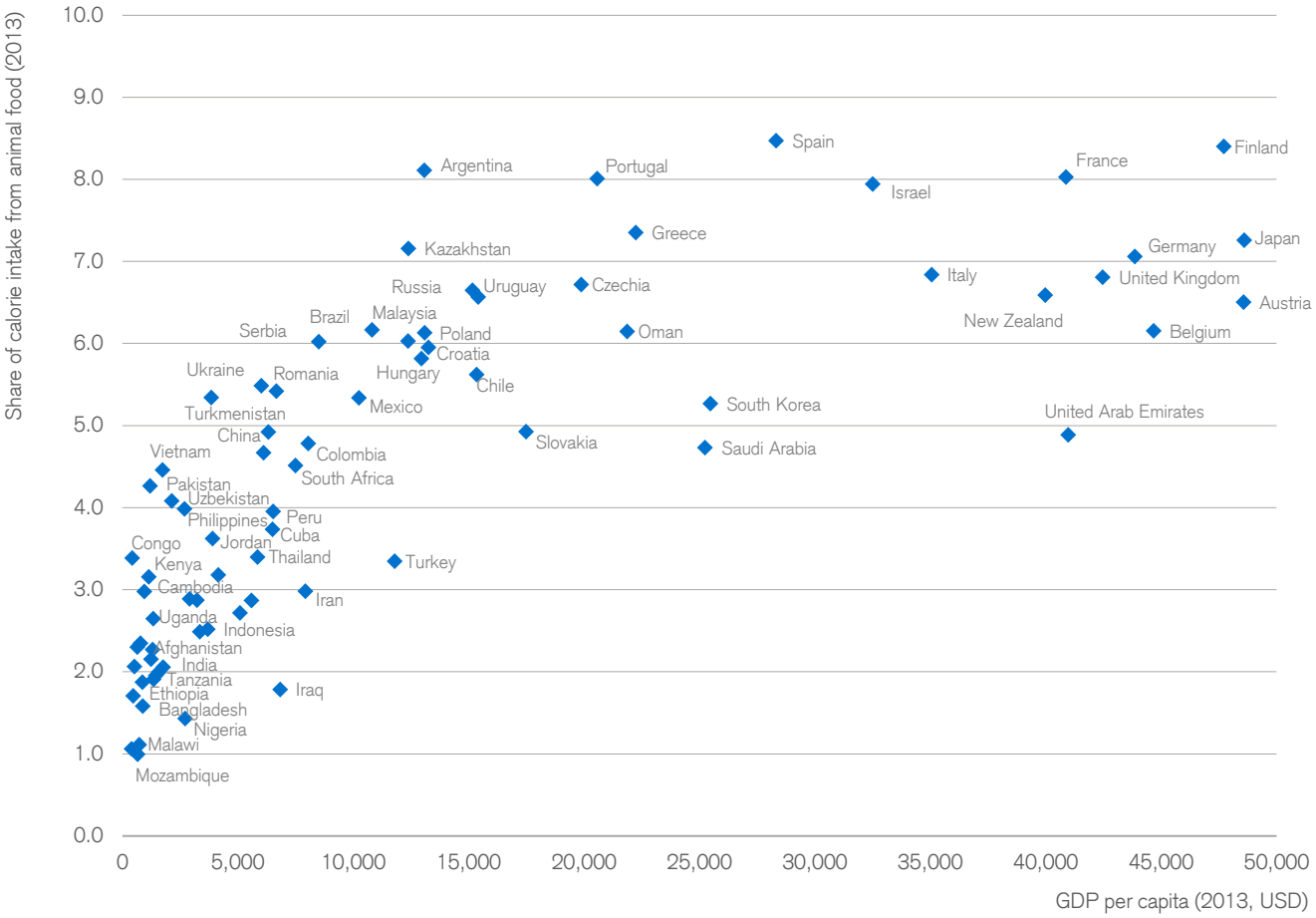
Source: Global Agro-WRR model

Figure 13: The impact of a no-change scenario is significant for all relevant ecological variables



Source: Springmann et al (2020)

Figure 14: Animal-based protein consumption increases with income



Source: FAO, World Bank, Credit Suisse Research

The environmental impact of population growth

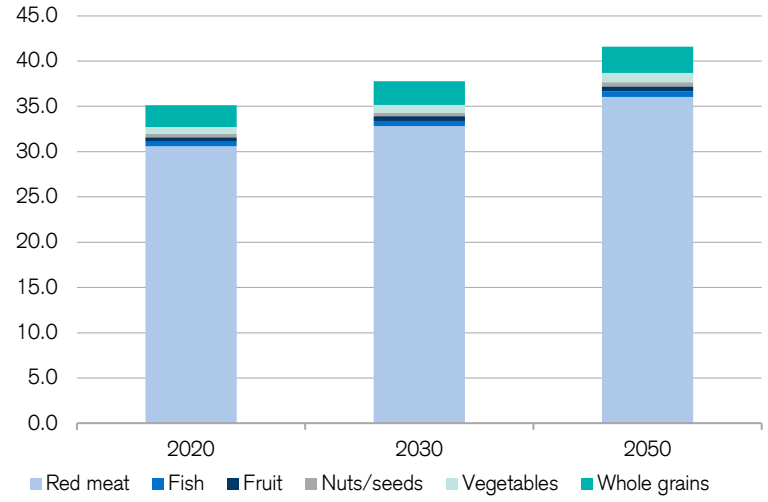
In order to assess how individual countries contribute to the environmental challenges posed by the food system, we have created our own simulations. In doing so, we have combined food consumption data for 155 countries from the FAO, with population growth forecasts from the World Bank and environmental footprint data for around 40 food groups. This allows us to estimate the total current environmental footprint of food consumption by country. Furthermore, we can run scenarios that take population growth and potential changes in future food consumption in certain countries into consideration depending on lifestyle changes. This latter point is not trivial, as **Figure 14** shows. Rising income levels as measured in terms of per-capita GDP, are positively correlated with animal-based food consumption, which, as we showed earlier, have some of the highest readings on emission intensity, water usage and land requirements.

By multiplying per-capita food consumption for individual items with the average environmental footprint of those items together with the total population size of countries, we can calculate current consumption patterns by country and their implications for the environment. This also allows us to assess which food groups currently dominate the environmental footprint either globally or by country.

Using constant consumption patterns, our calculations suggest that future food demand is likely to result in an 18% increase in total land use, a 17% increase in GHG emissions and a 15% increase in freshwater demand. The incremental challenges are largely associated with developing countries, not least China and India. In fact, we note that a number of countries currently account for around 750 million people and are likely to see around 100% growth in GHG emissions in the next 30 years based on population growth alone (**Figure 18**). Such a scenario is clearly not helpful given that global GHG emissions need to decline sharply over the next few decades in order to meet longer-term climate change targets.

Some might argue that overall growth rates are relatively positive given that they are lower than the estimated 24% growth in the world's population expected by the World Bank by 2050. However, we note that this is because most of the population growth is set to take place across developing countries where food consumption, especially of more environmentally intense food items, is currently substantially below levels seen across developed regions. The question is therefore what could happen if population growth is combined with consumption changes that converge toward diets seen in areas such as Europe or the United States.

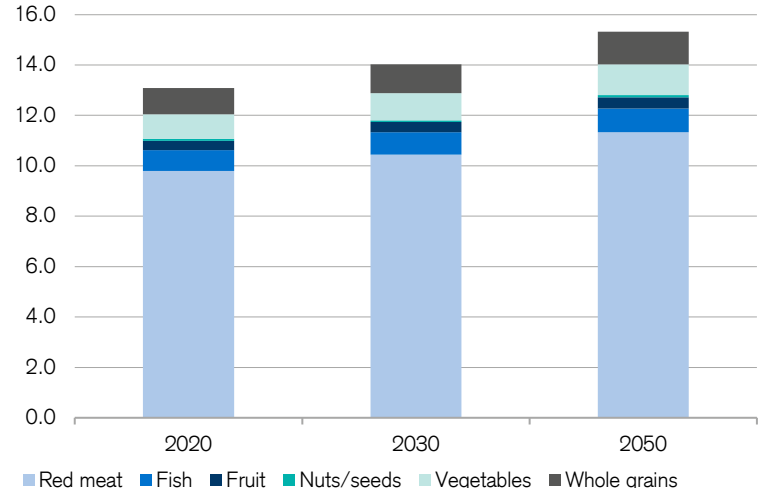
Figure 15: Land use to rise 18% owing to population growth (m km2)



Source: FAO, World Bank, Poore and Nemecek (2018), Credit Suisse Research

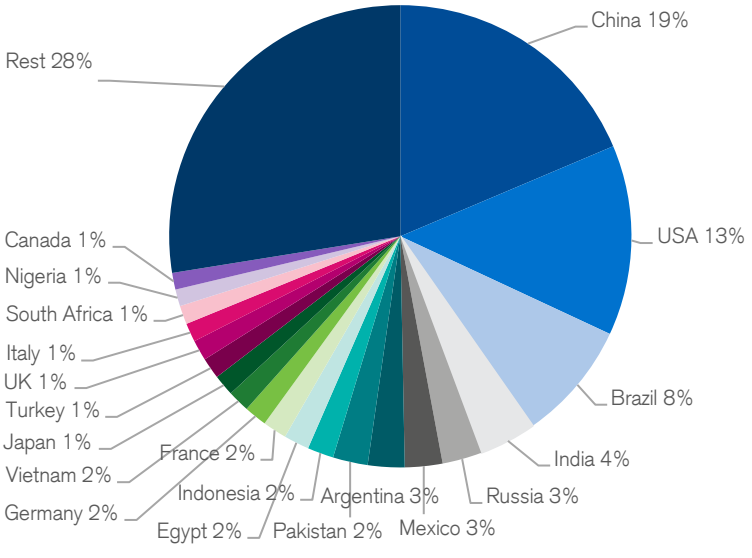
> "What could happen if population growth is combined with consumption changes that converge toward diets seen in areas such as Europe or the United States?

Figure 16: Meat drives a 15% potential rise in food-related GHG emissions (Gt CO2 equivalent)



Source: FAO, World Bank, Poore and Nemecek (2018), Credit Suisse Research

Figure 17: Food-related GHG emissions by country



Source: FAO, World Bank, Poore and Nemecek (2018), Credit Suisse Research

What if global food consumption converges?

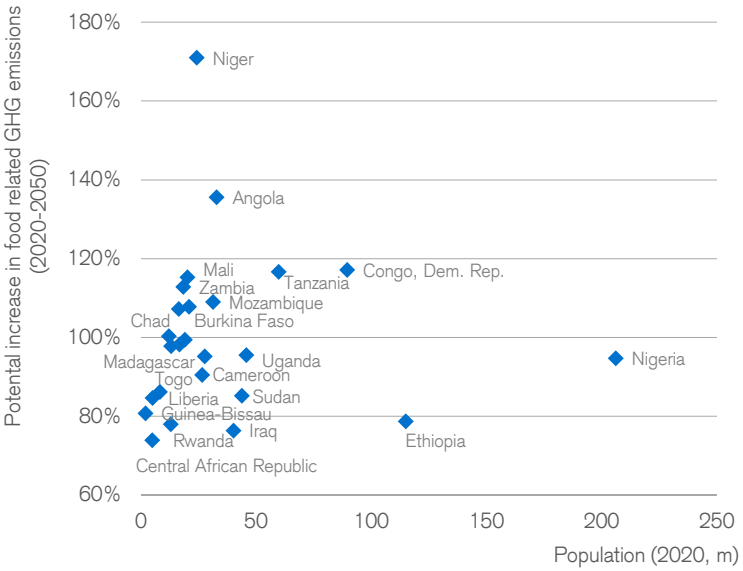
To better understand what might happen to the environmental footprint of food consumption if consumption patterns change, we have run a base case and a worst case scenario.

Base case scenario

Our base case scenario assumes a gradual increase in food consumption globally, but not a full convergence. We have made the following assumptions:

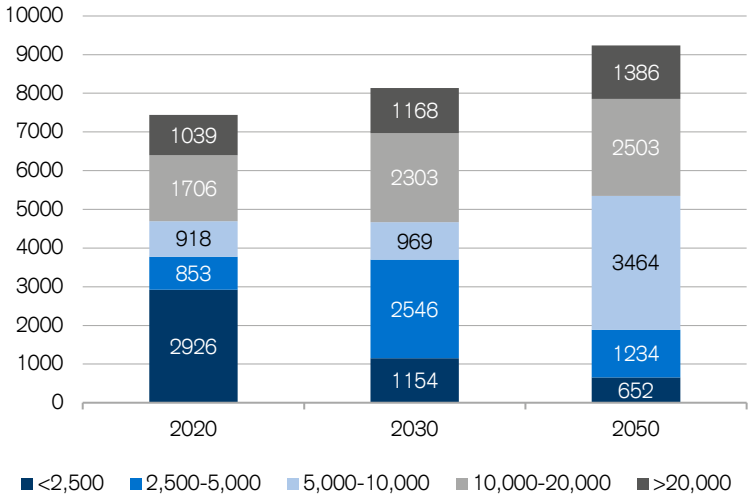
- First, we assume that countries with a lower GDP/capita will have a higher GDP growth rate over time than those with higher levels of per capita wealth. For this purpose, we group

Figure 18: Food-related GHG emissions growing at around 100% or more for a range of developing countries



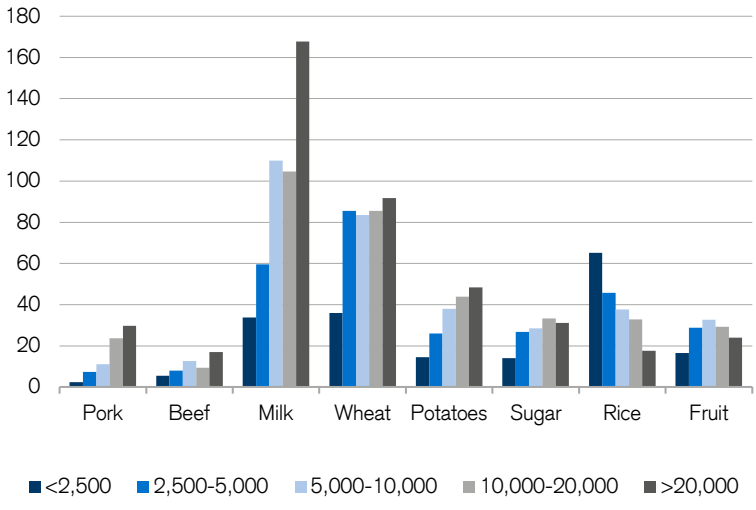
Source: FAO, World Bank, Poore and Nemecek (2018), Credit Suisse Research

Figure 19: Population (m) by GDP/capita bracket (USD)



Source: World Bank, Credit Suisse estimates

Figure 20: Per capita consumption (kg) of certain food items grouped by average GDP/capita (USD)



Source: World Bank, Credit Suisse estimates, Poore and Nemecek (2018)

countries into five different categories ranging from per capita GDP of USD 0–2,500 to USD 20,000 and above. The reason for taking USD 20,000 and above as the upper limit relates to **Figure 14**, which shows that animal protein consumption appears to stop increasing after that.

- Second, for the sake of simplicity, we assume that countries within a certain band of GDP per capita have similar consumption patterns. Based on food consumption statistics for over 150 countries from the FAO's database, we can calculate what the average diets are for countries in each of the five income categories.
- Using population estimates from the World Bank, we can estimate how many people will be in each of the five wealth categories in 2020, 2030 and 2050. Together with average diets consumed for each of these five categories, this allows us to estimate total food consumption for around 40 food groups in these years.
- Finally, using environmental intensity data for these food groups, we can estimate the potential change in land use, GHG emissions and freshwater consumption associated with the combination of population growth and changing dietary patterns.

Based on our estimates, we predict that the number of people living in countries with a GDP per capita of less than USD 2,500 will decline from around 2.9 billion in 2020 to around 1.15 billion by 2030, and 652 million by 2050. We expect the share of people living in countries with income of USD 5,000–10,000 to increase from 12% last year to 37% by 2050, and we expect this to have significant food-driven climate implications. For example, **Figure 20** shows only a few of the food items that have a positive correlation between per-capita consumption and wealth. We make the following observations based on our calculations:

- Land use requirements: Based on our assumptions, we believe a slow convergence of food-consumption patterns over time may result in a 49% increase in demand for land needed to grow the products that consumers want to eat. In our scenario, land requirements related to growing the required beef, poultry and pork would increase by between 53% and 67%, while increased milk consumption would need 61% more land. On the other hand, total land use associated with rice consumption would remain largely the same as rising incomes typically do not correlate with increased rice consumption.
- GHG emissions: Our calculations regarding emissions show similar dramatic increases in the event that the world's growing population becomes wealthier and starts to

adopt consumption patterns associated with increased income levels. We estimate that food-related emissions may rise by 46% between 2020 and 2050. The key drivers are highlighted in **Figure 22**, although we note that these do not necessarily represent the food items with the highest growth in emissions. **Figure 23** provides our estimates for the entire range of products.

- Water intensity: Finally, we note that a convergence scenario is also likely to place substantially more pressure on freshwater consumption. We estimate that this may increase 34% between 2020 and 2050. One of the reasons why water consumption is not set to grow as fast as, for example, emissions relates to the fact that certain water-intense food items are not expected to see strong growth in consumption as incomes rise. This includes rice, as well as fish.

Figure 21: Total land use needed to feed the global population in our convergence scenario increases by 49% (m km2)

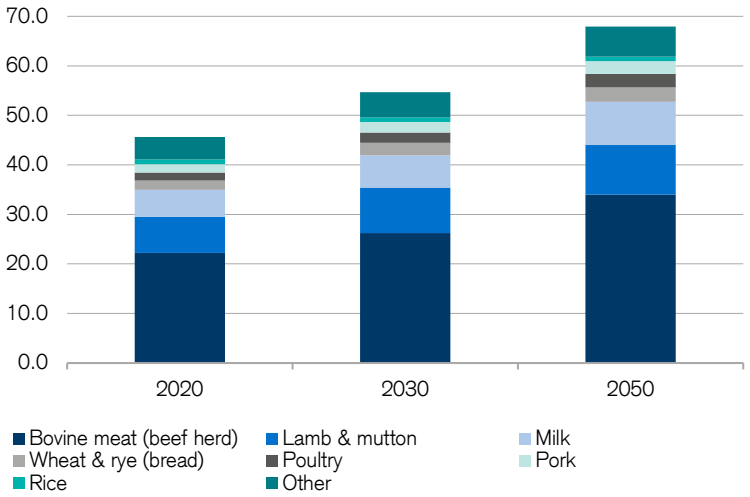
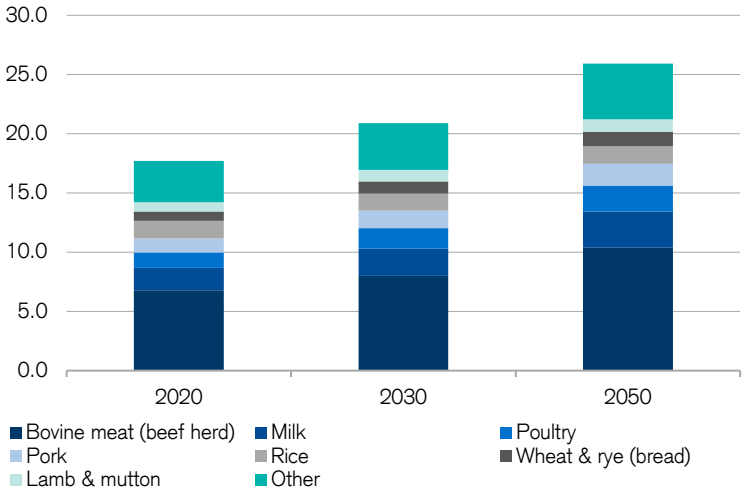


Figure 22: Total GHG emissions associated with our convergence scenario rise 46% by 2050 (Gt CO2 eq)



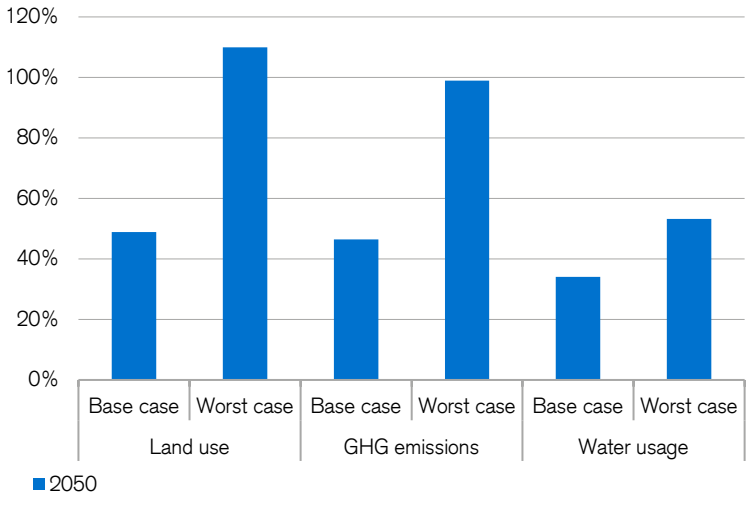
Source Figures 21 and 22: World Bank, Credit Suisse estimates, Poole and Nemecek (2018)

> “A convergence scenario is also likely to place substantially more pressure on freshwater consumption

Our own estimates very much echo the conclusions drawn by many others that a change in food production and consumption is needed if global climate change targets are to be met. However, the challenge that the world faces in terms of making the food system more environmentally sustainable is not just limited to reducing overall emissions. Population growth across developing regions and the likely expansion of the emerging middle class suggest that governments also need to address how the balance of emissions associated with the food system is shared between regions.

With population growth and per capita consumption likely to increase more in the developing world than in the developed world, we believe that a larger share of allowed or available emissions need to be allocated to emerging

Figure 23: Changes between our base case and worst case assumptions



Source: Credit Suisse estimates

Figure 24: Change in GHG emissions by product associated with our convergence scenario (2050 vs. 2020)

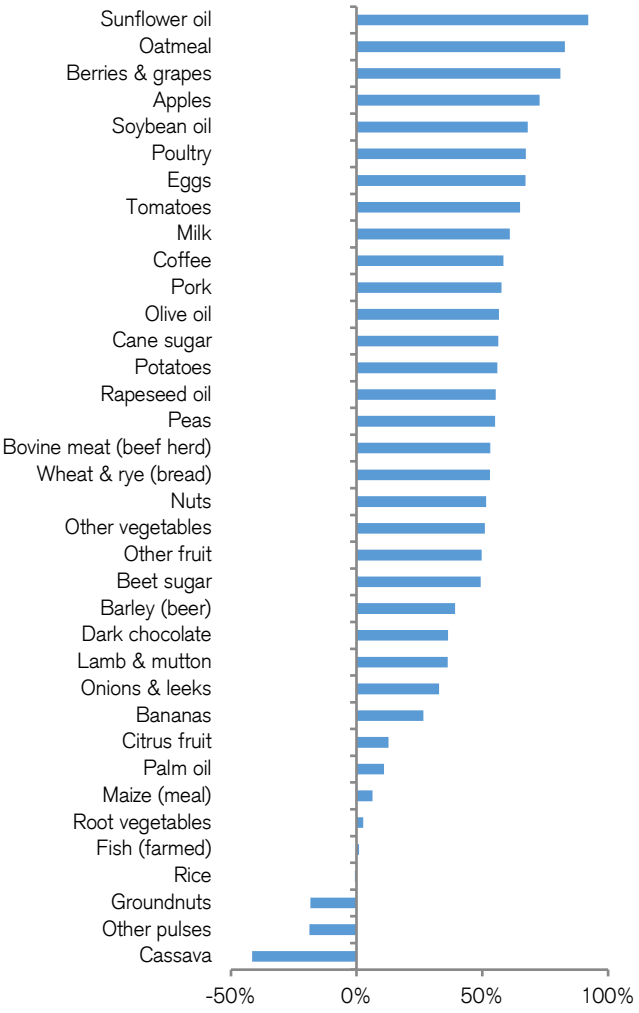
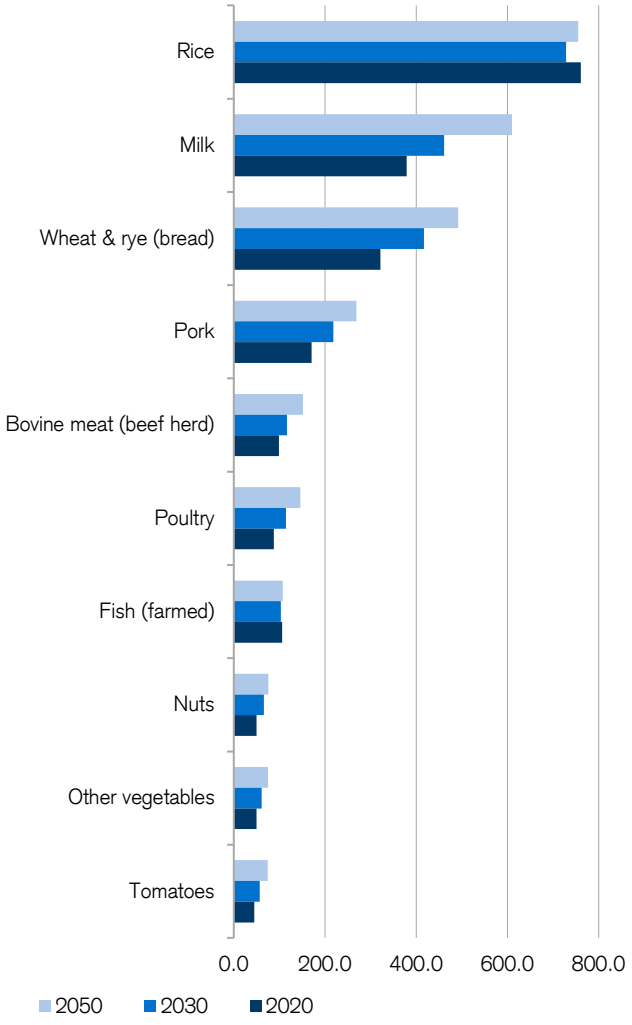


Figure 25: Total fresh-water consumption associated with the ten most water-intense foods by 2050 (bn m3)



Source Figures 23 and 24: World Bank, Credit Suisse estimates, Poole and Nemecek (2018)

countries. However, this does not appear to be an easy task, in our view, given the experience of environmental-related negotiations to date.

Worst case scenario

Our base case centered on the assumption that food consumption patterns will continue to differ between income groups going forward. This is, however, not necessarily the worst outcome, in our view. A much worse scenario would be one where the entire global population would have a diet similar to that currently seen across developed countries. To outline what this would mean for emissions, water use and land requirements, our worst case scenario projects the expected world population by 2050 on an average diet consumed by people living in countries with a per-capita GDP of more than USD 20,000.

Figure 23 shows that the environmental impact of a full food-consumption convergence over time would be very damaging for the world's ecosystem. For example, total land use requirements would increase by around 110% between 2020 and 2050 or more than double the already challenging increase that our base case scenario predicts. Emissions look set to rise very rapidly too. We would expect them to increase by roughly 100% or more than double the 46% increase suggested by our base case scenario. Finally, we note that total water demand would also increase, although not as much as our estimates for emissions or land use. The main reason is that the consumption of rice (which is a water-intense product) is likely to decline as income increases. Nevertheless, with growth in water demand of almost 53%, water scarcity in our worst case scenario would become an even greater challenge.

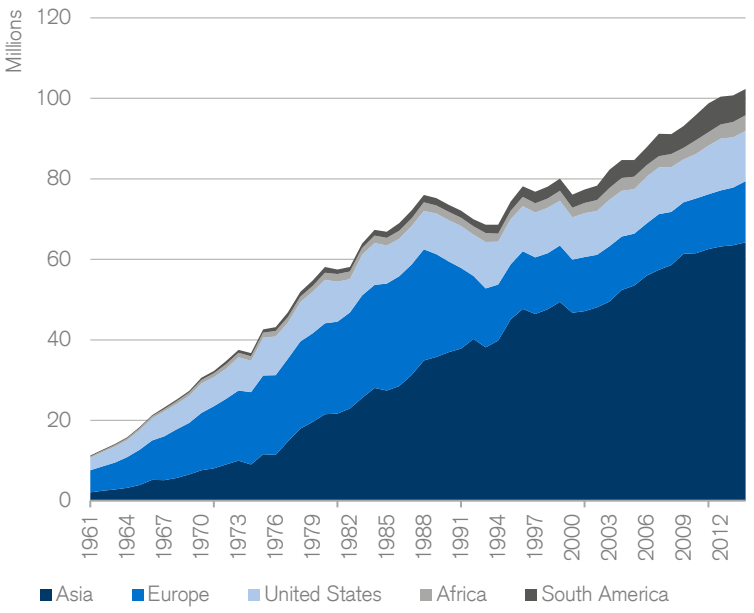
What role do fertilizers play?

The role that fertilizers and pesticides play in the global food system is relevant from both a health as well as an environmental perspective. However, while minimizing the use of chemicals benefits health and the environment, it is arguably a potential threat to the food sector given the need to produce more food to feed a growing global population. "Business as usual" is not an option, but what the exact role of fertilizers will be in the longer term remains unclear at this stage.

Solid growth in fertilizer use to date

Since 1961, the total use of nitrogen fertilizers globally has grown nine-fold, with most of this growth taking place in Asia (**Figure 26**). As we mentioned previously, population growth and the expanding middle class in developing countries (particularly Asia) has resulted in a strong increase in demand for food, thereby putting more pressure on the need for higher crop yields. As fertilizers have a beneficial impact on crop yields, they would appear essential in a world that is increasingly constrained in terms of arable land.

Figure 26: Global fertilizer use (tons of nitrogen)



Source: FAO, Credit Suisse Research

> "Since 1961, the total use of nitrogen fertilizers globally has grown nine-fold

In a business-as-usual scenario, total fertilizer use would likely rise further given that the global population looks set to increase to around ten billion people by 2050, with most of this growth taking place in Africa where, relatively speaking, fertilizer use has been low. However, a business-as-usual scenario may not be possible due to other concerns.

Environmental concerns

The use of fertilizers helps to improve crop yields, which in turn helps to address a number of the SDGs, including SDG1 "no poverty," SDG2 "zero hunger" and SDG3 "good health and well-being." However, the use of fertilizers has a number of damaging environmental side effects:

- Carbon intensity of fertilizer production: The production of fertilizers is an energy-intense process, whereby emissions generated per dollar of revenue for fertilizer companies tend to be substantially higher than for other chemical companies. Hence the high carbon intensity associated with fertilizer companies clearly challenges SDG13 "Climate Action."
- Pollution of soil and water: Excess fertilizers can run off and pollute the soil, underground water or rivers, thereby putting pressure on SDG6 "Clean water and sanitation," SDG14 "Conserve and Sustainably Use the Oceans, Seas and Marine Resources for Sustainable Development," and SDG15 "Protect, Restore and Promote Sustainable Use of Terrestrial Ecosystems, Sustainably Manage Forests, Combat Desertification, and Halt and Reverse Land Degradation and Halt Biodiversity Loss."

Regulation set to tighten
Regulation around the use of fertilizers is tightening as governments pay closer attention to pathways that help achieve long-term climate change targets. In Europe in particular, fertilizer companies are coming under increasing pressure due to the European Green Deal, including the "Farm to Fork" (F2F) and EU Biodiversity strategies. As part of this plan, the EU aims to cut nutrient losses (mainly nitrogen and phosphorus) by 50%, which, in their view, means a reduction in the use of fertilizers by at least 20% by 2030.

How can fertilizer companies adjust?
Given the need to cut emissions linked to the production of fertilizers and address the environmental challenges associated with their use, the question is what the future role of fertilizer companies should be.

Fertilizer use can be optimized through the adoption of the "4R" principles focused on using the right source of fertilizer at the right rate, time, and place. Site-specific nutrient management is therefore becoming increasingly relevant, which without doubt includes the use of smart technologies. All of this should help address some of the pollution-related arguments.

The carbon intensity of the fertilizer production process can be addressed in two ways. First, fertilizer companies can decide to move toward blue or green ammonia by incorporating hydrogen-related technologies. Companies such as Yara have already made a number of announcements in this area.

Second, there is the option to move from synthetic fertilizers toward organic fertilizers. This is arguably the most disruptive change for the incumbent fertilizer companies as their operations are synthetic-focused.

Photo: GettyImages, Andrea Pistolesi

Food loss and waste

In the previous chapters, we outlined the challenges of the current global food system due to the associated malnutrition and environmental footprint. These challenges are made worse by the fact that more than 30% of food produced is either lost or wasted. By way of example, around USD 408 billion of food produced in 2019 went unsold or uneaten. The FAO estimates the economic, environmental and social costs associated with food waste at USD 2.6 trillion. Eliminating food waste in the United States and Europe alone would add 10% to the world's available food supply. Solutions need to focus across the entire supply chain as about 50% of food is lost in the production and handling phase, while 45% is wasted in the distribution and consumption phase.

More than 30% of all food is lost or wasted

The United Nations has defined food loss and waste as food that is originally meant for human consumption, but for various reasons is removed from the human food chain. Specifically, food loss refers to food that is spilled, spoiled or otherwise lost, or incurs a reduction of quality and value during its process in the food supply chain before it reaches its final product stage. Food loss typically takes place during the post-harvest, production, processing and distribution stages in the food supply chain.

Food waste refers to food that completes the food supply chain up to a final product, is of good quality and fit for consumption, but is still not consumed because it is discarded, whether or not it has expired or is spoiled. Food waste typically (but not exclusively) takes place during the retail and consumption stages of the food supply chain.

Target 12.3 of the SDGs focuses on halving per capita global food waste at the retail and consumer levels and reducing food losses along the production and supply chains, including post-harvest losses. Food loss and waste will soon be measured by separate indicators:

1. The Food Loss Index (FLI) focuses on food losses that occur from production up to, but not including, the retail stage. It measures the changes in percentage losses for a basket of ten main commodities by country in comparison with a base period.
2. The UN is currently developing a proposal for the Food Waste Index (FWI), which will include the retail and consumption stages.
3. Together, the FLI and FWI will measure progress toward achieving SDG Target 12.3 and will provide an update to the FAO's 2011 estimate that around one third of the world's food is lost or wasted every year.

Framing the issue of food loss and waste
Globally, we lose around 14% of food from post-harvest up to, but not including, retail as measured by the FLI. This percentage is higher if we account for the large quantities of food that are wasted at the retail and consumption stages. The regions with the highest percentages of food loss include Central Asia and South Asia, followed by North America and Europe. In contrast, Australia and New Zealand rank the lowest on the FLI with a combined percentage of just 6%.

Different factors are at play along the supply chain in influencing the levels of food loss and waste. The FAO states that reductions in food loss at the farm and harvest stages are important in addressing food insecurity and reducing the burden on land and water. Combatting food waste that occurs during the consumption stage is crucial in reducing GHG emissions. To address malnutrition and micronutrient deficiencies, the FAO also stresses the missed opportunity costs of quantitative and qualitative food loss.

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> USD 408 billion worth of food went unsold or uneaten in 2019

Figure 2 shows that a total of 1.3 billion tons of food was lost or wasted in 2007, which equals 1.5 quadrillion kcal. At 44% in 2019, fruits and vegetables make up the biggest category of food loss and waste followed by roots and tubers at 20%. Put another way, USD 408 billion worth of food went unsold or uneaten in 2019. Porter et al. (2020) point out that reporting of on-farm food loss and waste data by producers is not required by EU regulations. Food loss and waste prior to harvest is not considered to be food and therefore not counted toward the loss and waste figures (European Parliament and Council, 2002, Art. 2).

The pattern of food loss and waste along the supply chain varies across regions. In high-income regions such as North America, Oceania and Europe, more than half of the food is lost at the consumption stage (**Figure 1**). In South and Southeast Asia and Sub-Saharan Africa, less food is wasted at the consumption level as most of the loss occurs closer to farming (i.e. production, handling and storage).

Figure 1: Food loss and waste as a percentage of food supply
Share of tonnage per region (2007)

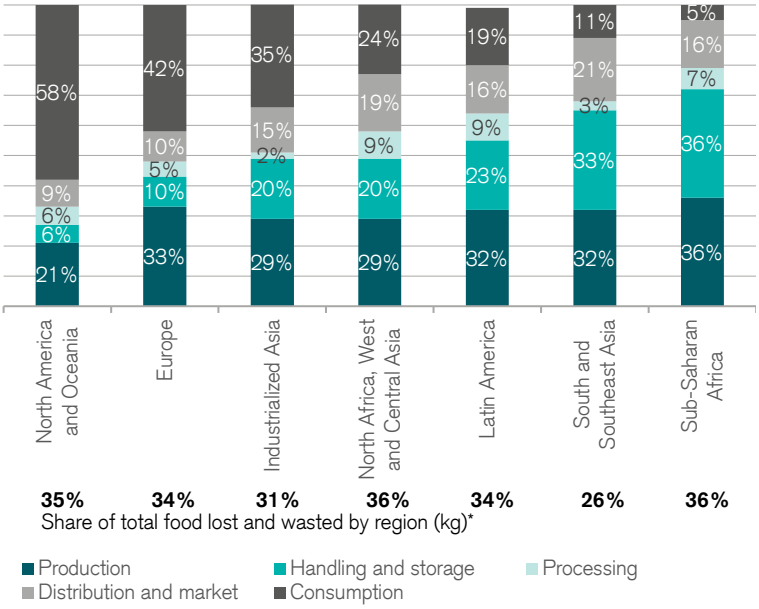
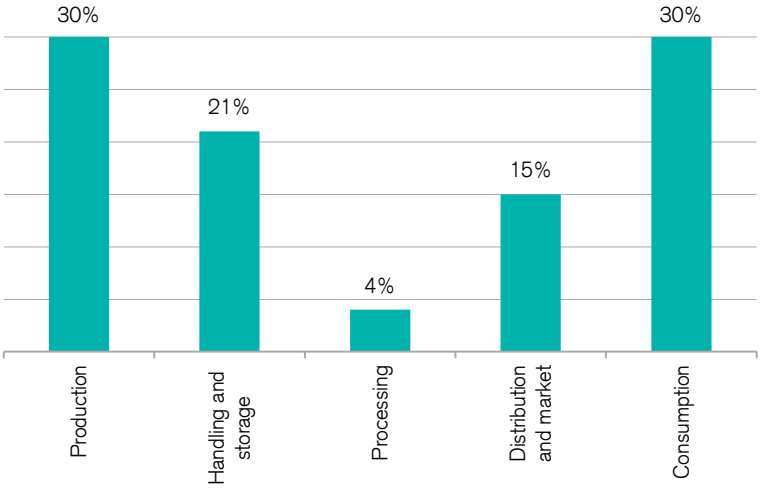


Figure 2: Distribution of total food loss and waste across the supply chain
100% = 1.3 billion tons (2007)



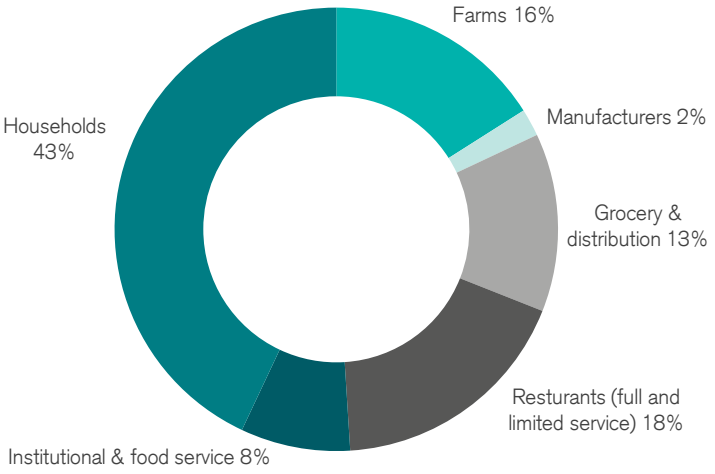
Source Figures 1 and 2: WRI analysis based on: “Global Food Losses and Food Waste: Extent, Causes and Prevention,” Rome: UNFAO, 2011

Table 1: Nutrient loss (%) from food loss and waste

	Global	High-income country	Upper-middle income country	Lower-middle income country	Low-income country
Calories	25	27	28	24	24
Protein	28	30	27	27	26
Carbohydrates	30	39	35	29	27
Fat	12	12	13	12	11
Calcium	23	20	20	26	24
Folate	33	37	32	34	28
Iron	33	38	36	32	30
Vitamin A	24	30	21	26	16
Vitamin B6	18	38	39	15	29
Vitamin C	41	45	44	41	37
Zinc	28	32	29	28	27

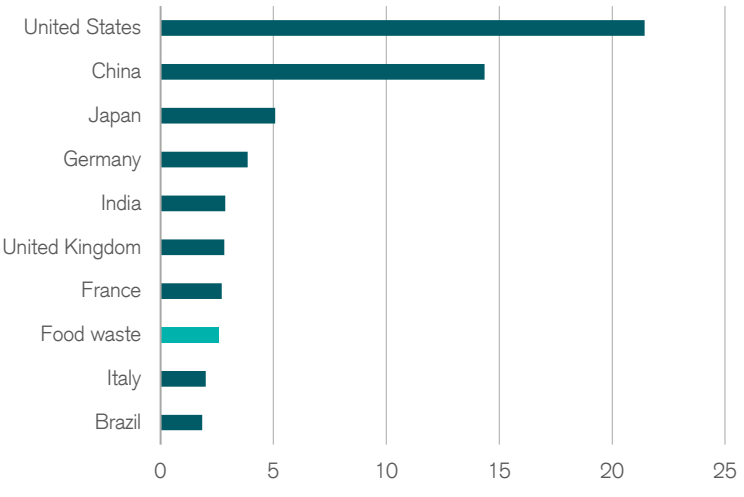
Source: Springmann (2018)

Figure 3: Food waste in the USA occurs most in households and restaurants (2015)
Note that by-products used for animal feed are not included



Source: NRDC (2017)

Figure 4: Full costs of food waste (USD trn)



Source: WRI analysis based on FAO

On a per-capita basis, more food is wasted in medium- and high-income countries relative to low-income countries. According to FAO estimates, per-capita food waste by consumers in Europe and North America amounts to 95–115 kg/year, but only 6–11 kg/year in South and Southeast Asia. As more countries develop and income levels rise, food loss and waste is expected to shift from the farm toward consumption.

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> In 2014, the FAO estimated that the economic, environmental and social costs of food waste are around USD 2.6 trillion

The impact of food loss and waste

Food loss and waste has social, environmental and economic repercussions. Current food production and distribution methods rely heavily on resources such as land, water, labor and capital. Food waste that occurs closer to consumption leads to significant losses of resources that were used in vain during the production, storage and handling, processing, distribution and marketing phases of the supply chain. In 2014, the FAO estimated that the economic, environmental and social costs of food waste were around USD 2.6 trillion. This is roughly equivalent to the GDP of France or twice the total annual food expenditure in the United States (**Figure 4**). According to the 2019 World Resources Report (WRR), food loss and waste consumes 25% of all water used by agriculture each year and an amount of land greater than the size of China. **Figure 6** shows that if food loss and waste were measured in country terms, it would be the third-largest source of GHG emissions in the world.

Reasons for food waste

Several drivers are at play in influencing food loss and waste around the world. We highlight a few key points from the literature below:

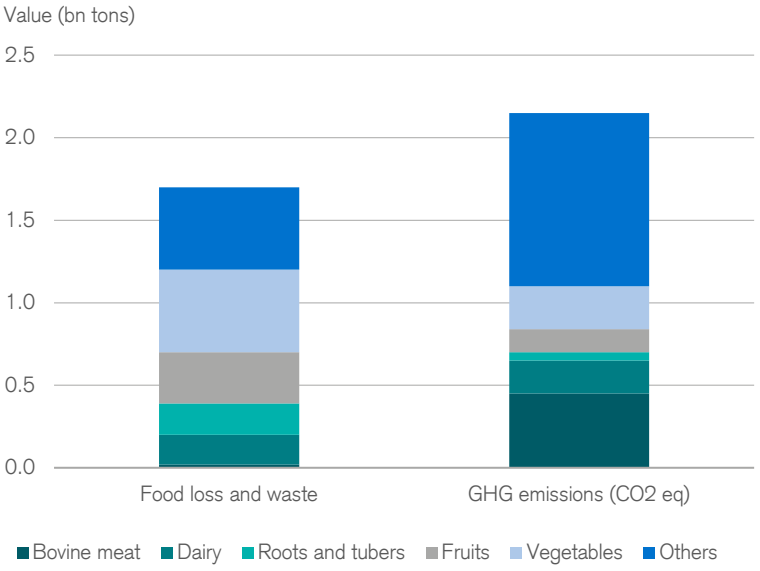
Cosmetic standards

Porter et al. (2020) argue that the use of esthetics for classifying and accepting fresh food for sale and consumption is built into food quality standards and regulations in the European Union. Estimates suggest that over a third of total farm production is lost for esthetic reasons. This accounts for around 970 kt CO2 eq. in the United Kingdom and 22,500 kt CO2 eq. in the European Economic Area. According to Porter et al., over-emphasis on the cosmetic and superficial qualities of fresh produce leads to unnecessary loss and waste.

Overplanting of produce

Farmers must meet their contractual obligations to deliver a specified tonnage of produce that meets food quality and regulation standards, including those that are of a cosmetic nature. As such, Porter et al. (2020) argue that the overplanting of produce is linked to loss and waste of food due to cosmetic standards.

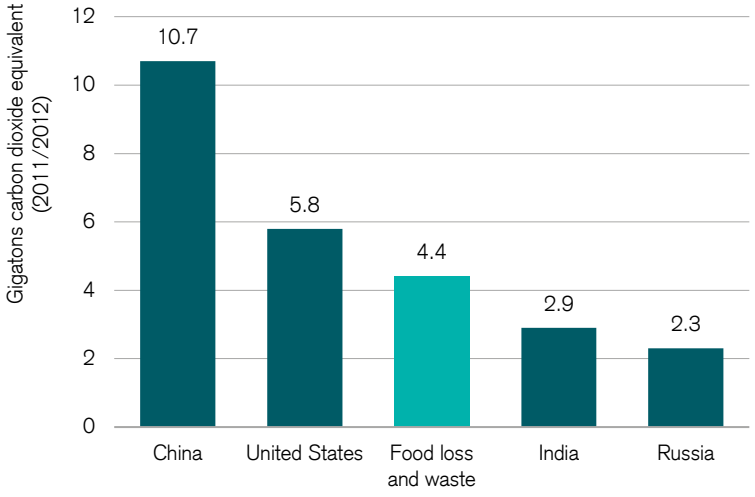
Figure 5: GHG emissions associated with food loss and waste are significant (2013)



Source: Guo et al. (2019)

Figure 6: Emissions associated with food loss and waste relative to major emitting countries

If food loss and waste were a country, it would be the third-largest greenhouse gas emitter in the world



Note: Figures reflect all six anthropogenic GHG emissions, including those from land use, land-use change, and forestry (LULUCF). Country data are for 2012, while the food loss and waste data are for 2011 (the most recent data available). To avoid double counting, the food loss and waste emissions figure should not be added to the country figures. Source: CAIT (2017), FAO (2015a)

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> Up to 10% of the food waste generated in the EU is linked to date marking

Date marking

In 2008, a study carried out by the European Commission estimated that up to 10% of the food waste generated in the EU is linked to date marking. Misinterpretation of the meaning of the dates, such as “best before” or “use by” can lead to food loss and waste. The “best before” date as opposed to “use by” is an indication of quality more than safety. As part of its waste-prevention efforts, the EU Platform on Food Losses and Food Waste makes the case for improved date-marking practices and guidance to both food business operators and consumers.

Consumer attitudes and behavior

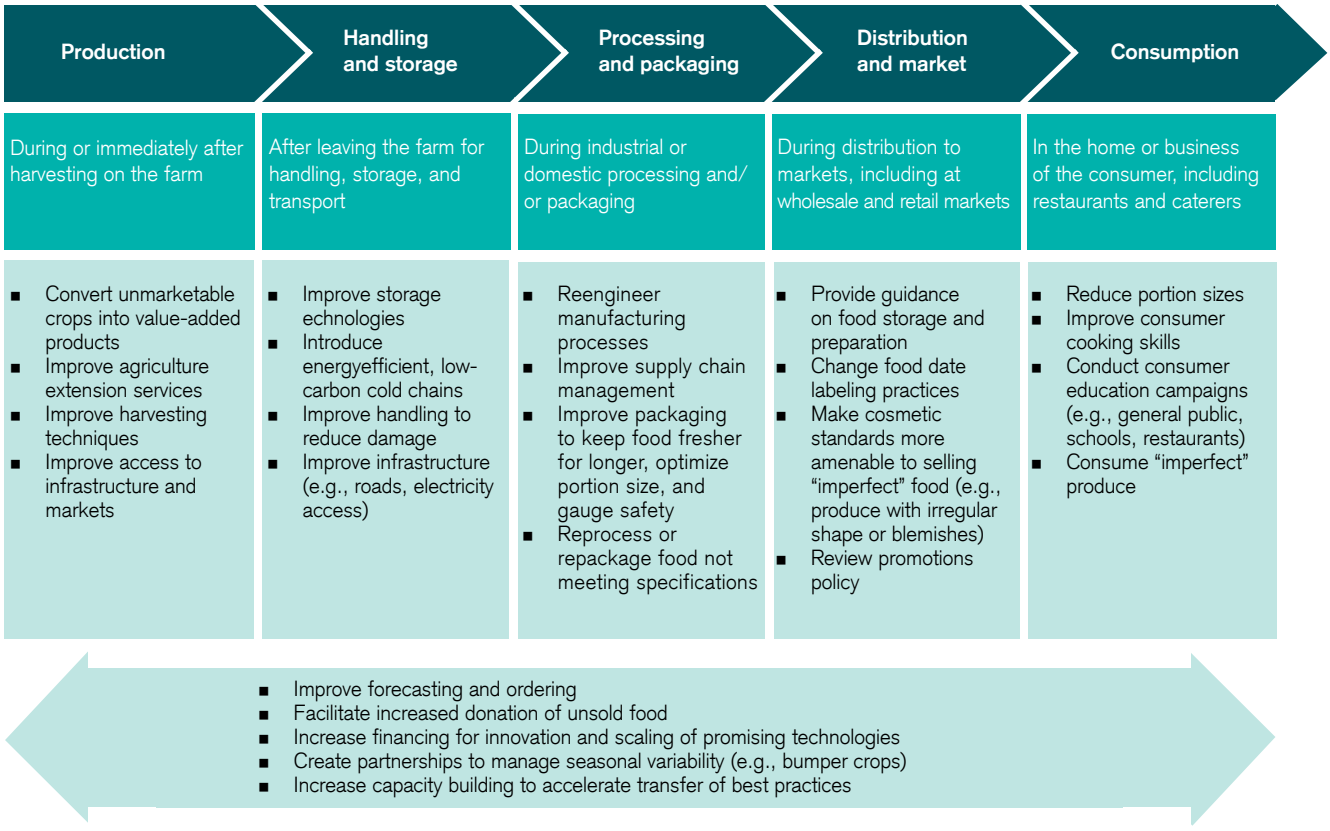
As the majority of food loss and waste occurs at the consumption stage in developed countries, consumer behavior and attitudes play a crucial rule in avoiding food waste. Janssens et al. (2019) argue that food management behaviors relate to planning, shopping, storage, preparation and consumption. Food waste is the result of how consumers deal with these different stages. Janssens et al. (2019) show that in-store purchase behavior was the main driver of food waste among Dutch consumers. In particular, consumers indicated that buying more food than was necessary would often lead to food waste.

How to address food waste?

The World Resources Report lists a wide variety of approaches at various stages of the supply chain to reduce food loss and waste. These approaches are predominantly centered around prevention, recovery and recycling solutions. Although some of the solutions require large-scale infrastructure developments, others can easily be implemented by changes in consumer behavior and attitudes. These approaches are comprehensive, but not exhaustive, and are summarized in **Figure 7**.

- Production stage: Food loss can be reduced at the production stage, by improving harvesting techniques and access to infrastructure and markets. Another approach is to convert unmarketable crops into value-added products. These interventions need to happen during or immediately after harvesting on the farm.
- Handling and storage: Once food leaves the farm for handling, storage and transportation, food loss and waste can be reduced by improving storage technologies. In developing countries, for example, the lack of widespread refrigeration and food processing leads to large food losses. By introducing energy-efficient, low-cold chains, food loss and waste can be avoided at this point in the supply chain.
- Processing and packaging: During industrial or domestic processing and/or packaging, loss and waste can be caused by inefficient factory machinery, poor order management and the loss of food due to damage. Improvements to tackle food loss and waste at this stage should focus on changes in production processes and improvements in food demand forecasting, according to the World Resources Report.

Figure 7: Approaches available for reducing food loss and waste



Source: Hanson and Mitchell (2017)

- Distribution and market: As soon as food is distributed to markets, including both wholesale and retail consumers, loss and waste can be avoided by improving food date-labeling practices, focusing on cosmetic and regulatory standards to make "imperfect" produce more likely to be sold, and providing guidance on proper storage and preparation.
- Consumption: Finally, at the consumption level, food loss and waste can be tackled by focusing on educational campaigns regarding date marking, reducing portion sizes and consuming imperfect produce. As mentioned earlier, some of the waste occurs because of a lack of education about spoilage dates. Reducing portion sizes is another approach that does not require large-scale interventions. According to the Cornell University Food and Brand Lab, diners on average leave 17% of their meals uneaten and 55% of edible leftovers are left behind at restaurants.

Food sustainability: Who's most at risk?

The simultaneous existence of undernourishment, obesity, the environmental footprint of food production and food waste puts the global food system under significant stress. However, these factors do not impact all countries the same way, suggesting that different solutions or strategies are needed for different countries. Using the Food Sustainability Index developed by the Barilla Center for Food and Nutrition, we find that France, the Netherlands and Canada score best, while sustainability is lowest in Russia, Bulgaria and the UAE. Sustainability challenges differ between regions: developed countries score worse on diet patterns and food waste, whereas emerging countries need to address food loss and general quality of life.

Food Sustainability Index

As mentioned above, the Barilla Center for Food and Nutrition Foundation (BCFN) has put together a Food Sustainability Index (FSI) that assesses the sustainability of food systems for 67 countries. The index measures sustainability for food loss and waste, sustainable agriculture and nutritional challenges. It thus effectively captures the impact of the previous three chapters of this report.

The FSI index reviews the performance of all countries on 38 parameters using some 90 metrics in total. Overall, the countries that have the highest score are deemed to have better sustainable food systems. Based on the most recent readings, the countries that score best

Figure 8: FSI score vs. GDP/capita (2018)

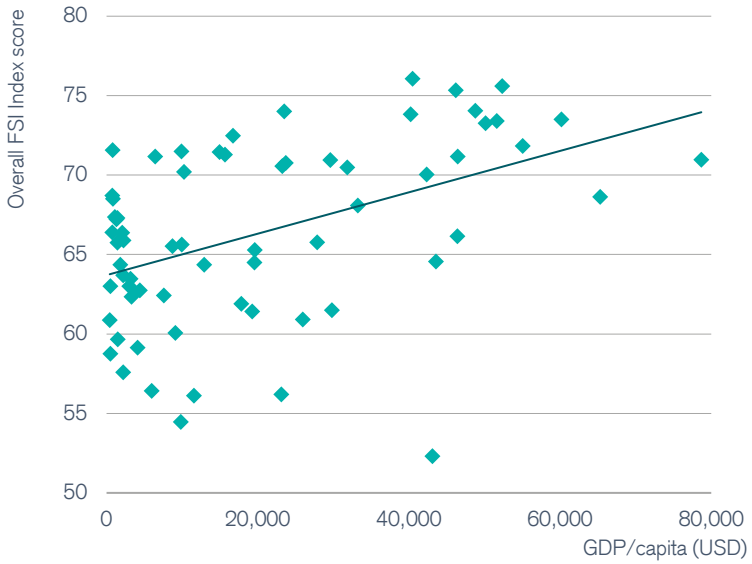
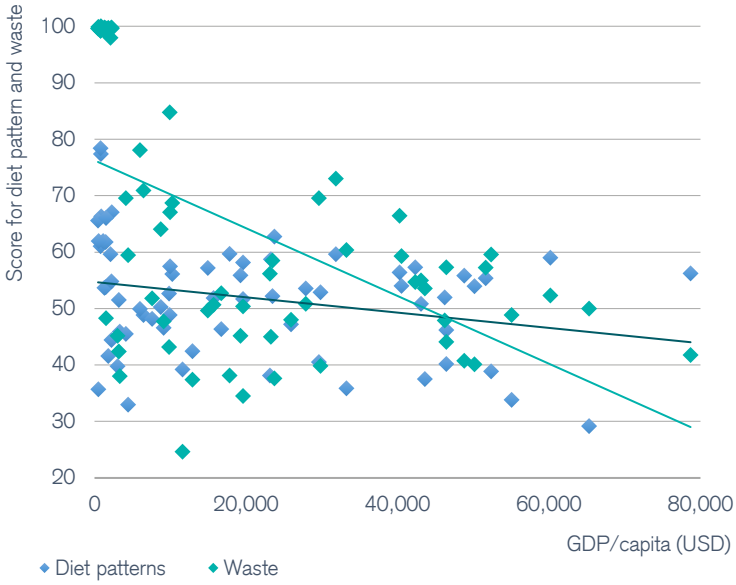


Figure 9: Diet quality and food waste negatively correlated with wealth (2018)

A lower score reflects that the diet pattern or mix is of a lower quality in terms of nutrition



Source Figures 8 and 9: "Fixing Food 2018," Barilla Center for Food & Nutrition, Economist Intelligence Unit, Credit Suisse Research

Table 2: Food Sustainability Index – key scores

			Nutritional		Sustainable agriculture			Food loss/waste	
	Overall	Life quality	Life expectancy	Diet patterns	Water	Land	Air	Loss	Waste
France	76.1	85	70	54	60	62	95	99	59
Netherlands	75.6	91	70	39	85	58	98	91	60
Canada	75.3	89	66	52	82	61	82	99	48
Finland	74.1	86	68	56	66	64	85	100	41
Czech Republic	74.0	83	56	52	88	56	95	91	58
Japan	73.8	85	85	56	75	67	82	74	66
Denmark	73.5	86	70	59	87	62	98	76	52
Sweden	73.4	87	70	55	84	66	72	84	57
Austria	73.3	86	67	54	85	65	98	84	40
Hungary	72.5	84	50	46	86	60	93	91	53
Australia	71.8	87	65	34	80	64	81	92	49
Rwanda	71.6	64	75	77	92	52	79	59	100
Argentina	71.5	82	56	49	76	58	72	83	85
Croatia	71.4	92	56	57	86	53	67	91	50
Poland	71.3	79	57	52	82	65	94	82	51
Colombia	71.2	78	60	49	89	58	92	74	71
Germany	71.2	88	62	40	79	65	97	76	57
Ireland	71.0	88	67	56	85	58	96	76	42
Spain	70.9	89	65	41	59	62	81	84	70
Estonia	70.8	81	59	63	67	62	84	92	38
Portugal	70.6	89	62	59	55	63	95	83	45
South Korea	70.5	86	78	60	83	61	82	57	73
China	70.2	77	66	56	68	57	58	89	69
United Kingdom	70.0	85	62	57	59	59	68	91	55
Uganda	68.7	51	72	61	91	57	65	66	99
United States	68.6	89	51	29	73	54	86	92	50
Ethiopia	68.5	37	75	66	66	55	85	73	100
Italy	68.1	85	63	36	76	60	80	76	60
Luxembourg	67.9	86	70	39	62	53	45	99	52
Tanzania	67.4	53	71	62	64	61	90	56	99
Zimbabwe	67.3	48	60	54	92	46	86	67	100
Zambia	67.2	38	65	54	93	50	88	67	100
Burkina Faso	66.4	42	67	78	89	46	77	57	99
India	66.4	32	72	60	72	57	71	73	98
Belgium	66.2	87	67	46	83	55	96	61	44
Cote d'Ivoire	65.9	45	51	67	88	52	92	56	100
Cyprus	65.8	82	63	54	75	54	67	73	51
Senegal	65.8	53	71	62	85	52	66	57	100
Mexico	65.6	67	57	57	72	54	91	66	67
Brazil	65.5	79	55	50	82	54	62	72	64
Lithuania	65.3	80	50	52	64	57	83	83	35
Israel	64.6	86	58	38	71	72	96	52	54
Greece	64.5	83	57	58	80	56	64	66	50
Romania	64.4	75	49	42	80	52	81	83	37
Kenya	64.4	37	76	42	86	56	62	65	100
Nigeria	63.7	41	59	55	63	54	89	61	100
Morocco	63.5	65	58	52	82	56	78	72	42
Egypt	63.0	72	47	40	77	44	90	79	45
Mozambique	63.0	32	67	36	89	51	74	65	100
Jordan	62.8	79	58	33	71	51	78	68	59
Lebanon	62.4	68	54	48	79	49	76	71	52
Tunisia	62.3	76	57	46	82	49	89	64	38
Latvia	61.9	78	49	60	62	56	42	83	38
Malta	61.5	89	57	53	83	54	84	48	40
Slovakia	61.4	86	61	56	63	56	44	68	45
Slovenia	60.9	85	63	47	61	60	70	55	48
Sudan	60.9	40	61	66	62	43	83	53	100
Turkey	60.1	81	58	47	76	48	91	48	48
Cameroon	59.7	49	59	66	89	49	90	51	48
Indonesia	59.1	56	63	46	56	51	81	57	70
Sierra Leone	58.8	26	53	62	68	50	90	47	100
Ghana	57.6	44	65	44	64	48	64	48	100
South Africa	56.4	67	48	50	58	58	39	52	78
Saudi Arabia	56.2	73	51	38	61	46	54	62	56
Russia	56.1	76	48	39	74	51	38	75	25
Bulgaria	54.5	75	38	53	55	52	55	57	43
UAE	52.3	83	57	51	47	48	80	24	55

Source: Barilla Center for Food & Nutrition, Economist Intelligence Unit, Credit Suisse Research

overall are France, the Netherlands and Canada. Russia, Bulgaria and the United Arab Emirates score lowest (see **Table 2**).

It might appear logical to assume that richer countries score better than poorer ones on this measure. In **Figure 8**, we plot a country's FSI score against its GDP per capita. While this suggests there is some correlation, it may not be as strong as we expected. We note, for example, that countries like Rwanda, Hungary, Argentina and Colombia have below-average wealth levels, but rank well above average on the overall index score (see **Table 2**).

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> Consumer behavior is an area that needs particular focus in developed markets

Diet quality and food waste are more of a developed market problem

Interestingly, the index data suggest that greater personal wealth is negatively correlated with the quality of diets and the amount of food that is wasted (**Figure 9**). Both indicators suggest that consumer behavior is an area that needs particular focus in developed markets.

Food loss is of greater concern across developing countries

Food loss appears more prevalent across developing nations. **Table 3** shows that the average readings for South America, Southern Africa, and the Middle East and Northern Africa are substantially lower than elsewhere. In our view, one possible reason could be that production and storage technologies (e.g. cooling) are not implemented as well across developing countries. This is likely related to the fact that farming is more small-scale in developing countries and that farmers there tend to have much lower income levels than those in developed countries and therefore do not have the means to invest in more efficient production and cooling equipment. We will review this in more detail later in this report; however, it would appear that support for greater access to technology is key for developing regions in order to improve food sustainability.

Table 3: Food Sustainability Index by region

			Nutritional		Sustainable Agriculture			Food loss/waste	
	Overall	Life quality	Life expectancy	Diet patterns	Water	Land	Air	Loss	Waste
North America	72.0	89	58	41	77	58	84	95	49
Western Europe	70.2	87	65	50	74	60	83	80	51
Asia	68.6	71	72	52	73	60	76	74	71
Eastern Europe	65.4	81	53	52	72	57	70	79	43
South America	65.1	51	63	57	79	52	78	62	91
Southern Africa	65.1	51	63	57	79	52	78	62	91
Middle East North	60.8	76	55	43	72	51	81	60	50

Source: Barilla Center for Food & Nutrition, Economist Intelligence Unit, Credit Suisse Research

Photo: GettyImages, Marko Geber

Solutions: A change in diet

A change toward a plant-based diet appears inevitable, in our view, if the global food system is to become more sustainable. Research suggests that a plant-based diet not only has around a 90% lower emission intensity than the current average diet, but also has the potential to reduce the number of premature deaths among adults by around 11 million. We see strong growth potential for alternative animal-protein products and estimate that the value of the market for alternative meat and dairy can grow to USD 1.4 trillion by 2050. Despite the involvement of more than 600 mainly small and private companies in this field, we expect the traditional food companies to continue to transition their operations toward healthier products.

National food-based dietary guidelines

Attempts have been made on a national level to bring about changes in food consumption. The need to change what and how much we eat should be one of the most obvious targets if the global food system is to become more sustainable. A range of governments around the world have adopted national food-based dietary guidelines (FBDGs) with the aim of achieving such a turnaround. Typically, these guidelines focus on recommendations and advice about healthy diets and lifestyles.

Early last year, Springmann et al published a health and environmental review of 85 different FBDGs around the world. Their analysis showed that, compared to global health and environmental targets, these recommended diets are still geared too much toward unhealthy and environmentally intensive foods (e.g. meat, processed food and sugars) and too little to more healthy options and ecologically less intensive products such as fruit and vegetables (see **Table 1**).

Springmann's analysis also showed that with regard to actual food intake, no country fulfilled all eight recommendations relating to recommended food groups (e.g. fruit and vegetables, legumes, nuts and seeds, whole grains and fish), as well as food groups that are discouraged (sugar, red meat and processed meat). No country fulfilled more than four recommendations, while only three of the 85 countries (Bangladesh, Indonesia and Sierra Leone) fulfilled four of them (**Figure 1**).

It is striking to note that none of the G20 and EU28 countries managed to meet more than two of the eight guidelines. Apparently, a greater level of economic development does not imply an increased eagerness on the part of consumers to improve what they eat and drink. Guidelines alone are clearly insufficient to bring about the necessary changes in the world's food system.

Springmann's analysis shows that, if the national guidelines were to be adopted by consumers, they would bring about a clear improvement

Table 1: National food-based guidelines differ substantially from actual food consumption

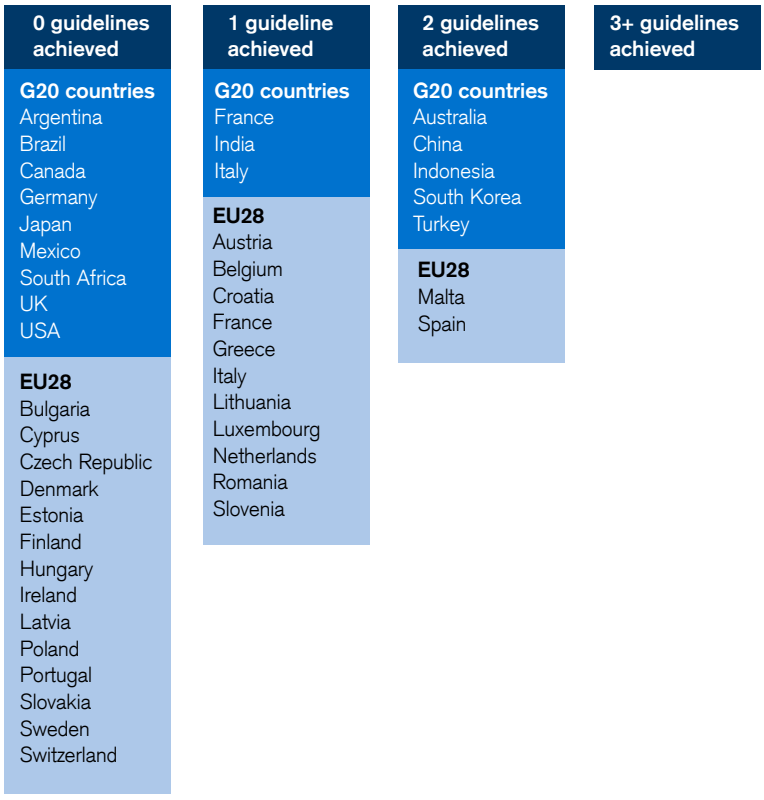
Food group	Percentage difference between recommended and current intake							
	Average	Europe	North America	Near East	"Asia and Pacific"	Latin America	Africa	EAT
Legumes	166	197	90	309	128	279	240	247
Whole grains	122	119	–16	194	144	160	113	362
Milk	60	16	21	534	103	53	32	9
Fish	36	56	21	0	32	53	55	5
Nuts and seeds	22	56	18	1	7	132	29	428
Fruits and vegetables	18	17	62	–43	14	29	54	15
■ Fruits	34	16	57	–18	43	13	50	28
■ Vegetables	9	18	67	–60	2	64	58	7
Eggs	17	5	–57	9	25	45	20	–51
Sugar	–6	–15	–47	–23	23	–41	2	–33
Meat	–28	–36	–48	–5	–29	–1	19	–49
■ Poultry	–13	–19	–48	–3	–13	29	18	5
■ Red meat	–34	–38	–46	–8	–39	–4	15	–68
■ Processed meat	–44	–51	–50	–11	–13	–73	46	–100
Energy intake	–6	–18	–18	–8	–3	–11	7	–6

Source: Springmann et al '"The healthiness and sustainability of national and global food based dietary guidelines," Credit Suisse ESG Research

over current food consumption patterns. For example, if they were adopted fully, it would likely result in a 13% reduction in food-related GHG emissions. Most of this reduction would be due to a decline in the consumption of ruminant meat although some of this would be offset by increased milk consumption. Demand for water, nitrogen and phosphorus would remain largely unchanged, mostly due to greater demand for fruit, milk and vegetables and the reduced intake of sugar, staples and animal products. Importantly, diet-related diseases and premature mortality should also decline on average by 15%.

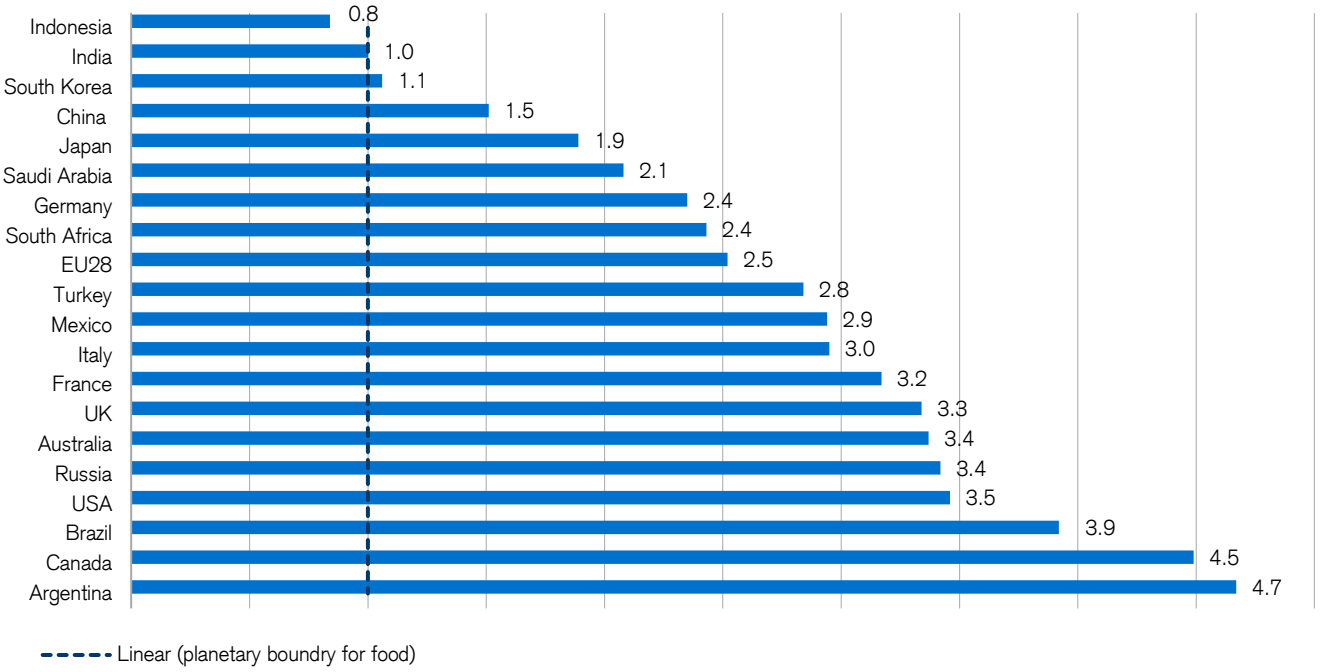
However, despite the improvements that consumer acceptance of these guidelines would bring, we note that they do not go far enough. For example, the ecological footprint of food consumption across all countries would still be excessive. **Figure 2** shows that the US guidelines would, if adopted by all countries globally, require 3.5 "earths" to support the resulting global food demand. In fact, only the guidelines proposed by India and Indonesia would, if adopted globally, be in line with our planetary food boundaries.

Figure 1: Number of FBDGs achieved in the G20 and EU28 (out of eight guidelines)



Source: Springmann et al. "The healthiness and sustainability of national and global food based dietary guidelines," Credit Suisse ESG Research

Figure 2: The number of earths needed to provide sufficient food if all countries globally adopt the FBDGs used by the countries listed



Source: FAO, Credit Suisse Research

Alternative healthy diet patterns

If national dietary guidelines are insufficient to reduce the ecological footprint, what are the alternatives? What kind of diet would meet both health and environmental needs? This question is not only relevant for today's world, but even more so for the future, given the likely increase in food demand as the global population increases to around ten billion people by 2050. A landmark publication by the EAT-Lancet Commission in 2019 was one of the first attempts to present a reference diet that meets both health and ecological requirements.

Dietary considerations for a healthy diet

Key in developing a healthy diet is to have a good balance between the major diet components of protein, carbohydrates, fruit and vegetables, added fats and sugar.

- **Protein**: High-quality protein is not only important for the growth of infants and young children, but also for older people who lose muscle mass later in life. People typically get most of their protein through meat consumption; however, this is sub-optimal due to the side effects associated with eating meat. Various studies have shown that replacing animal protein with plant-based protein is a healthy alternative and reduces mortality risk, type-2 diabetes and the risk of cardiovascular diseases.
- **Dairy products**: Numerous studies have been conducted to assess the relationship of dairy consumption with the risk of overall mortality and cardiovascular disease. The popular view is that it aids bone growth and fracture prevention. The EAT-Lancet study concludes that this evidence is mixed at best, suggesting that a low intake of dairy products is advised as this reduces environmental stress and does not negatively impact health.
- **Other sources of protein** such as fish, nuts and legumes are all recommended as they contain fatty acids and are low in poly-unsaturated fats associated with an increased risk of cardiovascular disease, among others.
- **Carbohydrate sources**: Studies have shown that high carbohydrate intake increases blood triglyceride concentration, reduces HDL (or good) cholesterol and increases blood pressure, especially in people with insulin resistance. This calls for limiting the intake of foods high in carbohydrates (especially in refined rather than whole grain form).
- **Added fat**: Most dietary recommendations suggest limiting or reducing the intake of total fat in order to decrease the risk of coronary diseases and cancer. However, scientific evidence for this is weak as randomized trials do not suggest that a reduced intake of total fat correlates with a reduction of these diseases. Evidence does indicate that

Table 2: The EAT-Lancet Commission reference diet

	Macronutrient intake (possible range), g/day	Caloric intake, kcal/day
Whole grains		
Rice, wheat, corn, and others	232 (total gains 0–60% of energy)	811
Tubers or starchy vegetables		
Potatoes and cassava	50 (0–100)	39
Vegetables		
All vegetables	300 (200–600)	–
Dark green vegetables	100	23
Red and orange vegetables	100	30
Other vegetables	100	25
Fruits		
All fruit	200 (100–300)	126
Dairy foods		
Whole milk or derivative equivalents	250 (0–500)	153
(eg, cheese)		
Protein sources		
Beef and lamb	7 (0–14)	15
Pork	7 (0–14)	15
Chicken and other poultry	29 (0–58)	62
Eggs	13 (0–25)	19
Fish§	28 (0–100)	40
Legumes		
Dry beans, lentils, and peas	50 (0–100)	172
Soy foods	25 (0–50)	112
Peanuts	25 (0–75)	142
Tree nuts	25	149
Added fats		
Palm oil	6·8 (0–6·8)	60
Unsaturated oils¶	40 (20–80)	354
Dairy fats (included in milk)	0	0
Lard or tallow‖	5 (0–5)	36
Added sugars		
All sweeteners	31 (0–31)	120

Source: Willett, Rackstrom et al, 'Food in the Anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systems

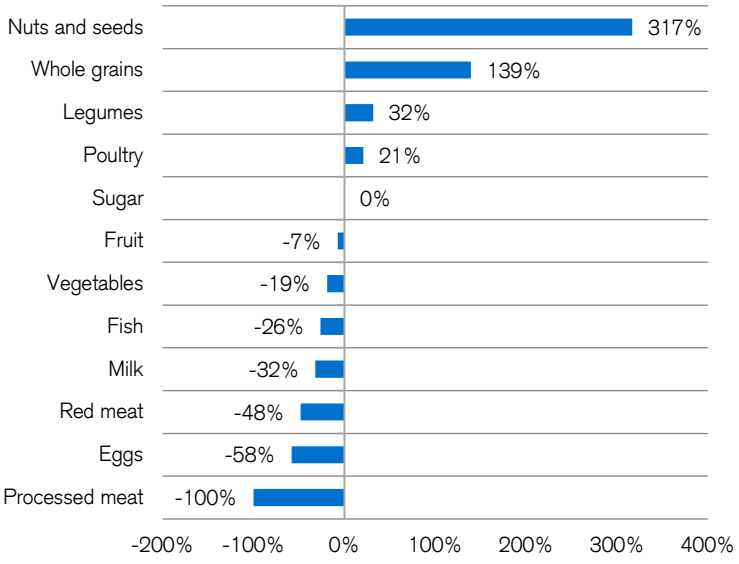
replacing saturated fat with polyunsaturated fat does have health benefits (see the Credit Suisse Research Institute report "Fat: the new paradigm.")

Based on input from 19 commissioners and 18 coauthors, and using the latest available research, the EAT-Lancet Commission presented its view of what makes a diet healthy. Its so-called reference diet is based on a daily intake of around 2500 kcal, which is deemed sufficient to meet the average energy needs of a 70-kilogram man aged 30 years and a 60-kilogram woman aged 30 years with moderate-to-high levels of physical activity. The reference diet also aims to meet environmental targets if globally adopted and implemented (**Table 2**).

To show how the EAT-Lancet reference diet differs from national dietary guidelines (NDGs), we refer readers to **Figure 3**, which compares the recommended daily intake for the EAT-Lancet diet with the average for NDGs. According to the chart, consumers should further reduce their intake of processed meat, eggs, red meat and milk in favor of nuts and seeds, whole grain products, legumes and poultry.

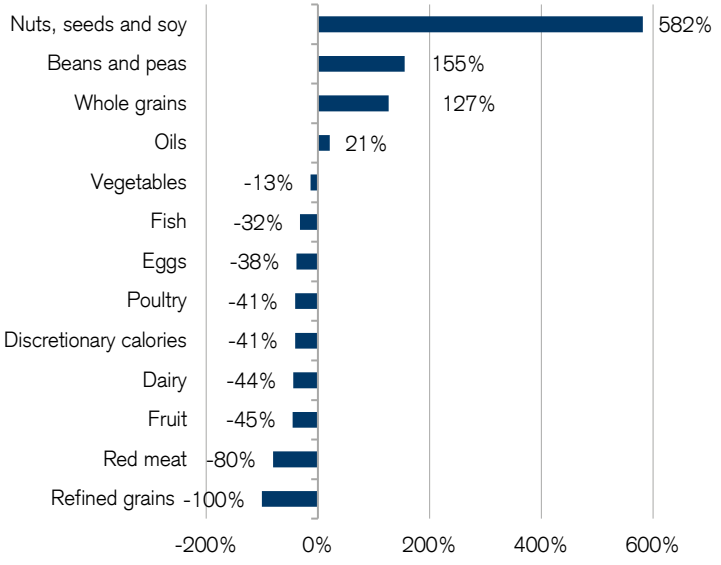
Work from Blackstone and Conrad compared the EAT-Lancet reference diet to the dietary guidelines issued for Americans (**Figure 4**). This shows more clearly the sizeable task ahead if a sustainable food system is to be achieved. The US guidelines are substantially more relaxed in relation to the consumption of refined grains and animal protein (e.g. red meat and dairy). On

Figure 3: Average daily consumption by food group: EAT-Lancet as percentage of NDG



Source: "The healthiness and sustainability of national and global food based dietary guidelines: modelling study," by Marco Springmann

Figure 4: Average daily consumption by food group: EAT-Lancet as percentage of dietary guidelines for Americans



Source: "Comparing the Recommended Eating Patterns of the EAT-Lancet Commission and Dietary Guidelines for Americans: Implications for Sustainable Nutrition" by Blackstone and Conrad

the other hand, support for the consumption of plant-based proteins (e.g. nuts, beans and peas) and whole grain products is substantially lower than what is advocated by academic research.

As noted before, if adopted by consumers, the national dietary guidelines would represent an improvement from current food consumption patterns. To assess how significant the challenge will be to change current consumer behavior further toward a diet that is both healthy and supportive of broader environmental targets, we compared the EAT-Lancet reference diet to food consumption data on a regional basis as provided by the FAO. Table 3 shows food consumption patterns that were recorded in 2010. The key conclusions are:

- Consumption of plant-based products is too low everywhere: A healthy diet requires substantial consumption of fruit, vegetables, nuts and whole grain products. None of the regions currently reach the targets set by the reference diet. On a global average basis, fruit consumption needs to rise by 146%, whereas the intake of vegetables and nuts and seeds needs to rise by 44% and 462%, respectively. Whole grain consumption needs to increase more than five-fold on average in order to provide sufficient energy and nutrients as part of a healthy diet.

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>
> Consumption of plant-based products is too low everywhere

- Seafood consumption appears better than it actually is: Although a number of regions do not eat more seafood than is recommended by the reference diet, we note that this is not by choice. In our view, a lack of supply and/or affordability is likely to be the reason why consumption of seafood is below the reference point in most regions.
- Meat consumption needs to fall substantially: Meat consumption, both red meat and processed meat, is too high across almost all of the regions reviewed. Red meat consumption needs to decline by 67% on average, whereas processed meat consumption needs to be eliminated completely if consumers want to reach the standards adopted in the reference diet.

Table 3: Consumption relative to the EAT-Lancet reference diet (grams/day)

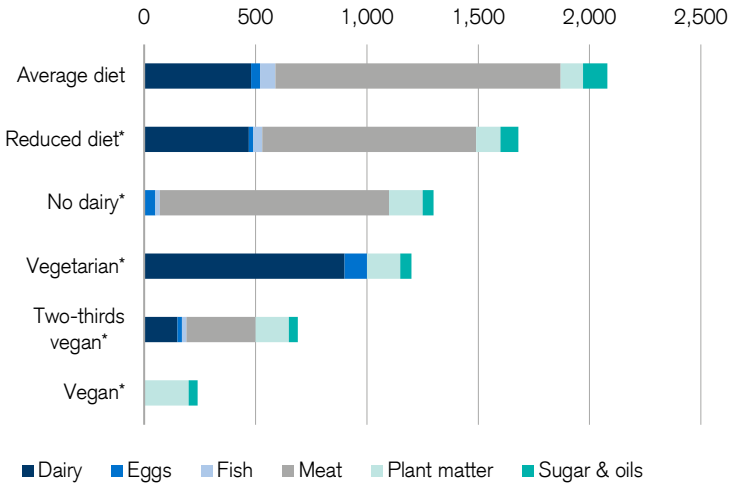
	Fruit	Vegetables	Nuts/seeds	Whole grains	Seafood	Red meat	Processed meat
EAT-Lancet	200	300	50	232	28	14	0
Global Average	81	209	9	38	28	42	14
High income APAC	123	282	3	9	81	48	7
Central Asia	65	86	5	25	12	40	17
East Asia	42	294	3	11	34	54	4
South Asia	28	169	11	16	17	7	9
Southeast Asia	112	146	33	145	34	26	13
Australasia	166	165	3	72	28	76	19
Caribbean	165	140	5	30	26	34	10
Central Europe	143	167	3	15	16	56	32
Eastern Europe	100	173	11	24	29	64	32
Western Europe	165	171	4	62	35	60	26
Andean Latin America	149	156	4	35	24	60	27
Central Latin America	170	229	7	26	10	51	44
Southern Latin America	103	123	1	20	24	80	16
Tropical Latin America	97	260	2	14	40	91	26
North Africa and Middle East	125	229	11	31	20	58	4
North America	99	123	5	48	20	46	35
Oceania	72	103	8	39	43	46	13
Central Sub-Saharan Africa	105	274	3	28	25	51	8
East Sub-Saharan Africa	69	243	4	75	22	34	6
Southern Sub-Saharan Africa	49	217	0	112	9	55	10
West Sub-Saharan Africa	93	204	16	74	31	33	6

Source: Willett, Rackstrom et al, "Food in the Anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systems," Micha, Khatibzadeh "Global, regional and national consumption of major food groups in 1990 and 2010: a systematic analysis including 266 country-specific nutrition surveys"

The benefits of a more plant-based diet

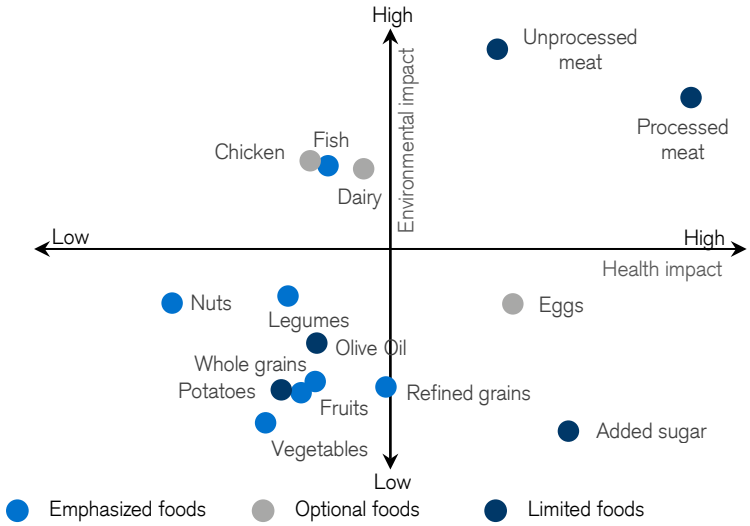
The strong increase in plant-based food seen in the recommendations put forward by the EAT-Lancet commission aims at increasing the consumption of healthy fats (mono and poly-unsaturated fatty acids) and decreasing more unhealthy saturated fats. The research also suggests that the intake of most micronutrients increases, including iron, zinc and vitamin A. However, plant-based food is low in vitamin B12, which would therefore have to be supplemented. Calculations by the authors suggest that a shift to a plant-based diet would have the potential to significantly reduce the number of premature deaths among adults. Their estimates suggest that this reduction ranges between 19% and 23.6% or around 11 million lives on an annual basis.

Figure 5: Emission intensity can be greatly reduced
United States, greenhouse-gas footprint kg of C02 equivalent per person per year



* Simulated diets to reach 2,300 calories per day
Source: "Multiple health and environmental impacts of foods," by Clark et al.

Figure 6: Moving to a plant-based diet has both health and environmental benefits



Source: Clark et al (2019), EAT: "Diets for a better future"

Figure 7: Comparison of the health and environmental impacts for various diet guidelines

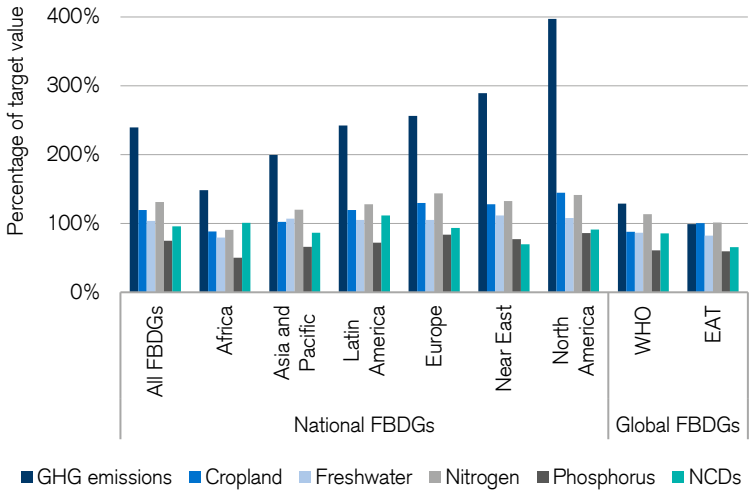
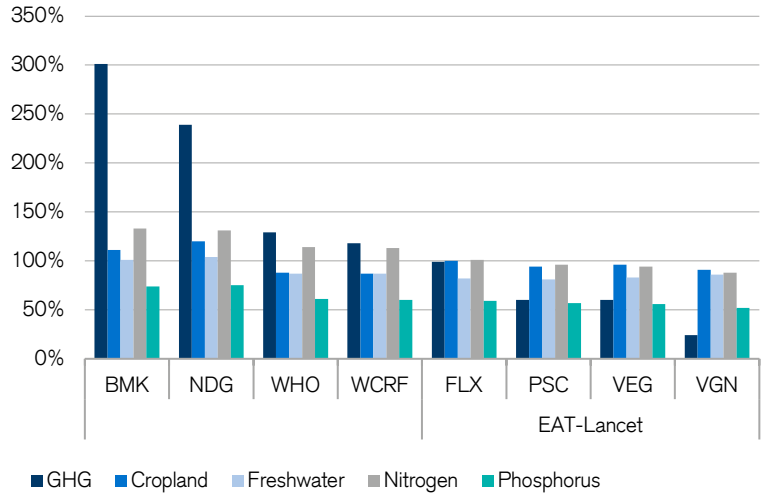


Figure 8: Environmental intensity of various diets; percentage of target value



Source Figures 7 and 8: "The healthiness and sustainability of national and global food based dietary guidelines: modelling study," by Marco Springmann, Credit Suisse Research

As mentioned previously, the benefits of moving to a more plant-based food system are not just health-related. Plant-based foods tend to be good for both people and the planet (**Figure 6**). Analysis by Springmann et al. indicates that the food guidelines previously issued by the WHO are much less demanding in terms of GHG emissions, cropland use, water consumption or nitrogen and phosphorus needs compared to the EAT-Lancet reference diet. Also compared to national FBDGs and the WHO food guidelines, it is the only diet that does not breach any of the global environmental targets (**Figure 7**).

The reference diet from EAT-Lancet and other organizations such as the WHO and the World Cancer Research Fund (WCRF) call for substantial shifts in food consumption when compared to current practices. While these would already provide a more sustainable food system, we note that more can be achieved after analyzing a few alternatives to the reference diet proposed by EAT-Lancet.

> "Plant-based foods tend to be good for both people and the planet

A pescatarian diet (all meat replaced by fish products), a vegetarian diet (no meat or fish products) and a vegan diet in particular (no meat, fish, poultry products or dairy) are even less environmentally demanding and would thus be preferred over the reference diet if ecological considerations are the key drivers.

Why livestock products are likely to remain

Some of the analysis highlighted above appears to suggest that a shift toward a vegan diet would be best from a health and environmental perspective. We see two reasons why a full shift towards a vegan diet is unlikely:

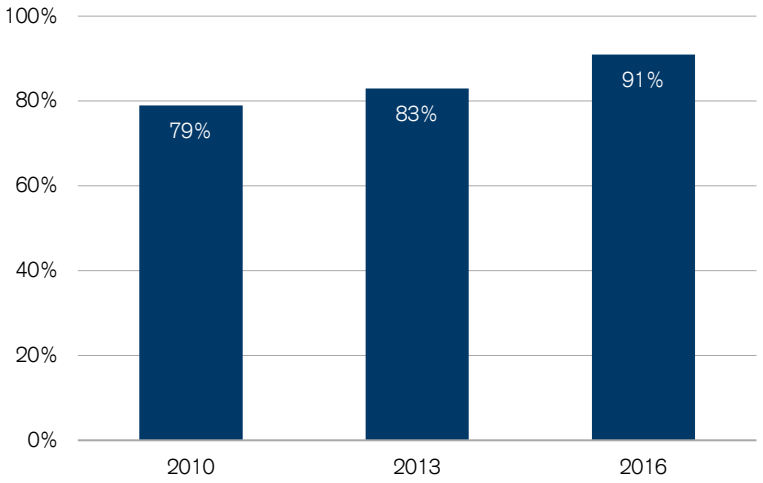
- First, practically speaking, we believe it is unlikely that consumers will make a full shift to a vegan diet due to the appeal of unhealthy

food (e.g. those products with a high fat or sugar content). In general, consumers simply "like" food that is processed, low in nutrition and/or unhealthy. In the United States, for example, the share of adults buying fast food for their children stood at 91% in 2016, a 15% increase from the 79% share recorded in 2010 (see **Figure 9**). Data on the consumption of processed food and drinks for various regions globally show that this share appears to be falling in developed countries (**Figure 10**). We would caution against reading too much into this development when taking a global view because the absolute level of processed food and drink consumption remains (too) high across developed countries in relation to healthy diets, and the consumption of processed food and drinks is rising strongly everywhere else in the world.

> "The most efficient land use requires animal-based protein to remain part of people's diets

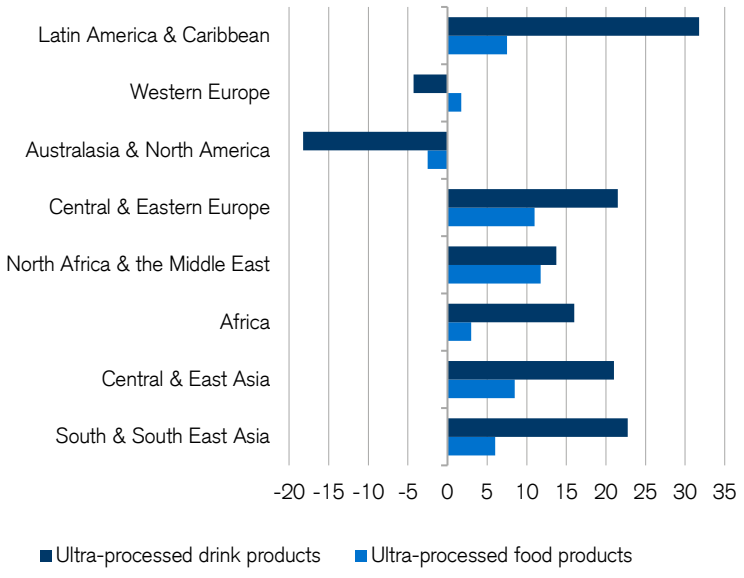
- Second, agriculture already occupies roughly 38% of the terrestrial surface of the earth and total land demand for agricultural use is set to increase substantially over the next few decades given the expected increase in global population. Most studies analyzing the impact of diet shifts tend to ignore (growing) competition for land among humans, animals and crop production. Analysis by van Kernebeek et al (2015, "Saving land to feed a growing population: consequences for consumption of crop and livestock products") shows that the most efficient land use requires animal-based protein to remain part of people's diets. Their analysis concluded that animal-protein intake would need to be around 12% of total dietary intake for smaller countries with populations of around 15 million. For larger countries, the share of animal-based food would need to be higher. One reason is that livestock uses agroindustrial by-products that cannot be consumed by humans (e.g. by-products from mills, factories, breweries, etc.), suggesting that these products need not be wasted if animal products continue to be part of our diet. Another reason is that a full shift to a plant-based diet would require more land than is available for crop production or require an increase in crop yields that may not be achievable.

Figure 9: Share of US adults buying fast food for their children



Source: Rudd Center for Food Policy and Obesity at Yale (2018)

Figure 10: Change in consumption of processed food and drinks between 2002 and 2016

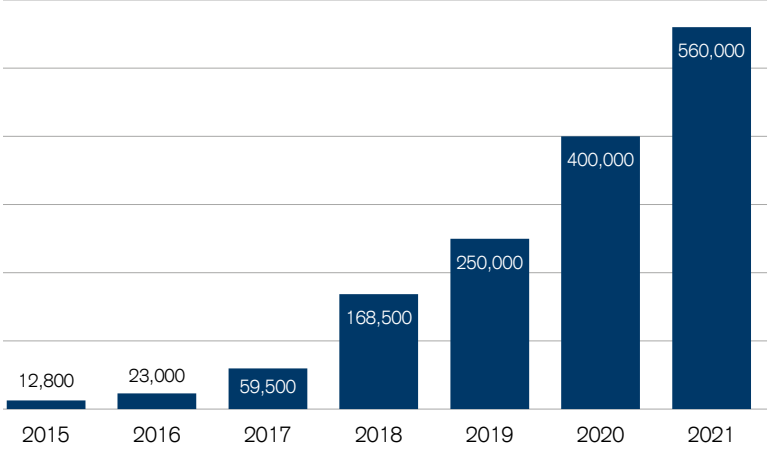


Source: Vandevijvere et al. (2019)

Processed food and health

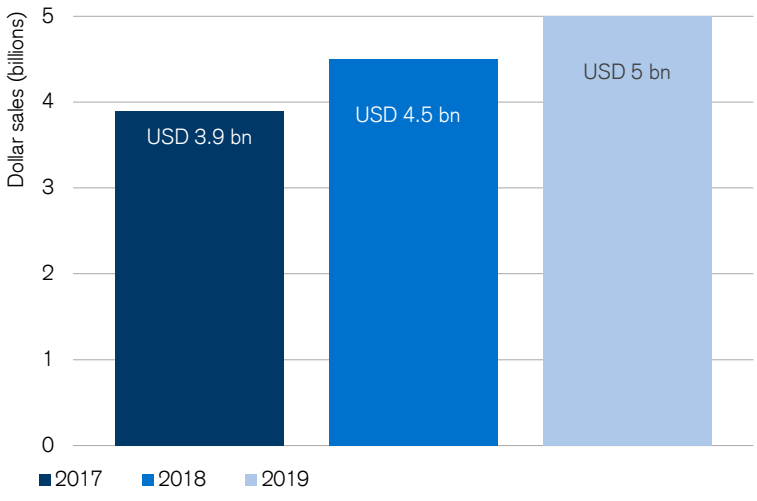
The topic of processed food is often hotly debated in relation to a healthy lifestyle given that it is generally thought to be inferior to unprocessed food. Whether this is the case, however depends very much on the definition of processed food. For example, the US Department of Agriculture defines a processed food as one that has undergone any change to its natural state. This includes washing, cleaning, cutting, freezing, packaging and also the inclusion of ingredients such as preservatives, flavors and nutrients. The Institute of Food Technologists adds additional processing activities to the USDA definition such as storing, filtering and fermenting. Based on these standards one could argue that virtually all food sold is "processed."

Figure 11: Veganuary popularity is rising rapidly
Number of people participating in the the Veganuary campaign



Source: The VeganSociety

Figure 12: Strong growth seen in plant based food products
Total US plant-based food market



Source: The Good Food Institute

Why processed food is not necessarily bad

From a nutritional point of view, we note that processed food is not necessarily unhealthy. First, certain nutrients like protein can be retained throughout the processing of food. Second, processing food companies can add back ingredients that are lost as a result of processing, e.g. vitamins and iron. Furthermore, we note that processing activities such as the freezing of fruit and vegetables does allow the retention of key ingredients such as Vitamin C. Another notable aspect in relation to processed food is that it can help preserve the lifespan of products. In addition, pasteurization, cooking or drying of food are activities that help inhibit the growth of, or destroy, harmful bacteria.

But not all processed food is good

Despite a number of positive features that processed food provides, we note that there are certainly a number of disadvantages too. Specifically, we refer here to ultra-processed foods that have a high ratio of calories to nutrients and include large amounts of saturated fat, sugar and sodium, all of which are associated with a poor quality diet and heightened risk of obesity, heart disease and high blood sugar.

Beyond the more immediate health implications from an excessively high intake of sugar, fat and salt, numerous studies have shown that ultra-processed food might cause people to eat more. For example, a recent study by Hall, Ayuketah et al. ("Ultra-processed diets cause excess calorie intake and weight gain," May 2019) investigated food consumption between two groups of men and women, one group eating unprocessed food and one eating a menu that was equal in terms of carbs, fats, protein, fiber, sodium and sugar, but that consisted of processed food. Subjects eating the processed menu ate around 500 kcal more each day than those that did not. It appears that processed foods influence the brain's system of identifying satiety, causing us to eat more than is needed (or desirable). Other studies have shown a positive correlation between the consumption of ultra-processed food and the risk of death (Rico-Campa et al., "Association between consumption of ultra-processed foods and all cause mortality," BMJ May 2019), while the WHO in 2015 categorized processed meat as cancer-causing for humans.

The bottom line is that not all processed food is bad. However, foods with high levels of sugar, salt, fat, sweeteners and ingredients that increase the palatability of food are associated with increased health risks, suggesting that their intake should be minimized. Examples are sugary drinks, cookies, chips and breakfast cereals.

The growing market for plant-based food

The need to change food consumption away from meat to plant-based diets and alternative food products has already provided relevant end-markets that have experienced substantial growth in the past few years. This is partly reflected in the rising popularity of veganism. Sign-ups for the Veganuary campaign, for example (where people eat vegan for the month of January), reached 560,000 people in 2021, up from 12,800 in 2015 (**Figure 11**). In the UK, the share of the population that is vegan increased four-fold between 2015 and 2019. Given the current state of food consumption, we believe that this growth is likely to continue and probably accelerate as the focus on a more sustainable food system intensifies further.

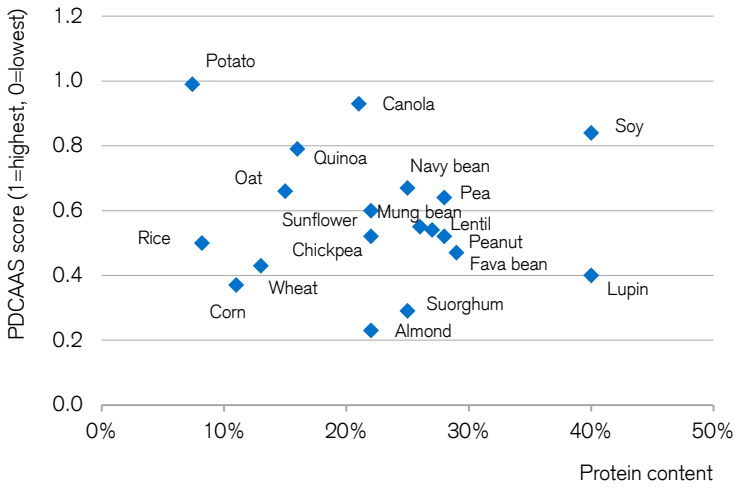
The ingredients of plant-based foods

Discussions about plant-based food mostly refer to food that is made using one of three alternative or non-meat protein products.

- **Plant-based meat**: The plant-based meat market is the best-known area of plant-based food, not least due to the recent success of companies such as Beyond Meat and Impossible Foods. The reason for supporting the growth of plant-based meat is that it uses 72%–99% less water and 47%–99% less land than traditional animal-based meat. In addition, water pollution is substantially lower, whereas GHG emissions are also between 30% and 90% lower. One other aspect worth highlighting is that plant-based meat does not require the use of antibiotics, which is very common with animal-based meat production. There is a range of plant-based proteins available for use in alternative food products. Those used most often are highlighted in **Figure 14**. The protein digestibility-corrected amino acid score (PDCAAC) was adopted by the FAO and WHO in 1993, and is often used to assess the quality of a protein. Plant-based proteins that score especially high in this regard include potato, canola and soy protein.
- **Cultivated meat**: Traditional animal-based meat production is very inefficient. For example, livestock provides just 18% of calories consumed by humans, but takes up close to 80% of global farmland. Cultivated meat, which is meat grown directly from cells, is a more recent phenomenon, but one that is far more effective. A recent study from CE Delft (the LCA of Cultivated Meat) shows the potential cultivated meat has in relation to climate change. The environmental impact in terms of emissions generated is substantially lower than for animal-based protein, whereby land use is also reduced considerably (**Figure 15**). Another aspect worth highlighting from this work is that the conversion factor (feed to meat) is also

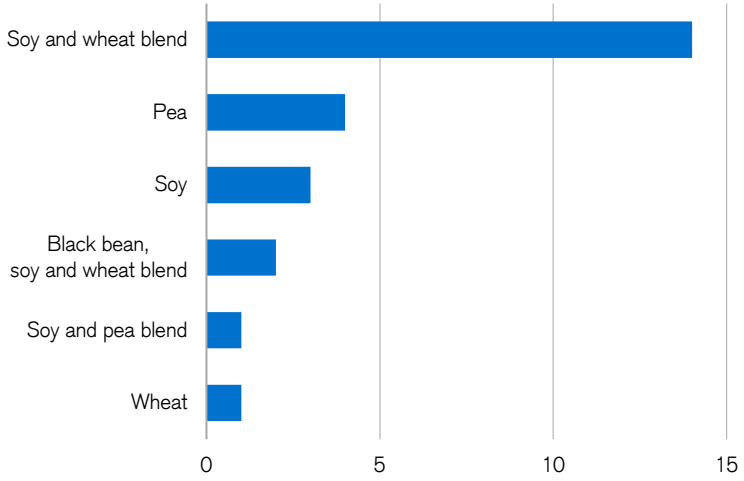
Figure 13: Plant protein – protein content versus PDCAAS score

A high score in both is a good start for plant-based products



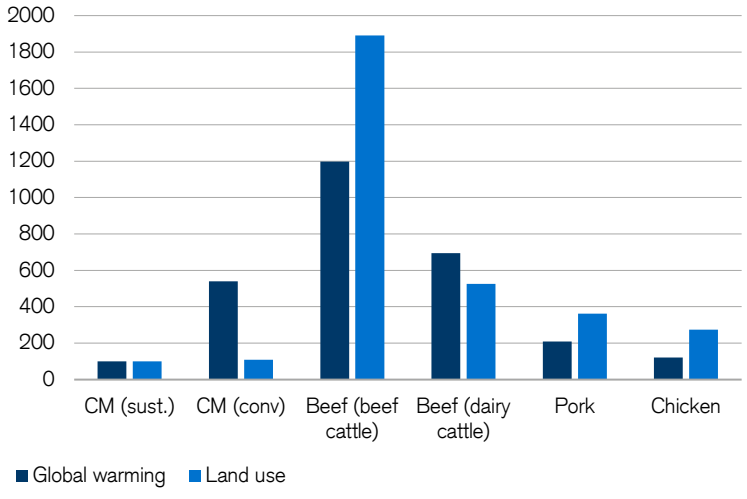
Source: The Good Food Institute, Credit Suisse Research

Figure 14: Plant protein bases of the top 25 plant-based meat products by dollar sales (2020)



Source: The Good Food Institute

Figure 15: Impact of animal-based protein products relative to cultivated meat when the latter is produced using renewable energy

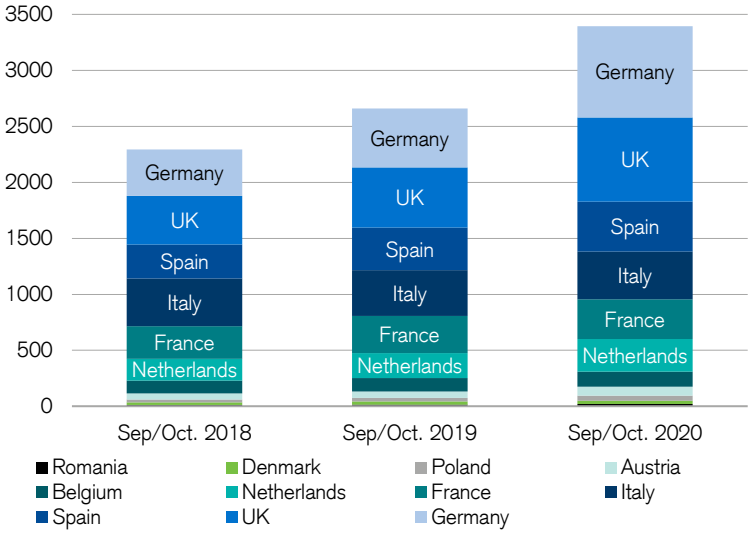


Source: CE Delft 2021, "LCA of cultivated meat" (LCA = life cycle assessment)

much better for cultivated meat. For example, cultivated meat has a feed conversion ratio (kg in per kg out) that is more than seven times higher than that of beef cattle and almost six times higher than that of pork.

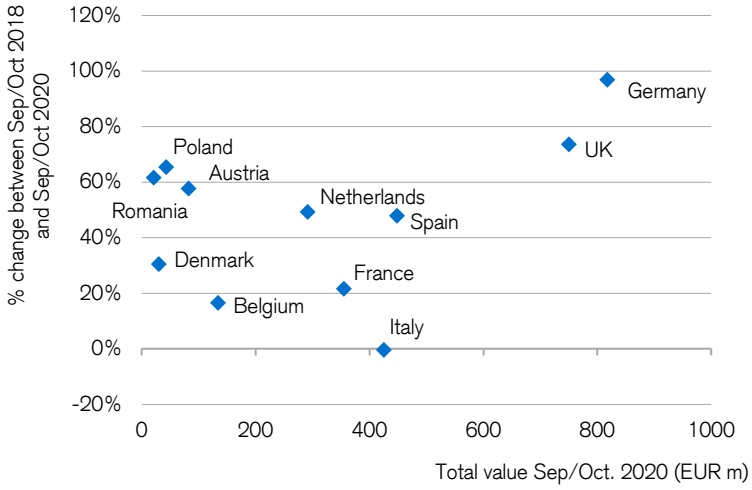
- **Fermentation**: Alternative proteins can also be produced through fermentation processes using microorganisms. Traditionally, fermentation has been used to make beer, wine and cheese, and the same process can be used to improve the flavor of plant ingredients. Biomass and precision fermentation are also used to make protein-rich foods. Biomass fermentation has the clear advantage of speed. The doubling time of the microorganisms used is hours compared to months or longer for animals.

Figure 16: Plant-based sales in 11 European countries (EUR m)



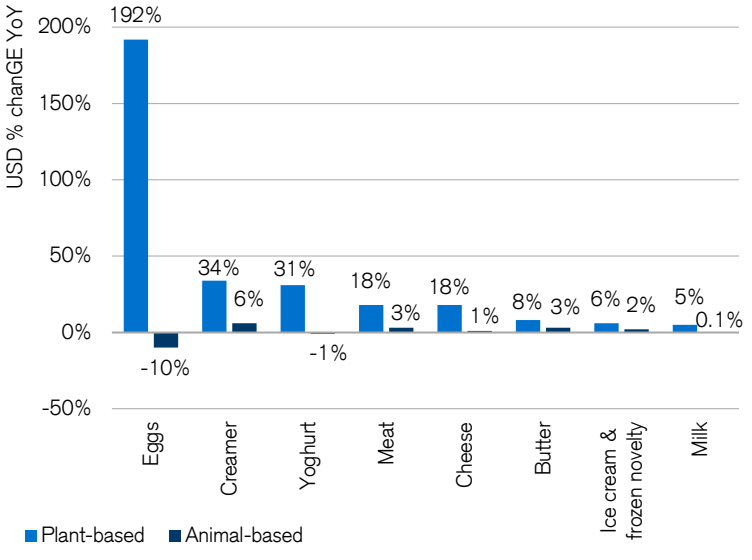
Source: Nielsen, Smart Protein Project

Figure 17: Plant-based food – growth rate versus market size



Source: Nielsen, Smart Protein Project

Figure 18: US sales growth (2019); animal vs. plant-based



Source: The Good Food Institute 2020

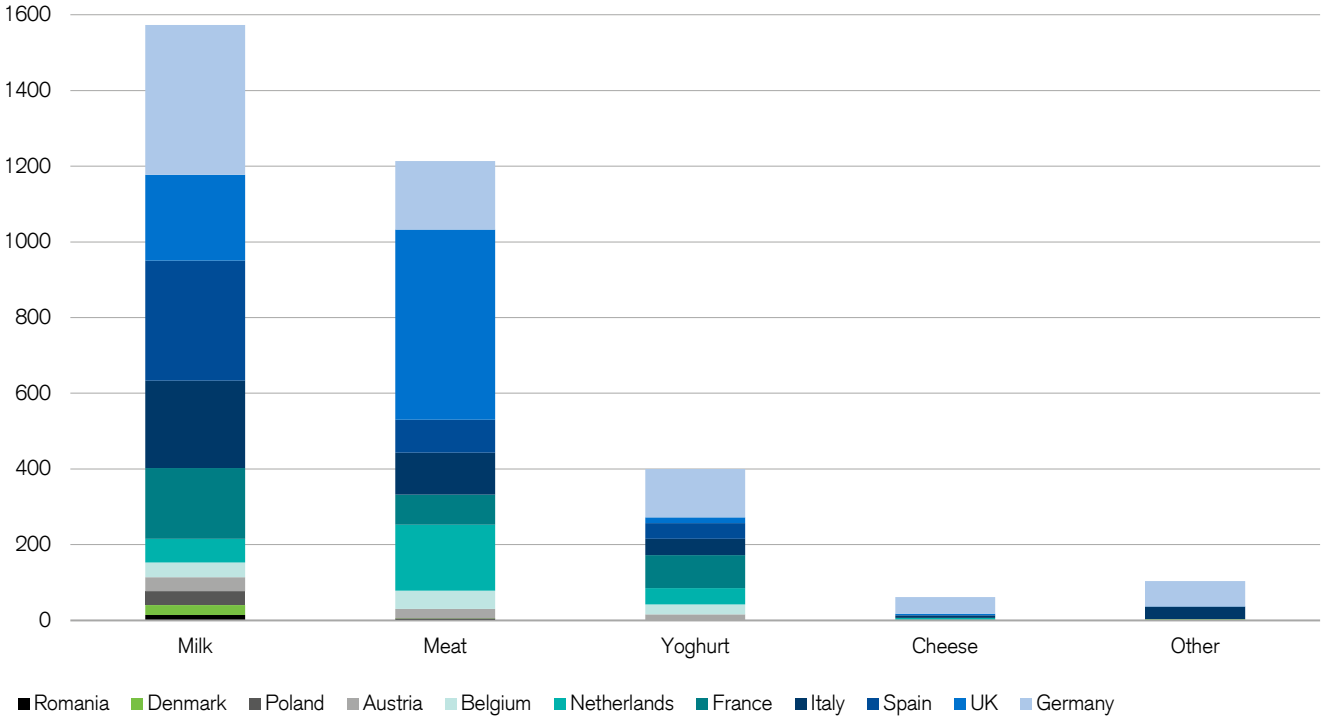
> “
>
> Plant-based products achieved stronger growth in all major categories in 2019 than their animal-based versions

Strong growth in plant-based food seen across the globe

In the United States, sales of plant-based food products increased by about 26% between 2017 and 2019 to an annualized USD 5 billion according to the Good Food Institute. In Europe, data from Nielsen suggest that the plant-based food market is accelerating faster. Growth across the region reached 49% between September/October 2018 and September/October 2020 (**Figure 16**). Interestingly, market data compiled by Nielsen for the Smart Protein Project suggest that the growth rates for most countries average around 50% or more, with Italy being the outlier (**Figure 17**).

When reviewing US growth rates by product, we find that plant-based products achieved stronger growth in all major categories in 2019 than their animal-based versions (**Figure 18**). Looking at the data for the European market, we find that

Figure 19: Total plant-based product sales by product and country (EUR m, 2020)



Source: Nielsen, Smart Protein Project, Credit Suisse Research

plant-based milk products account for 47% of the total market, with plant-based meat accounting for an additional 36% (**Figure 19**). Plant-based yoghurt, cheese and other products such as plant-based ice cream make up the balance. Despite the high growth rates for sales of plant-based products, we note that they have yet to go mainstream.

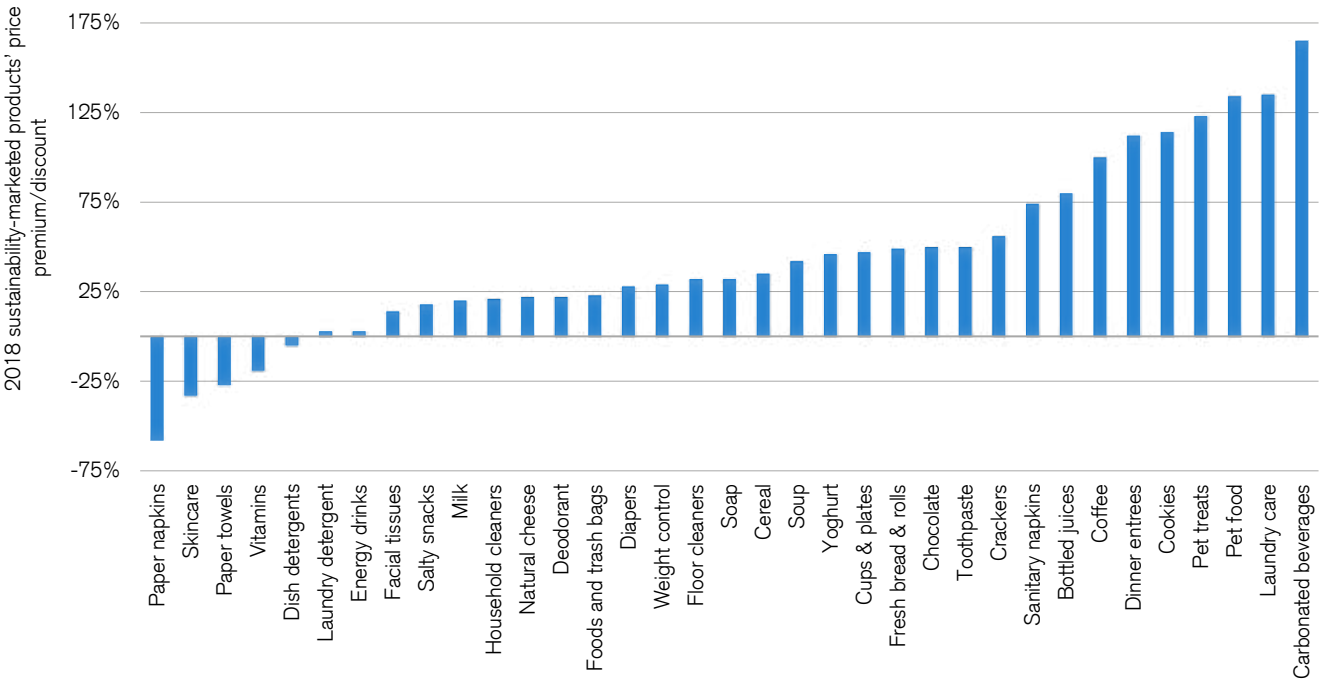
> “
> It will take some time before plant-based food becomes a standard staple product

Work by the NYU Stern Center for Sustainable Business on the profiles of sustainability-focused buyers suggests that they are mostly younger, better educated and above-average earners. Survey results from the International Food Information Council provide similar readings. They found that, in January this year, 32% of consumers with an income of more than USD 80,000 per year had tried plant-based meat alternatives compared to 25% of consumers with an income of less than USD 40,000. For college versus non-college graduates, similar shares were seen at 32% and 22%, respectively. This clearly suggests that it will take some time before plant-based food becomes a staple product for the average consumer.

One of the reasons why sustainable foods tend to be consumed more by higher earners is that most sustainable food products are currently sold at significant premiums to their non-sustainable alternatives. We are not convinced that these premiums will remain in the long run if sustainable food becomes the norm, but for now they are likely to limit the ability of sustainable food to penetrate other consumer segments.

The market for alternative meat reflects the price-premium observations of sustainable products more broadly. Work from FAIRR in 2020 suggests that all but one of their reviewed plant-based burgers were more expensive than a traditional US beef patty. At the same time, however, these plant-based burgers score on average better than beef alternatives in terms of calories, cholesterol and saturated fat. While the need for protein is typically seen as a reason to eat meat, FAIRR’s analysis suggests that this argument does not hold as most plant-based burgers have a protein content that is not too dissimilar to that of a meat burger.

Figure 20: Most sustainable products are sold at a premium



Source: NYU Stern CSB Sustainable Market Share Index 2020

Table 4: Comparison between plant-based and meat burgers

Plant-based burger	Calories (per 100 g)	Cholesterol (per 100 g)	Saturated fat (per 100 g)	Sodium (per 100 g)	Sugar (per 100 g)	Protein (per 100 g)	Price per packet (30 June 2020)	Price per patty
Sweet Earth Sensational Burger	230	0 mg	6 g	354 mg	<1 g	23 g	USD 5.99 (2 patties)	USD 2.99
Impossible Burger	212	0 mg	7 g	327 mg	<1 g	17 g	USD 6.99 (2 patties)	USD 3.50
Beyond Burger	230	0 mg	4 g	310 mg	0 g	18 g	USD 7.35 (2 patties)	USD 3.67
Simple Truth Emerge Plant Based Patties	204	0 mg	8 g	345 mg	0 g	18 g	USD 4.49 (2 patties)	USD 2.24
BOCA All American Veggie Burger	155	7 mg	1 g	648 mg	<1 g	18 g	USD 3.79 (4 patties)	USD 0.95
Gardein Ultimate Plant Based Burger	212	0 mg	14 g	398 mg	<1 g	17 g	USD 4.49 (2 patties)	USD 2.24
Plant Pioneers Smoky 'Jack' Quarter Pounder	141	Not reported	2 g	461 mg	1.9 g	6.2 g	USD 3.07 (2 patties)	USD 1.53
Naked Glory Legendary Quarter Pounder	186	Not reported	3.5 g	490 mg	0.73 g	15 g	USD 3.37 (2 patties)	USD 1.68
Average US beef patty	295	84 mg	9 g	230 mg	0 g	23 g	USD 2.99 (2 patties)	USD 1.49

Source: FAIRR: "Appetite for Disruption, a second serving"

Company feature: Solar Foods

Air-based protein production using fermentation

Solar Foods is a Finnish company founded in 2017 by Pasi Vainikka and Juha-Pekka Pitkanen as a spinoff from the VTT Technical Research Centre of Finland and Lappeenranta University of Technology. The company is exposed to alternative protein production through the use of fermentation technologies.

Solar Foods has developed a production process that produces a natural protein called Solein, which is meant to be the first product on the market made without the use of agriculture or fossil fuels. To produce Solein, Solar Foods uses renewable energy, wind and solar, and carbon capture technologies. Hence, as a protein source, Solein's emission intensity is just 1% of that of traditional meat protein and even 80% lower than that of plant-based protein products such as soy or peas.

Solar Foods puts microorganisms (microbes) in a liquid in a fermentation tank. The liquid is supplied with growth drivers consisting of hydrogen, oxygen and carbon dioxide. To make the protein, the company adds nitrogen and various nutrients including potassium, calcium and phosphorus. As the liquid grows thicker, some of it is removed and dried. The resulting product is Solein, which has a macronutrient composition that is very similar to that of dried soy or algae. Importantly, Solein contains all nine so-called essential amino acids that the human body cannot produce and instead must be part the food consumed to provide the necessary proteins.

Solein is neutral in taste and can be used in a wide range of food products. For example, it can be used as a protein ingredient in existing foods such as bread, pasta and plant-based dairy. Second, Solein can be used as a protein ingredient in alternative meat and dairy products. Third, the amino acid platform of Solein can be used by companies engaged in cell-based meat production.

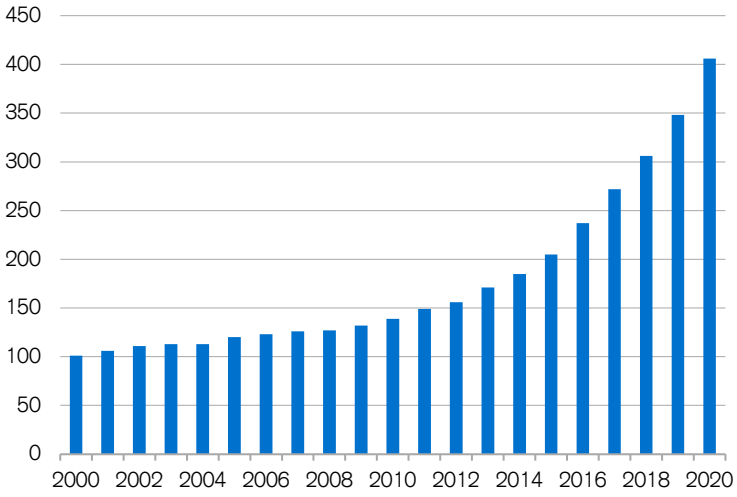
> "Solein contains all nine so-called essential amino acids that the human body cannot produce

Solar Foods' CEO Vainikka told us that regulatory approval is obviously needed for his company to sell its Solein product commercially. While he does not expect this process to be difficult, he did note that the speed of approval is likely to be higher in Asia than in the EU where approval has to be reached between 27 countries.

The company also highlighted that at present its product is not competitive as production costs would have to continue declining for Solein to act as a substitute for soy or pea-based products. Its recent funding round provides the platform for constructing its so-called "demo" production capacity of 100 tons per year. The company believes this launch should be in 2022. A full-scale factory would provide up to 100 times the annual production capacity, which would allow Solein to become cost-competitive with other protein products, excluding soy. Solar Foods plans to have a full-scale factory up and running by 2025 and believes its products can be cost-competitive with soy by 2030. This assumes the installation of more factories, which might require further funding. Uncertainty over the outlook is thus high as Solar Foods is at an early stage of development.

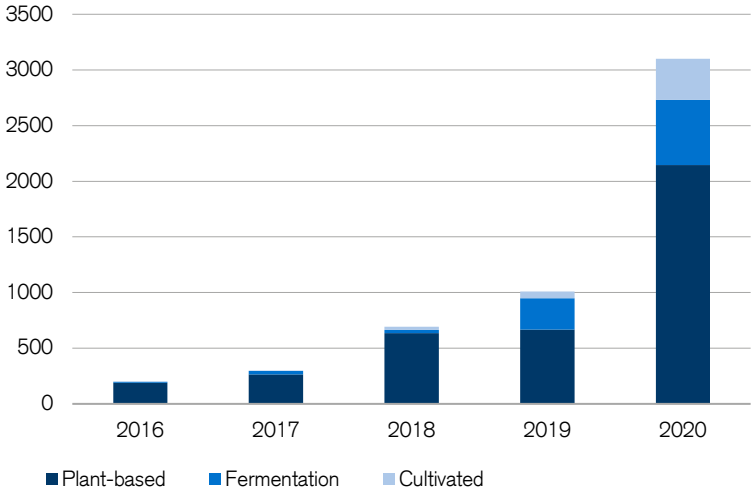
Photo: Solar Foods

Figure 21: Number of alternative protein companies by year



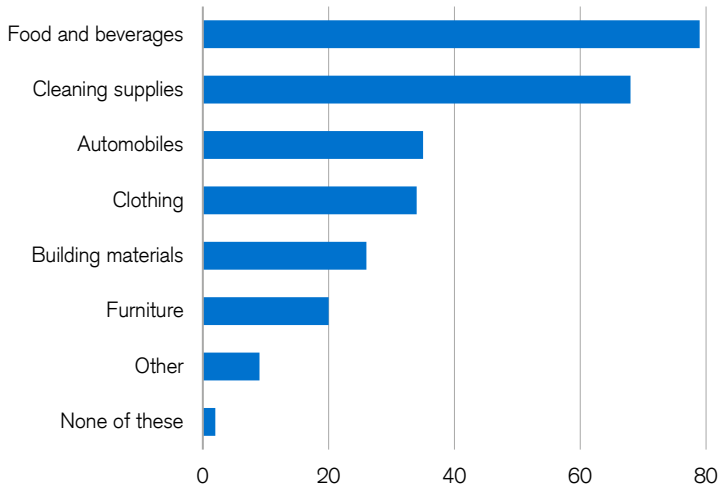
Source: The Good Food Institute, Credit Suisse Research

Figure 22: Annual investment in alternative meat companies (USD m)



Source: The Good Food Institute, Credit Suisse Research

Figure 23: In which areas of your life do you seek out environmentally friendly products?



Source: Food Insight, Survey on Climate change and food consumption (2020)

The growth outlook for healthy food looks promising

We believe that the long-term growth outlook for alternative foods looks strong for the following reasons:

- First, we note that consumers appear to be more focused on buying healthier, sustainable food. For example, survey data from Food Insight show that environmental considerations matter more for consumers in relation to food and beverage products than any other product (**Figure 23**).
- Second, there is a large and growing number of companies active in developing alternative meat or protein solutions. Currently, well over 600 companies globally are highlighted by the Good Food Institute as involved in developing alternative protein sources (**Figure 21**). We have included a subset of these companies in Appendix 2. The majority of these companies are working on plant-based meat solutions and, while they tend to be located in Europe and North America, we note that over 20% are based across Asia, Latin America, Africa and the Middle East. We also note that the number of new companies involved in developing alternative food products appears to have begun accelerating recently, probably made possible by a growing interest from investors. Data from the Good Food Institute suggest that more than USD 3 billion was invested in alternative meat start-ups last year, or around three times the investment rate seen in 2019 (**Figure 22**).
- Third, the cost premium of plant-based products is also coming down. For example, most of the key plant-based meat producers have been able to introduce price cuts in the past year or two, and we expect this development to continue as volumes increase and economies of scale become more meaningful. This view is also shared by market participants. In June 2020, the CEO of Beyond Meat reiterated the company's prediction that it will be able to underprice animal protein with some of its products within the next three years.
- Fourth, we note that consumer awareness of alternative protein sources is already relatively high (**Figure 26**). A survey by the International Food Information Council published in January 2021 showed that over 80% of consumers surveyed had heard of plant-based meat alternatives.

Existing food companies are playing a key role in developing the theme

Data on the around 670 companies involved in developing plant-based solutions show that most of them are early-stage developers or companies where alternative meat or plant-based solutions are the primary focus. Some

investors might wonder whether this puts the large, traditional, packaged food companies at a disadvantage. Some even wonder whether the large traditional food companies might be facing similar challenges in the future to those currently faced by oil and gas or tobacco companies, as both of these industries are also grappling with a structural shift from unsustainable toward sustainable products and services.

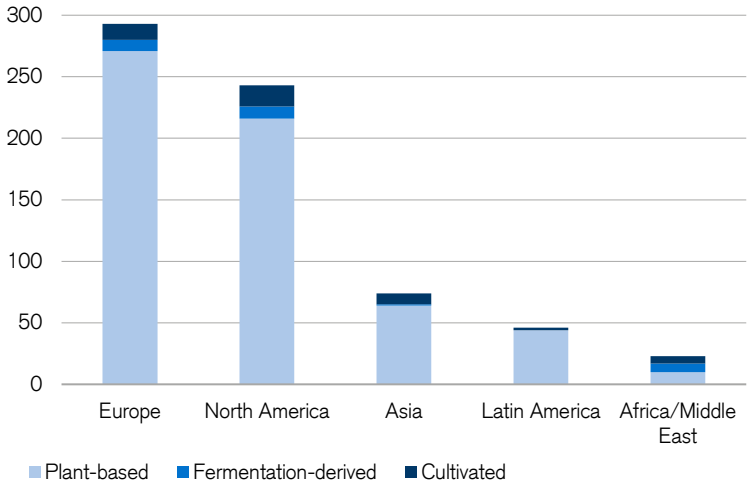
As part of the fast-moving consumer goods industry, the large packaged food companies are well aware of the need to respond to changing consumer perceptions and attitudes in order to survive and prosper. The fact that so many of the largest packaged food brands are over 50 years old (with some like Campbell's, Knorr and Cadbury over 100 years old) is testimony to their ability to adapt. At the same time, the large packaged food companies have also been able to remain relevant by constantly evolving their product and brand portfolios, both organically and through mergers and acquisitions. By way of example, we note that most food companies have added plant-based products and brands to their portfolios in the past five years (**Figure 25**).

> "The packaged food industry will need to be part of the solution for achieving greater sustainability

Most large packaged food companies enjoy relatively high returns from providing highly standardized products with a long shelf life that offer economies of scale. Low unit costs allow the industry a sufficient gross margin to invest in brands and still offer consumers attractively priced food. Indeed, the origins of the packaged food industry lie in the industrial revolution of the 19th century when rapid urbanization put an end to self-sufficiency and food preservation technologies were capable of being mechanized.

In some respects, sustainable food is the antithesis of this dynamic. For example, a jar of Nescafe soluble coffee, despite being cheaper (on a per cup basis), is much more profitable for Nestle than a bag of coffee beans carefully sourced from a specific grower. It boils down to consumer choice and the willingness to pay more for sustainable food. Unless society wants to return to purchasing more basic, local and seasonal foods, the packaged food industry will need to be part of the solution for achieving greater sustainability, not part of the problem.

Figure 24: Companies involved in developing alternative meat solutions



Source: The Good Food Institute, Credit Suisse Research

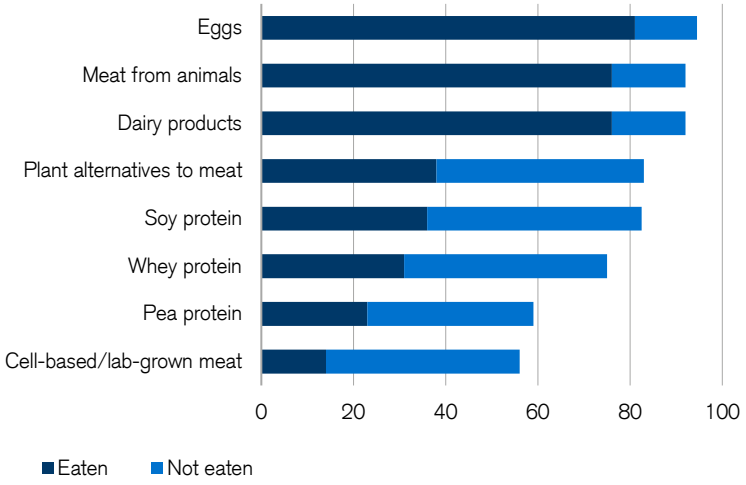
Figure 25: Revenue exposure to plant-based and healthy food by key food companies

Source: Company data, Credit Suisse estimates

The sheer scale and portfolio breadth of the large packaged food companies (and their understandable reluctance to pivot away from their cash cows) make it impossible for them to grow sales much faster than the overall food market (low-mid-single digits). In contrast, small start-up companies that see opportunities in the sustainable food segment may enjoy a period of impressive growth.

At the same time, few of these small food companies (where success rests almost solely on being early to spot a nascent trend) can progress to the next level. They often end up being acquired by larger packaged food companies (where the ability to scale up their revenue base can justify the economics of buying rather than building). One example of this would be Blue Buffalo, a company founded in 2002 that offered natural or organic pet food and was bought by General Mills in 2018 for an enterprise value of USD 8 billion. Moreover, unless these small companies can erect barriers to entry, they are quickly joined by other players that ultimately drive down their returns. In our view, the large packaged food companies with portfolios that have a low incumbency risk and that demonstrate the agility and ability to leverage their scale to improve sustainability that are key to driving the global food system more in that direction.

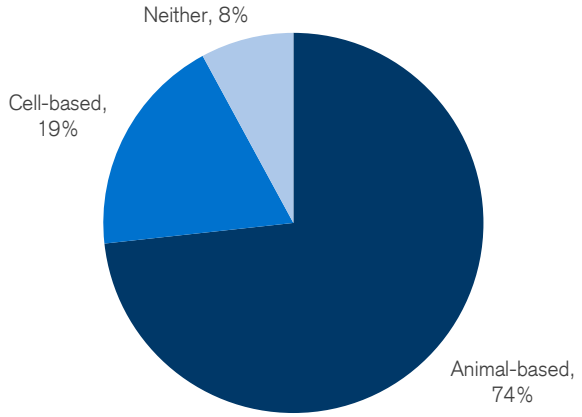
Figure 26: % of consumers that had heard of the following protein products and eaten it or not (January 2021)



Source: International Food Information Council, Credit Suisse Research

> “Consumer acceptance of certain alternative or plant-based foods is still in the development phase

Figure 27: “If you had the choice between an animal-based or a cell-based protein product which would you chose”



Source: International Food Information Council

The need for the larger food companies to be involved also relates to the fact that consumer acceptance of certain alternative or plant-based foods is still in the development phase. For example, survey data from the International Food Information Council indicate that consumers, especially those with lower incomes, are very familiar with traditional animal-based protein such as eggs and meat, but far less with some of the more recent developments such as cell-based, pea, soy or wheat-based products. Furthermore, their research also suggests that, when confronted with the choice of animal protein or a cell-based meat option, nearly three out of four consumers would opt for the former even if both products taste and cost the same (**Figure 27**).

The market for plant-based meat and milk could reach USD 143 billion by 2030 and USD 1.4 trillion by 2050

The size of the current global plant-based food market is approximately USD 14 billion in terms of sales, with around USD 5 billion generated in the United States, around USD 4 billion generated in Europe and the remainder in Asia. The majority of this consists of alternative dairy products.

To assess the potential market for alternative meat and dairy products, we have used the estimates for global meat and dairy production from our conversion scenario in the chapter on the environmental impact of food.

We overlaid these estimates of total market size with assumptions about the market share that alternative meat and dairy could achieve in the longer term. Given that alternative meat, in particular, remains more expensive and has yet to receive regulatory approval for general sales, we assume that market share growth rates will increase only slowly during the next five years, but then start to accelerate.

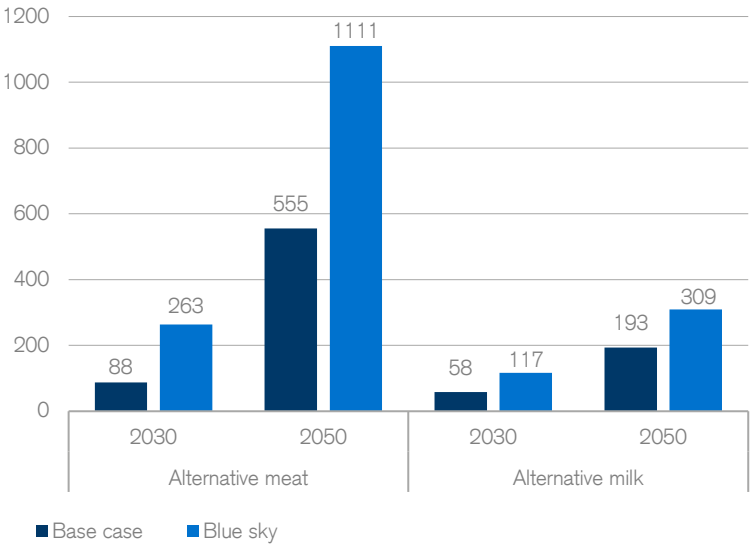
For our long-term market share estimates, we take a number of aspects into consideration. First, we note that alternative-dairy in the United States has a market share of approximately 14% and see no reason to believe that a market share for alternative meat would be lower than this. In addition, we note that surveys frequently suggest that consumers have a strong awareness of the environmental footprint of food and that they want to make a change. In our view, this suggests that, in the medium to long term, the potential market for alternative meat and dairy is likely to be substantially larger than 14%.

Market share assumptions

For the alternative milk market, we expect that, in the base case, its share will increase from around 6% last year to 20% by 2030 and 50% by 2050. In a blue sky scenario, we believe that as much as 80% of the total milk market could consist of alternative milk by 2050. A high share is not unlikely when we realize that diets associated with a sustainable world call for a decline in milk consumption in order to meet longer-term climate change and health targets (see **Figure 28**). Consumers could opt instead to switch more toward plant-based milk as this would help achieve these objectives too.

For the alternative meat market, we have less aggressive assumptions given that surveys show a greater degree of resistance toward alternative meat than is the case for plant-based milk. Our base case assumption has the share

Figure 28: Potential size of alternative meat and milk market globally (USD bn)



Source: International Food Information Council, Credit Suisse Research

of the alternative meat market reaching just 5% by 2030, before increasing to 25% by 2050. Our blue sky scenario assumes that 50% of the meat market globally will be driven by alternative products.

Based on these assumptions and by keeping prices constant, we believe that, in the base case, the alternative meat market could represent annual sales of around USD 88 billion by 2030, whereas alternative dairy sales could reach in the area of USD 58 billion. In our blue sky scenario, we would expect combined sales for alternative meat and milk to reach around USD 380 billion by 2030 and USD 1.4 trillion by 2050.

Against the backdrop of our overall market growth estimates, we have reviewed the actions taken by key food producers globally and their current exposure to plant-based products as well as their commitments and achievements toward a number of sustainability indicators more broadly.

European companies

Of the publicly listed food companies in Europe, the most exposed to plant-based foods is Danone (around 9% of group sales). Approximately 75% of sales are plant-based liquid milk alternatives (under the Silk and Alpro brands) and yogurt (under the Silk, Alpro, So Delicious, Light & Fit and Activia brands). In the United States, plant-based milk alternatives already have around 35% household penetration; in Europe, the penetration is significantly lower. The remaining 25% of Danone's plant-based

Company feature: Meatable

Lab-grown, cultivated, meat

Meatable is a Dutch food start-up company that was founded in 2018 and has raised over USD 60 million in funding to date from investors including DSM. The company produces lab-grown, cultivated, meat, which eliminates the need to slaughter animals and strongly reduces land and water requirements as well as greenhouse gas emissions.

Demand for alternative meat products is set to grow exponentially according to Meatable's CEO and co-founder Krijn de Nood. The company appears well positioned for this growth given its patented opti-ox™ technology. The company isolates stem-cells from a living cow or pig and cultivates these cells in an animal-like environment into muscle or fat cells. The texture of the lab-grown meat is the same as that of regular beef. The production process replicates the natural process of fat and muscle growth. However, and importantly, when fully developed, the process to produce meat is likely to take only weeks whereas growing a live animal takes years. The company's aim is to be able to start selling ground meat first and, depending on regulatory approval, expects to be able to do this as of 2025.

While the need to receive regulatory approval to sell cell-based or cultivated meat is often seen as a headwind by some, the company does not agree that this is the case. Singapore recently approved the sale of the first alternative meat product (Eat Just's chicken nuggets) as it aims to become less reliant on meat imports. Meatable expects other areas such as the Middle East and Hong Kong to follow Singapore's example. The EU is currently seen as the most burdensome for Meatable from a regulation perspective; however, the region's focus on addressing climate change, biodiversity and food loss and waste suggest that it is likely to engage more in new technologies such as cultivated meat in the future.

> "More than 130 billion pounds of traditional meat is consumed globally each year

In addition to addressing the growing need to provide food in an environmentally friendly manner, Meatable's process also targets the issue of animal welfare. The company's production process allows for the production of meat without having to kill a single animal. Furthermore, their products also mean an end to the use of antibiotics for livestock farming, with additional health benefits for consumers.

Meatable's view on its growth potential is optimistic. The company sees the meat market as one of the single largest undisrupted global markets today with an annual turnover over more than USD 1 trillion. More than 130 billion pounds of traditional meat is consumed globally each year, a figure that the company believes is set to increase by 2% per annum until 2050. Moreover, Meatable refers to work from Kearney, a global management consulting firm, estimating that 35% of all meat consumption in 2040 will be cultured.

We agree with Meatable's CEO that the growth outlook for alternative meat looks promising. At the same time, we note that capturing this growth will require the company to meet two challenges. First, consumer appetite for cultivated meat remains low and needs to improve. Second, we expect the market for meat alternatives to become more crowded as traditional meat producing companies are also developing alternative food products.

sales are in the more nascent categories of plant-based coffee creamers (including in a ready-to-drink (RTD) coffee product), plant-based ice cream and plant-based high protein performance nutrition products (under the Vega brand). Plant-based animal milk alternatives offer both a health benefit (lower saturated fats than animal milk) and an environmental benefit (less water usage and lower CO2 emissions). Danone is the leader in plant-based milk alternative beverages and yogurts in North America and Western Europe, although in the United States, it has been losing share in the beverages segment because it is underweight in the fast-growing oat-based segment. The category growth rate has accelerated post-COVID, partly due to a sharpened awareness of health and partly a shift from out-of-home (OOH) consumption of coffee, etc., in our view.

US companies

Aside from Beyond Meat, which is a pure play plant-based meat company, we highlight that, of the publicly listed food companies in North America, the most exposed to plant-based foods are B&G, Conagra and Nomad. B&G and Conagra's exposure to plant-based products includes sizeable businesses in the frozen-vegetable area. In addition, B&G has become the leader in plant-based carbohydrate substitutes, while the acquisition of Farmwise should help propel exposure to a wider range of vegetable-based food alternatives (e.g. "Veggie Fries"). Conagra has a plant-based meat substitute business through Gardein, with annual sales of around USD 170 million, and 39% of that from chicken alternatives. In 2019, Conagra announced that it would expand the Gardein Brand more aggressively in response to the strong growth achieved by Beyond Meat and Impossible Foods. One of the results was the introduction of the "Ultimate Plant-Based Burger." Nomad also has a large frozen-vegetable business, but the company has more recently expanded into plant-based meat products too. Within 12 months of launching its plant-based burger product, Nomad is now the third-largest meat-free frozen brand in the United Kingdom. The company has reiterated its strong optimistic view on the future growth outlook for its plant-based products.

Emerging market-related observations

India: The packaged foods market is still at a very early stage in India. Since it is a low-income emerging market (per capita income of ~USD 2,000), packaged foods are a sunrise sector in India, and one of the fastest-growing fast-moving consumer goods (FMCG) segments. Overall, less than 10% of food consumption in India is in packaged form, and household penetration levels of many basic packaged food categories like chocolates, sauces, spreads and coffee are below 50%. Many categories have a large proportion of loose product sales or unorganized sector presence. For example, around 99% of consumption in pulses, around 80% in spices, over 70% in milk and around 35% in biscuits is in loose form.

> "Packaged foods are a sunrise sector in India

The first structural move in Indian consumer preference will be to move from loose/unbranded to trusted brands where the need for basic hygiene, safety and quality of food is a key driver. This means safety from contamination and protection from damages. The health need at India's level of per capita income is thus very basic at this stage. Consumers are moving from loose spices, milk, flour or pulses that could have a high pesticide content or contamination to trusted national brands that should be safer for consumption. Companies like Tata Consumer (packaged tea, packaged salt, packaged pulses), HUL (packaged tea), Nestle (packaged milk) and ITC (packaged flour) are the key players in this development.

Consumers also tend to prefer healthier brands that are not fried and have lower sugar content. However, given the low-income levels, many consumers are unwilling to pay a premium or compromise on taste, thus making health brands a niche at this stage, although they are growing strongly. For example, Marico's Saffola brand of healthy edible oils and oats generates about 20% of the company's revenue) and Hindustan Unilever generates about 12% of its revenue from health food drinks. Other companies have healthy variants, e.g. Britannia's low-sugar biscuits and Nestle's low-fat milk, but these are niche segments and do not make a large contribution to revenues. Moving from meat to plant-based protein is not a mainstream trend in India and has yet to commence even as a niche trend at this stage. With rising income,

protein consumption will continue to increase through higher meat and dairy consumption. Over 95% of poultry consumption (the main form of meat in India) is in the form of live birds, and there is a trend for consumers to move to packaged meat, driven by a rising awareness of hygiene.

China: Most food companies in China have minimal exposure to alternative or plant-based food. Our consumer surveys in China suggest that consumer appetite for alternative meat remains low, which is partly related to cost, but also due to the perception of Chinese consumers that alternative meat is processed food and deemed to be unhealthy.

> “
> Our consumer surveys in China suggest that consumer appetite for alternative meat remains low

Food companies that have ventured into alternative or plant-based food include Mengniu, the second-largest dairy company in China, which introduced a soymilk-based brand called “Silk” in 2017, with products made from freshly ground soybeans. Dali Foods, a leading food and beverages company in China, also began producing packaged soymilk in 2016 and has subsequently launched numerous product variants under the brand “Doubendou,” including an organic line, a breakfast line, etc. Doubendou represents about 10% of Dali Foods’ total revenue. WH Group, the largest pork processor in the world, launched a plant-based protein portfolio under the “Pure Farmland” brand in 2019 in its US division Smithfield, with the portfolio consisting of breakfast patties, meatballs, burger patties, pre-seasoned protein starters, etc. At present, however, Pure Farmland represents less than 1% of WH Group’s revenues.

Thailand: While plant-based solutions are at a very early stage of development in Thailand, one of the listed companies, Thai Union, has been particularly active in the food-tech segment via its own venture capital fund, which focuses on alternative protein, functional nutrition and value chain technology start-ups. The company is investing in Alchemy Foodtech Pty. Ltd., a Singapore-based diabetes food-tech innovation company. Other companies include Manna Foods Co, an insect tech and e-commerce company in the USA, and HydroNeo GmbH, an aquaculture technology company based in Germany and Thailand. All three companies were part of the first cohort of SPACE-F, the first food-tech incubator and accelerator program in Thailand, of which Thai Union is a founding partner, alongside Mahidol University and Thailand’s National Innovation Agency (NIA). In addition, Thai Union is investing in VisVires New Protein, a Singapore-based food-tech investment fund, to deepen its network of co-investments and collaborative opportunities in the global agrifood-tech ecosystem.

> “
> Plant-based solutions are at a very early stage of development in Thailand

Latin America

Brazil: Plant-based protein is still a niche market in Brazil, although the food industry agrees that it is a potentially attractive growth market. According to the Brazilian Vegetarian Society (SVB), around 14% of Brazil’s population (or roughly 30 million people) said they were vegetarian in 2018, which was a 75% increase from 8% in the previous survey conducted by the Brazilian Statistics Bureau (IBGE) in 2012. The key meat-based companies in Brazil have all stated their intentions to diversify toward plant-based protein, indicating a possible change in consumer behavior. Multinational company JBS currently has a 60% share of the Brazilian market for plant-based foods and has also

recently entered the US plant-based market. Food company BRF has identified the plant-based segment as one of five main goals for substantially increasing its net revenues over the next ten years. Marfrig, the largest hamburger producer in the world, operates mostly as a food supplier to other companies. The company provides plant-based proteins to Outback and Burger King in Brazil, and exports alternative proteins to China. Last year, the company started the PlantPlus joint venture with ADM (70% owned by Marfrig), which received antitrust approval in October 2020. Minerva Foods has entered the alternative protein market mainly through exposure to companies involved in fermentation-based alternative protein production techniques.

> “
> The key meat-based companies in Brazil have all stated their intentions to diversify toward plant-based protein

Ingredient companies play a key role in developing alternative food products

Ingredients play a vital role in the food and beverage value chain – manufacturers depend on the suppliers for quality, taste, appearance, and functionality – despite forming only a small part of the final product value. This ranges from single ingredients accounting for about 1% of the cost of final products and solution providers accounting for 5%–10%. The USD 75 billion fragmented specialty ingredients market supplies a USD 5 trillion food and beverage industry that is currently growing at 1%–3%.

Over the past few years, consumers' increasing demand for healthier alternatives, clean labeling and personalization, as well as different point of sale/distribution models (e.g. e-commerce and out-of-home sales) has driven an unprecedented fragmentation that has caught the larger companies' mass-market models by surprise. The result is that smaller local players are gaining a greater proportion of the growth in the food and beverage category. Ingredients companies are also supplying and partnering with local/regional manufacturers that have been better able to adapt to consumer trends, e.g. Halo Top's high-protein ice cream, Chobani's Greek yoghurt, and RxBar's natural snacks.

To combat this, after a few years of cost savings, a number of food and beverage manufacturers have entered a period of reinvestment in innovation and marketing to reinvigorate top-line growth. In addition, a number of large food and beverage manufacturers are looking to improve partnerships with their suppliers, which is likely to increase their value share of the final product. According to Nestlé, for example, suppliers are an integral part of the value chain, and strong relationships and leveraging their expertise are critical to business success.

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> Smaller local players are gaining a greater proportion of the growth in the food and beverage category

Consequently, we believe ingredient companies are better positioned in the current environment of greater social and environmental awareness from consumers. One of the key issues faced by manufacturers is balancing taste and quality with nutritional integration, which is where ingredient providers have expertise, development capabilities and R&D know-how, e.g. balancing the flavor and seasonings in a plant-based burger with the right texturants, protein and appearance. We anticipate that ingredient companies will gain a greater share of the value chain as they aid manufacturers in improving innovation/speed to market.

Photo: Credit Suisse

Solutions: Smart agriculture

The combination of continued population growth, rising spending power and declining arable land per capita suggests that a shift in diet alone may not be enough to make the food system more sustainable. Further productivity improvements across the food supply chain and in both developed and emerging economies can be achieved by large-scale adoption of new technologies. For example, vertical farming could provide 80% of food demand in urban areas. Precision farming through the use of artificial intelligence, drones, autonomous machinery and smart irrigation systems could yield productivity increases of 70% by 2050. All in all, the market for connected agricultural products and services could add USD 500 billion to global GDP by 2030.

National food-based dietary guidelines

From the analysis shown so far, it is clear to us that meeting the challenges associated with creating a more sustainable food system globally requires a substantial transition of all relevant parts of the supply chain. The problem is, however, that traditional agricultural technologies and a move toward a diet that resembles the EAT-Lancet suggestions might not be sufficient. Studies supporting this view include not only the EAT-Lancet study, but also others such as Rockstrom et al., 2020, "Planet-proofing the global food system;" Searchinger et al, 2018, "Creating a sustainable food future: a menu of solutions to feed nearly ten billion people by 2050;" and Gao & Bryan, 2017, "Finding Pathways to national-scale land-sector sustainability."

It appears that new technologies and innovation are required to help achieve the transition toward a food system that will be sustainable even when the world's population increases to close to ten billion inhabitants. A recent study by Herrero, Thornton et al ("Innovation can accelerate the transition towards a sustainable food system," 2020) provides a very detailed overview of more than 70 technologies that can help accelerate progress toward a sustainable food system. These technologies were grouped by their position in the value chain as well as the state of their development (readiness). **Table 1** overleaf shows how these technologies impact the various positions in the value chain.

Importantly, we note that a number of the technologies shown in **Table 1** are in a very early stage of development and will therefore not make an impact for quite a while. However, a number of technologies are already available that provide exciting prospects for improving the sustainability of the agricultural sector, in our view. These connectivity technologies are related to precision agriculture and include artificial intelligence/big data, the use of sensors, GPS and radar technologies, and the implementation of blockchain technology.

Table 1: Technologies with potential to transform the food system

	Position in value chain					
	Production	Processing	Packaging	Distribution	Consumption	Waste
Cellular agriculture						
Artificial meat/fish	■	■			■	
Artificial products	■	■			■	
Molecular printing	■	■	■	■	■	■
Smart agriculture						
Advanced sensors		■	■	■	■	■
Artificial intelligence	■	■	■	■	■	■
Assistive exoskeletons	■	■		■		
Big data	■	■	■	■	■	■
Data integration	■					
Disease/pests early warning	■					■
Drones	■			■	■	■
Farm-to-fork virtual marketplace		■	■	■	■	■
Improved climate forecasts	■					■
Intelligent food packaging		■	■	■		■
Internet of things	■	■	■	■	■	■
Nano-drones	■			■	■	■
Nanotechnology		■	■	■		■
Omic data use	■					
On-field robots	■					
Pest control robotics	■					
Pre-birth sex determinations	■					
Robotics	■	■	■	■		■
Sensors for soil	■					■
SERS sensors		■	■	■		■
Smartphone food diagnostics		■		■	■	
Traceability technologies		■	■	■	■	
Tracking/confinement tech for livestock	■			■		
Food processing and safety						
Biodegradale coatings			■	■		■
Drying/stabilization tech		■	■	■		■
Food safety technology		■	■			■
Micro-organisms coating			■	■		■
Nanocomposites			■	■		■
Sustainable processing technologies		■	■	■		■
Whole-genome sequencing	■	■				■
Gene technology						
Apomixis	■					
Biofortified crops	■				■	
Disease/pest resistance	■					■
Genome editing	■					
Genome-wide selection	■					■
Genomic selection	■					
GM-assisted domestication	■					
Novel nitrogen-fixed crops	■					■
Novel perennials	■					
Oils in crops	■					
Plant phenomics	■					
Reconfiguring photosynthesis	■					
RNAi gene silencing	■					
Synthetic biology	■					
Weed-competitive crops	■					■

Table 1: Technologies with potential to transform the food system, continued

	Position in value chain					
	Production	**Processing**	**Packaging**	**Distribution**	**Consumption**	**Waste**
Health						
Personalized food		■	■	■	■	■
Inputs						
Botanicals	■					■
Enhanced efficiency fertilizers	■					■
Holobiomics	■					■
Macrobials	■					■
Micro-irrigation 'fertigation	■					■
Microbials	■					■
Nanoenhancers	■					■
Nanofertilizers	■					■
Nanopesticides	■					■
Soil additives	■					■
Intensification						
Electro-culture	■					
Irrigation expansion	■					■
Vertical agriculture	■			■		
Other						
3D printing	■	■	■	■	■	■
Battery technologies	■	■		■		■
Ecological biocontrol	■					■
Resurrection plants	■					
Replacement food/feed						
Dietary additives for livestock	■					■
Innovative aquaculture feed	■	■				■
Insects for food	■	■			■	■
Livestock/seafood substitutes	■	■			■	■
Microalgae and cyanobateria for food	■	■			■	■
Microbial protein	■	■			■	■
Omega-3 products for aquaculture	■					
Seaweed for food	■	■			■	■
Resource use efficiency						
Circular economy	■	■	■	■	■	■

Source: Herrero, Thornton et al, 2020, "Innovation can accelerate the transition towards a sustainable food system"

Vertical farming

Numerous cities are facing growing farmland scarcity due to increasing urbanization. The United Nations estimates that urbanization will cause a yearly loss of 1.6–3.3 million hectares of agricultural land between 2020 and 2030. To solve the problem of land scarcity, farming efficiency will need to improve in regions like Sub-Saharan Africa and East Asia. An innovative option is vertical farming, which is an indoor approach consisting of controlling all environmental factors such as light, humidity and temperature, with the aim of producing more food by harvesting crops vertically. This concept enables the cultivation of various crop types ranging from leafy greens and tomatoes to herbs and flowers, as well as microgreens, and fulfills environmental, social and economic goals.

Figure 1: Yield improvement from hydroponics

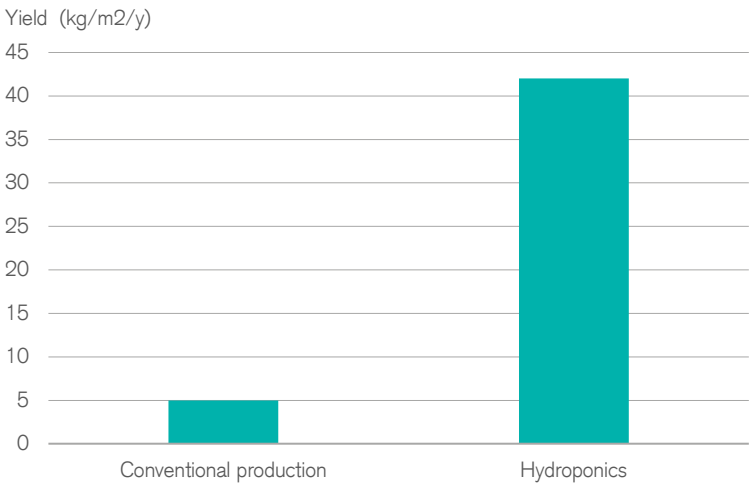
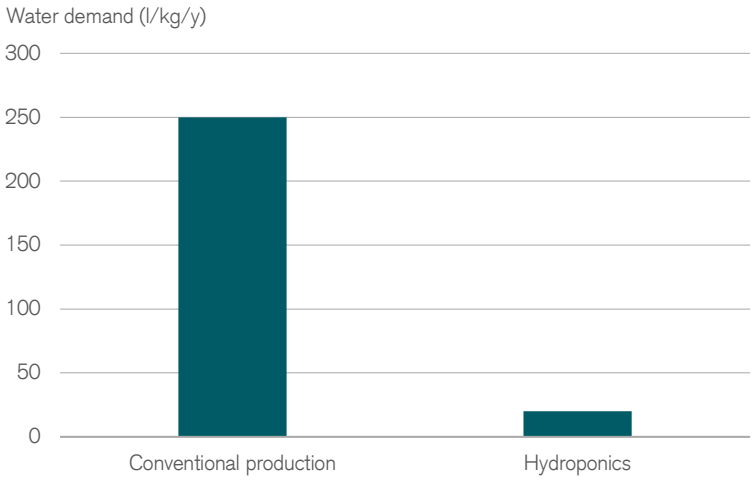


Figure 2: Hydroponics reduces water demand



Source Figures 1 and 2: International Journal of Environmental Research and Public Health, Lages Barbosa et al. 2015

> “The production yield of vertical farming is estimated to be around 350 times higher than that of conventional farming

Various high-tech cultivation methods of replacing soils have been developed, including:

- Aeroponics, which consists of growing crops in the air with visible roots that can be sprayed with a nutrient-filled water solution to enable growth. According to vertical farming leader, AeroFarms, this method uses 95% less water than traditional farming and is 390 times more productive per square foot than traditional open fields.
- Hydroponics, where plants grow in the nutrient-water solution. From an environmental standpoint, this method requires 12.5 times less water per kilo of lettuce per year, for 11 times higher yields (Lages Barbosa et al., 2015; **Figures 1 and 2**).
- Aquaponics, which integrates hydroponics and aquaculture (fish farming). Fishing generates waste that is an ideal plant fertilizer. At the same time, plants grown

using fish waste filter the water used by the fish. According to the US-based company Aquaponics, only one tenth of the water is necessary in comparison to conventional farming.

Beside environmental aspects, vertical farming also has social and economic aspects. Vertical farming is not subject to unfavorable weather conditions that might impact crop production or environmental hazards since there are no toxic fertilizers used that may affect the health of farmers and consumers.

When situated in urban areas, vertical farming also helps to improve the consistency of local crop production. Furthermore, it could also help reduce food prices given the reduction in transport or intermediary costs, which typically account for 60% of total costs (Karnawat et al., 2020).

The production yield of vertical farming is estimated to be around 350 times higher than that of conventional farming. According to the Ellen MacArthur Foundation, it is possible that, by 2050, 80% of the food consumed in urban areas could be produced using vertical farming technologies. We do note that vertical farming has some disadvantages, not least its reliance on technology and skilled labor. More specifically, we note that a problem with one of the technologies used in vertical farming could cause the entire production process to shut down, with obvious implications for costs and profits.

Precision agriculture

Precision agriculture (PA) is a new approach making use of digital innovations such as artificial intelligence, drones, intelligent sensors, mobile applications and satellite technologies. With these technologies, farmers can base their decisions on real-time data about soils, livestock and weather. Put another way, the advanced forecasting analytic software used in precision agriculture can help farmers manage, for example, soil quality, planting times, fertilization, irrigation, harvesting and marketing. Remote sensors have numerous applications like testing soil for nutrient scarcity or the presence of toxic chemicals, livestock monitoring or autonomous vehicle guidance systems.

AGCO (Allis-Gleaner Corporation) estimates that farmers could save USD 80 billion by using the full range of precision agriculture products. John Deere has been investing in precision agriculture for over 20 years. The creation of a separate unit, Intelligent Solutions Group (ISG), along with the acquisition of Blue River Technology in 2017 has made Deere a leader in using smart robotics and machine learning for agriculture. Unlike its peers, the company has adopted a unique strategy to develop its enabling technologies, telematics, digital solutions and electrification on a standalone basis. According to Deere's most recent sustainability report, a single John Deere customer farming 6,500 acres using technologies to prepare, plant, protect, harvest and manage over the course of each production cycle could have achieved the following savings: over 1,600 gallons of diesel fuel saved, over 70 bags of seed corn saved, over 160 bags of soybeans saved, over 1,000 gallons less herbicide applied, over 250,000 lbs less fertilizer applied and over 400,000 kg of CO2 equivalent emissions avoided (equivalent to almost one million passenger car miles driven per year).

> “
> Precision agriculture is a new approach making use of digital innovations such as artificial intelligence, drones, intelligent sensors, mobile applications and satellite technologies

Drones: Historically, farmers have monitored large fields relying on satellites or aircraft images, although these methods are expensive and the image resolution is poor due to weather conditions. The use of drones could become a more efficient technique for aerial crop and cattle surveillance, precision irrigation, planting and spraying as well as identifying diseases. Over the years, firms like American Robotics or Skycision have developed drones relying on advanced AI algorithms to handle these tasks. Most importantly, drones also collect data via images or video. These data are then stored in the cloud to create predictive models and guide farmers' decisions. As a result, we believe that agriculture is one of the largest potential markets for

commercial drone usage given the vast amount of land needing mapping, monitoring and spraying. Data is becoming the most critical element in increasing economic value on farms. Access to better data empowers farmers to make more profitable and sustainable decisions. At 165 million engaged acres globally (compared to 100 million acres in 2018), the John Deere operation center is the largest data platform in the industry connecting devices with the cloud. Deere has built its ecosystem into an open digital platform, which connects over 150 software companies integrated into its platform through application programming interfaces (APIs). Similarly, AGCO's partnership with Bayer can enable its customers to connect with the Climate Corp Field View system to integrate machine data. Fuse, which is AGCO's precision agriculture unit, focuses on delivering connectivity, sensors, machine control, and actionable insights to customers that could enhance farmers' profitability by 20%.

> “
> Companies are on the verge of integrating machine learning, artificial intelligence, and computer vision... into their technologies

Achieving plant-level management through a combination of data and automation advancement will be the true measure of success for precision agriculture. A single cornfield may have as many as eight million individual plants. This means optimizing the microenvironment around each plant so that farmers realize higher value and outcomes with fewer fertilizers and herbicides, and less fuel emissions. This is essential to making agricultural practices more sustainable for the future. Companies are on the verge of integrating machine learning, artificial intelligence, and computer vision (recognizing patterns from images and videos) into their technologies, which should help achieve plant-level management and ensure sustainable value creation for generations of equipment. A good example is See and Spray by Blue River Technology, expected to commercialize in 2021, which uses computer vision and advanced algorithms to distinguish between crops and weeds, and then selectively sprays only the weeds, enabling a 90% reduction of herbicides in some cases. Precision agriculture companies anticipate that customers will increasingly adopt these technologies, either through the introduction of new models with increasingly integrated technology or through selecting premium features as an add-on, which helps the profitability and positioning over the long term.

Autonomous machinery: Recently, autonomous vehicles have benefited from growing consumer and investor interest. Agricultural machinery could also benefit from these tailwinds. In fact, the use of autonomous vehicles drives higher efficiency by freeing up time and requiring less labor (no need to employ drivers). Moreover, autonomous machinery lowers fuel consumption due to more precise routing than human operated tractors. John Deere's goal is to have autonomous vehicle systems for harvesting, planting, spraying, and other tasks relying on sensors, GPS and radar combined with machine learning algorithms. However, even though driverless tractors are an attractive option in the long term, human-operated tractors will remain the norm in the short term. Indeed, even if the software adopted for driverless farming vehicles is similar to the software employed for autonomous cars, it will need to be adapted to monitor plant development (planting, fertilizing, harvesting) or support weather-related changes in the environment (debris, drought, dust, mud). Another interesting idea is to replace fossil-fuel vehicles with their zero-emission counterparts in the coming years, although the current advances are solely pilot projects.

Smart irrigation systems: Precision irrigation denotes sensors applying the exact amount of water required by plants. This approach allows for improved yields, while simultaneously reducing water consumption. Besides improving returns, precision irrigation also reduces electricity consumption. Irrigation techniques include field flooding, which irrigates crops by flooding the land and is the most commonly used irrigation system outside the USA. Center pivot irrigation is a more efficient system than field flooding and features a water-wheel rotating around a pivot and sprinkling water on plants. Drip irrigation is the most precise system, but expensive, necessitating a drip feed for each plant and commonly used in vineyards. More resource-efficient irrigation systems, particularly in dry

regions, are becoming crucial. The company T-L Irrigation could solve this issue with its hybrid irrigation approach based on center pivot in conjunction with drip technology. This system reduces evaporation and water waste, enhancing yields by 10%–15% compared to conventional central pivot systems.

A major drawback of precision irrigation is the upfront costs of implementing this technology, making it challenging to render it widely accessible to all farmers.

Greater use of wireless connectivity

One of the next big steps in the digital agriculture transformation is to implement superior connectivity through which the industry could potentially add USD 500 billion to global GDP by 2030, according to McKinsey. At present, numerous farmers consult data about crops, soils or weather, but only a few have sufficiently advanced digital tools to interpret this data and take the corresponding actions. In the United States, only 25% of farms have adopted connected equipment, mostly using 2G or 3G networks, which is not exactly cutting-edge technology (McKinsey). To achieve significant growth in productivity, the industry has to use the full spectrum of advanced connectivity including:

- Short-range efficient device-to-device connectivity (e.g. Bluetooth).
- Low-power wide-area network (LPWAN) supporting high density of connected devices.
- Low-to-mid-band 5G offering a high-speed connectivity.
- Low earth orbit (LEO) satellites offering global coverage with reduced latency compared to current satellites.

Introduction of blockchain technology

Blockchain technology (saving and structuring vast amounts of collected information in "blocks that are chained together" in a global peer-to-peer network) has become an important tool in various applications from financial payments to supply chain monitoring and food safety. BIS Research expects the market for blockchain technological solutions in precision agriculture and across the food supply chain to rise from USD 41.9 million in 2018 to USD 1.4 billion in 2028.

A use case for blockchain at the farmers' level is funding. In fact, small farms frequently do not have a credit history or land-ownership documentation, which makes access to funding either impossible or only through loans with higher interest rates. Through blockchain, farmers gain the opportunity to raise funds. Another application of blockchain can be found in the food supply chain, enhancing food safety, as consumers can track their products, guaranteeing the quality and provenance of the product. Founded in 2013, Provenance is the first blockchain platform to enable producers and consumers to simultaneously track goods through the entire supply chain, leading to more transparency in the food industry. In the same vein, the company AgriDigital allows farmers to sell their physical goods in the form of digital assets called "tokens." As the token shifts to each stage of the supply chain, data on the physical asset is generated, enabling consumers to receive data and track their products.

> "The agricultural industry could add USD 500 billion in value to global GDP by 2030

Growth outlook for smart agriculture solutions

A study published by McKinsey Center for Advanced Connectivity and Agriculture Practice last year concluded that digitalization and connectivity will go through a technological transformation and agriculture will become more efficient, more precise and more automated if connectivity is implemented successfully. According to the report, the agricultural industry could add USD 500 billion in value to global GDP by 2030, and much of the pressure on farmers would be alleviated. With the exception of Africa, it is expected that advanced connected infrastructure will cover four fifths of the global agriculture landscape over the next ten years.

Regionally, the largest potential is attributed to East Asia and the Pacific, which are expected to enjoy almost half of the aforementioned GDP growth over ten years (**Figure 3**). In terms of the different technologies, smart-crop monitoring is expected to unlock the largest potential of USD 130–175 billion by 2030. Drone farming could contribute some USD 85–115 billion, while smart-livestock monitoring is expected to grow by USD 70–90 billion, according to McKinsey (**Figure 4**). Increasing automation in the form of autonomous farming machinery could add USD 50–60 billion to global GDP, while the growth potential of smart-building and equipment management should not be underestimated as, besides machinery, this is another substantial capital-intense area of farming. Chips, sensors and computer vision could generate some USD 40–60 billion of cost savings for buildings and equipment in the next ten years.

The main drivers behind the steady increase in production yields over the past few decades have been fertilizers and seeds thanks to R&D spending in the agriculture chemicals segment (i.e. hybrid and bitoech seeds). In the years to come, it should be possible to improve yields further through the adoption of the above-mentioned technologies.

All these new technologies open the field for various players and, the more niche-specific technologies are, the more fragmented the industry and players are likely to be. On a global scale, the two largest industrial leaders John Deere and AGCO also own a high share of the technologies and services that are sold together with the equipment. Both companies have grown their share through acquisitions and are benefiting from their direct connection to farmers and their needs. Deere owns and develops its own technologies, telematics, digital solutions and electrification, while its peers AGCO and CNH Industrial utilize partnerships and joint ventures. Furthermore, in the area of precision farming, Trimble Navigation stands out as an expert in GPS, laser, optical and inertial technology. Another important listed company is Hexagon AB, which is a global provider of sensors, software and autonomous solutions providing various components for the agriculture industry. Faven Industries develops precision agriculture products such as field computers, applications controls, guidance and steering tools, wireless connectivity, cloud-based data management and machine controls among others. FarmersEdge is a globally active company offering digital agriculture risk management solutions and consulting services to farmers, retailers and the agriculture industry. Switching from listed companies to privately held companies, aWhere delivers weather-based agriculture intelligence to farmers, among other things, via almost two million virtual weather stations and advanced analytics. Finally, Adapt-N, which has been acquired by Yara International, is a software tool for agronomists to help deliver better in-field performances to farmers and growers.

In the field of vertical farming, AeroFarms is a leading company maintaining several vertical indoor farming plants. The company maintains fully controlled indoor vertical farming plants using no pesticides and 95% less water than traditional farmers. Sky Greens is the first low-carbon, hydraulic-driven vertical farm using green urban conditions. The company is the innovation hub of its holding company Sky Urban, which is continually seeking innovation in next-generation farming. Both companies are privately held in a well-fragmented innovative niche area.

Figure 3: Value potential of agriculture connectivity

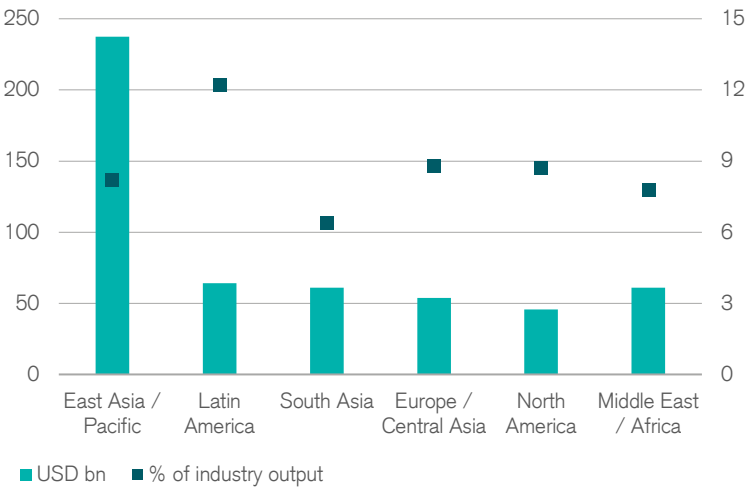
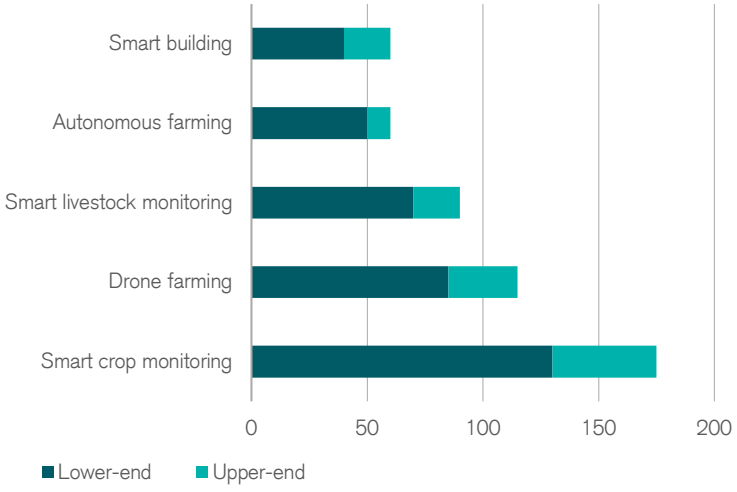


Figure 4: GDP growth potential



Source Figures 3 and 4: McKinsey, Credit Suisse

Company feature: Apeel

Protective coating for fruit and vegetables

Apeel was founded in 2012 and is one of the leading companies providing solutions to address food loss and waste. Specifically, the company's technology aims to extend the lifespan of a wide range of produce, which helps to address both food loss during the production and transportation phase as well as food waste that occurs during the retail and consumption phases.

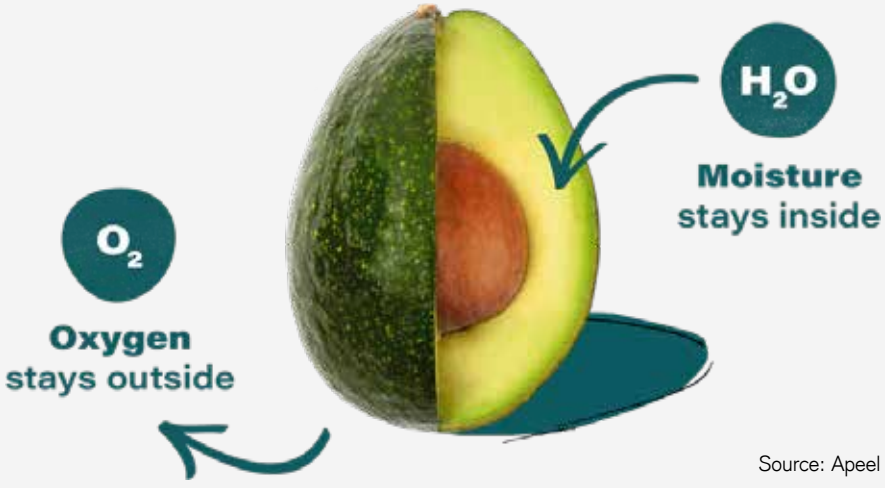
Apeel has developed a technology that produces a protective coating for fruit and vegetables to extend the shelf life of these products. This extra layer slows the rate of water loss and oxidation, which are the key causes of food going to waste. The protective coating is completely colorless, tasteless and safe to eat. Apeel uses ingredients for its products that are plant-based and exist in the peels, seeds and pulp of all fruits and vegetables. The fact that some products have a longer shelf life than others is not necessarily due to different molecular ingredients, but more because their molecular structure is different to those that have shorter shelf lives.

After producing the coating product in powder form, Apeel mixes it with water and applies it to produce. This can be done by dipping fruit or vegetables in the coating mix or spraying the mix onto the produce. In our conversation with Apeel, the company highlighted that it is the only end-to-end provider of shelf life expansion solutions. Other technologies focused on extending a product's lifespan include Bluapple, which aims to remove ethylene gas produced by fruits and vegetables and speed up the ripening process. However, this technology only focuses on the consumer end of the supply chain. Data analytics forms an important part of Apeel's process. The company uses hyperspectral imaging to monitor treated fruit in order to assess how ripe it is. Apeel recently acquired Impact Vision, which will add greater capability to the company's imaging capacity and help advise clients on how ripe and fresh fruit is in order to make better decisions about shelf life.

> "The protective coating is completely colorless, tasteless and safe to eat

Apeel-treated products are sold in the USA, Canada and Europe. In North America, this includes avocados, limes, organic apples and (plastic-free) English cucumbers. In Europe, this includes avocados, mandarins, oranges, grapefruits and lemons. One of the reasons why different products are sold in Europe compared to the USA is that the regulatory structure in Europe is not as well defined as in the USA. Specifically, there are differences between produce with edible or non-edible skins. It therefore takes longer to gain full approval in Europe. By the end of 2021, the company expects its products will be installed with suppliers of more than ten different crop categories who together sell several million tons of produce annually. While the lifespan of all produce can be extended using Apeel's coating, the company does not expect to offer it for some products. Products with large surface areas could make it uneconomical to treat them. The company's analysis suggests that retailers carrying Apeel-treated produce have experienced a 50% reduction in in-store waste as well as an increase in sales.

While Apeel is currently only sold in developed countries, the company clearly sees a role for reducing food loss in emerging countries too. To date, Apeel has raised USD 385 million in funding from a range of investors. A recent USD 15 million investment from the IFC is allowing the company to increase its focus on emerging markets, particularly Latin America and Africa. The lack of typical cooling facilities means that food-loss ratios are high across emerging markets. Extending the lifecycle of produce would help address this problem, while at the same time limiting the need for energy-consuming cooling facilities.



Source: Apeel

Photo: GettyImages, Luis Alvarez

Solutions: Circular economy, packaging and cooling

Reducing the more than 30% of food that is either lost or wasted would significantly aid the quest for a more sustainable food system. Donating or sharing food would be an obvious and very effective way to address food waste. Circular-based solutions such as those that use food waste to create new (food) products also help. Smart packaging solutions are being developed that not only help improve production yields but importantly help reduce food loss and waste across the entire supply chain from the farm to the home. The development and introduction of cooling and storage solutions would help extend the lifespan of food even more.

Circular economy solutions

In the first chapter of this report, we outlined that the average consumer living in developed countries eats too much. An easy solution to help improve health and address food waste at the same time would therefore be to reduce how much food we buy. To put this into perspective, we note that eliminating household food waste in America and Europe would add 10% to the world's food supply available for other countries.

Next up from reducing the amount of food we buy is food recycling or rather food donation. Feeding human food to humans is a far better option than putting it in a landfill, especially considering the environmental footprint associated with the production of that food in the first place. Furthermore, it helps to feed people who may not have access to sufficient food or cannot afford it. Work by Mike Berners-Lee and his team at Lancaster University provides a useful insight into the effect of redistributing food relative to other options for food waste from an environmental perspective (**Figure 1**).

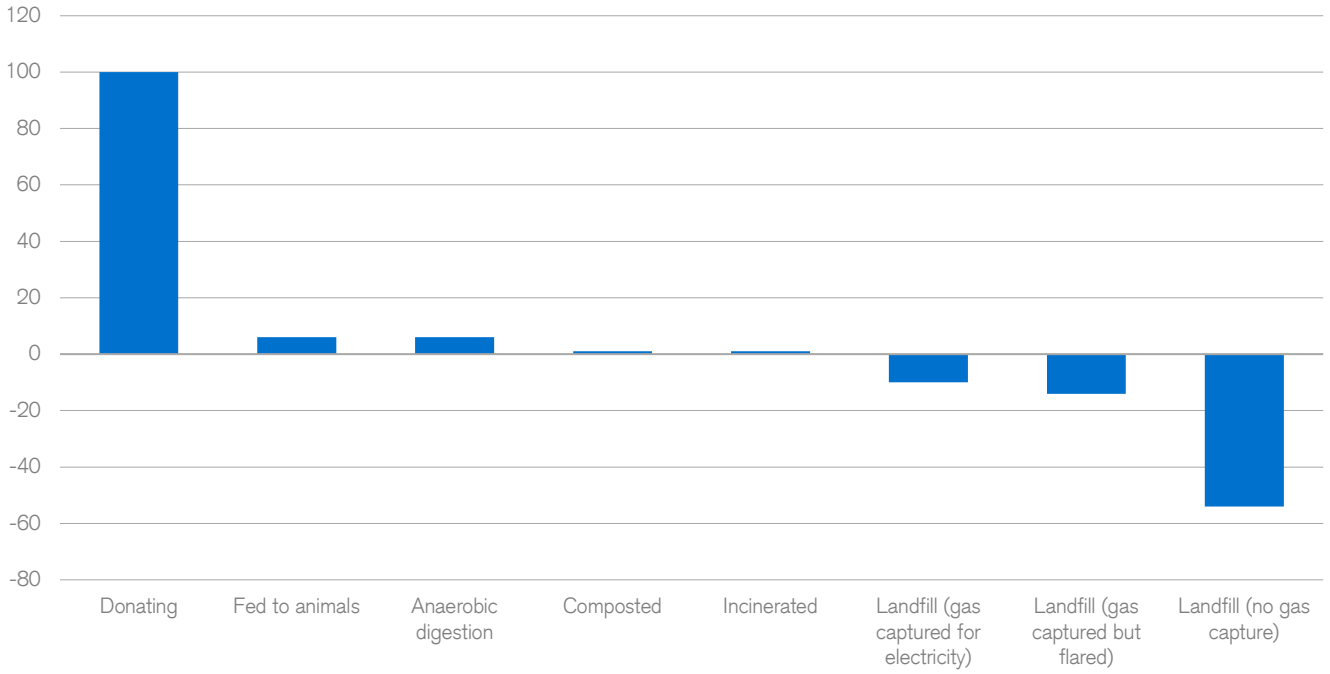
Donating food for others to eat saves all GHG emissions that were associated with the production of that food. All other methods are far less environmentally friendly. In fact, food that is sent to landfills actually increases GHG emissions through the methane that is produced.

If food is not eaten it does not mean that it cannot be re-used in a circular approach where food waste is used as ingredients for new food or beverage products. In **Table 1**, we show a number of examples of solutions that have been developed and that help address food waste and create job opportunities at the same time.

Packaging, cooling and storage solutions

In public opinion, food packaging is often viewed as having a negative impact on the environment. However, packaging plays a crucial role in the supply chain of food in essentially all steps from farm to fork. While the use of packaging is critical for reducing food waste, consumer knowledge, awareness

Figure 1: Reduction in GHG emissions of food based on disposal method (in %)



Source: Mike Berners-Lee: "There is no planet B"

and appreciation of this important function of packaging is comparably low. The relationship between consumers and food packaging, and the influence of public opinion on political decisions, runs a risk of creating a barrier to food-saving practices, in our view.

> "Packaging plays a crucial role in the supply chain of food in essentially all steps from farm to fork

Agricultural films protect and incubate crops, films and bags protect animal feed. Potentially wider use of these materials would increase yields and reduce wastage of animal feed in the supply chain, which is critical in reducing the environmental footprint of animal-based protein production. The use of recycled material, recycling of agricultural films and/or the use of bio-based organic materials that can be directly mulched into the soil are solutions that can materially reduce the environmental impact from the use of packaging products.

Corrugated board plays a crucial role in agriculture during the crop season in the handling and storage stage and the general distribution of food and beverages to retailers and restaurants. As a transport container, corrugated board is lightweight, fully recyclable, widely recycled and ultimately based on a renewable resource, i.e. wood. Improved box designs, including the development of ready-shelf and display packaging, have reduced handling and unpacking at the retail level, thus also lowering the risk of in-store damage.

In the process and packaging stages, we believe the development of new packaging materials and automated packaging systems have the potential to reduce food waste, improve health and safety related risks, and prolong shelf-life. This is an area where we see potential for technology advancements in terms of barrier properties (including the increased use of bio-based and recycled material), packaging line automation and the use of clean technology in packaging lines.

In retail, we think packaging has the potential to evolve from providing only basic information about products (nutrition, storage guidance, origin, etc.) to providing advanced information by way of interactive communication and using

Table 1: Examples of companies using food waste as ingredients for new food or beverage products

Company Name	Solutions
Regrained	When grain is made into beer, the brewing process takes out sugar – leaving behind protein, fiber, and micronutrients that Regrained makes into a flour it calls "SuperGrain+" and incorporates into snack bars. The company also sells the flour to other manufacturers and is working on another line of products.
Render	Bay Area-based Render partners with chefs to create new products like Weyla, a beverage that blends whey from a Sonoma creamery with fruit, herbs and botanicals, and Bryner, a savory drink mix made with upcycled pickle brine that can be used in making a Bloody Mary. In collaboration with chefs from San Francisco's State Bird Provisions, it recreated a snack that the chefs make for themselves in the restaurant kitchen to make use of leftover quinoa.
Coffee Cherry Company	When a former Starbucks engineer learned about the challenge of coffee cherry waste – tiny fruits that hold coffee beans and usually end up rotting on coffee plantations – he created a new process that converts the fruits into flour and launched a start-up (formerly known as CoffeeFlour) to produce it. The ingredient, which can be added to drinks, baked goods and other products, also helps coffee farmers increase incomes.
The Real Dill	This Denver-based pickle company did not want to throw out the cucumber-infused water that it creates as part of the pickling process, so it started making it into a Bloody Mary mix. Now the company says it is better known for the mix than for pickles, and the product has helped it achieve a goal of zero waste.
Planetarians	When sunflower seeds are processed for their oil, the end-result is a hard dry wood-like "oilcake" that is usually used as animal feed. But the ingredient has more protein than meat, and the founders of this start-up realized that it had potential as a food for humans. They found a way to process the oilcake with steam, heat and pressure to puff it up and turn the ingredient into chips.
Sallt & Straw	Salt & Straw, a chain of West Coast ice-cream shops, made a "Second-Steeped Rum Spices and Apple Butter" flavor in 2017 from spices rescued from a Portland distillery and apple butter made from bruised apples that otherwise would have been wasted.
Sir Kensington's	The vegan mayo made by Sir Kensington's replaces eggs with aquafaba, the liquid made from cooking chickpeas – something that it sources from a hummus manufacturer that otherwise would have been thrown out. The brand was acquired by Unilever in 2017.
Baldor	Baldor, a major food processor that makes products like "baby" carrots (i.e. regular carrots carved into tiny pieces), turns fruit and vegetable scraps into multiple products: some fruit scraps go to juice companies, vegetable scraps go to chefs for use in stocks, a mix of vegetables are dried and crushed into a flour that can be used in place of wheat, and other scraps are used in meal kits that include veggie noodles.
Toast Ale	If the spent grain from brewing can be used to make bread – something that the Chicago-area Hewn Bakery does in one of its loaves – bread can also be used to make beer. Toast Ale, which first launched in London, makes a pale ale with surplus bread as an ingredient. The company estimates that around 44% of bread is wasted and that it can save roughly one slice of bread per bottle.
Fopo	This European company rescues fruit and vegetables that are on the verge of being wasted, freeze-dries them, and turns them into a powder that contains most of the nutrition of the original fruit, but can last as long as two years.
Real Good Stuff Co.	A Chicago-based cold-pressed juice company turns its extra juice pulp into fruit-and-vegetable-filled popsicles. One combines apples, lemons, cucumbers and spinach; another makes use of extra beets, ginger and carrots. The company also uses leftover pulp to make dog treats.
Rise Products	Using spent grain from breweries in Brooklyn and Queens, this start-up creates a barley "super flour" that has twice as much protein, 12 times as much fiber, and one-third of the carbs of regular flour. It sells the flour directly to consumers, along with a brownie mix and brownies. Its underlying technology can also be applied to other by-products ranging from fruit skins to coffee waste.
White Moustache	Making yogurt results in large quantities of whey, a liquid that is often discarded. Brooklyn-based yogurt company White Moustache decided to start marketing it as a "probiotic tonic." The company also uses surplus fruit along with whey in frozen yogurt probiotic pops.
Treasure8	Based on Treasure Island, a small artificial island in the San Francisco Bay, this start-up designed technology that dehydrates fruits and vegetables to turn them into nutritious, shelf-stable chips that do not require preservatives. The company sources produce that would otherwise be wasted from food-processing plants.
Rubies in the Rubble	This UK-based company makes condiments from surplus food, such as a spicy tomato relish that uses tomatoes that are too ripe or flawed to be sold in the produce section, or a pear chutney made with imperfect pears.

Source: FastCompany

smart labels integrated in the packaging, as well as moving from current static date-labeling practices (use by, best before) to dynamic "safe-to-consume" labeling. This would have the potential to materially reduce food waste, especially in high-income regions where more than half of food waste occurs at the consumption level.

Cooling and storage solutions

Successfully cutting down the amount of food waste not only means people should only buy what they eat, adopt circular economy solutions and find better packaging solutions, but we also see a role for cooling companies in this respect as cooling helps to extend the lifespan of food before it can no longer be eaten. Here we would point to examples from a number of operators in this field.

> "We see a strong need for the implementation of more sustainable cooling and storage solutions

In the United States, Carrier Transicold and Trane Technologies are two examples of sustainable cold chain solution providers. Carrier Transicold provides transport refrigeration equipment and "cold chain" tracking solutions to help customers monitor and protect temperature-sensitive products across supply chains. According to the company, one-third of the world's food is unable to be consumed in part due to cold chain and spoilage issues. Carrier recently mentioned how data analytics can be utilized in food and produce delivery, and its partnership with AWS could extend digital offerings. Refrigeration accounted for around 19% of Carrier's 2020 sales.

Trane's ThermoKing solutions are used in truck/trailer transportation (North America Trailer generates approximately 25% of Thermo King revenues), including marine, air, bus, and rail. It includes additional offerings such as ultracold, parts, and telematics, all aimed at improving food transportation and allowing food to be stored for longer. Trane also operates a global philanthropic program called "We Move Food" to increase access to fresh food by reducing waste and supporting nutrition education. ACT Research forecasts 2021 production of reefer vans to grow 39% year-on-year.

Additional commercial refrigeration highlights

In North America, Lennox's commercial refrigeration products include condensing units and unit coolers, which are used for preserving food and other perishables in supermarkets, convenience stores, restaurants, warehouses and distribution centers. Cold storage is one of Lennox's largest verticals in the refrigeration segment and has been relatively strong due to the cold chain built up to support changing consumer habits in ordering food. Emerson's food value chain (FY 2020 sales: USD 1.7 billion) also covers refrigeration, cargo tracking and monitoring, temperature management, and waste management solutions. At its 2021 investor day, Emerson highlighted its software development, such as in-transit cargo monitoring, a cellular based IoT service to improve food quality and safety. To help address the growing food imbalance across the developing world, we see a strong need for the implementation of more sustainable cooling and storage solutions.

Other solutions for food waste

Further along the food value chain, Emerson's InSinkErator provides another food waste solution by turning and sending waste to advanced water treatment facilities to transform it into energy or fertilizer. InSinkErator food waste disposers target residential use and range from garbage disposal to instant hot water dispensers. This product is easy to install and is another way to help with food spoilage and foster sustainability.

Company feature: Footprint

Plant-based fiber technology

Footprint is a US company engaged in plant-based fiber products that provide environmental and sustainable alternatives to plastic and polystyrene foam products. The company's products are made from tree fiber, agricultural waste or recycled paper boxes and are fully biodegradable, compostable and recyclable.

Footprint has developed a so-called Barrier Technology™ that eliminates the need for plastic liners in their products and protects them against oil, water and oxygen. The use of plant-based fiber also has the advantage of making Footprint's products both microwave and oven safe. This latter point is typically not the case for plastic products.

We held an interview with Footprint's CEO and co-founder Troy Swope to better understand Footprint's offering and its potential for disrupting the existing, plastic-based, food packaging industry. Footprint currently employs around 120 engineers and scientists globally, but is in the process of expanding its production and R&D capabilities. The company is establishing a new R&D facility in the Netherlands and intends to have a European production base in Poland. This should add to its existing production facilities in the United States.

The market for plastic alternatives is growing exponentially according to Footprint's CEO, with particular focus from large multinational companies such as McDonald's and Starbucks. While the move toward plant-based plastic alternatives is led by demand from US and European corporates, Footprint expects demand from Asia to accelerate in the next few years. The desire to replace plastic products with more sustainable solutions is currently driven by pollution considerations and the fact that the lifespans of some plastic products can be hundreds of years. Footprint also believes that growing health concerns about the possible effects of toxic chemicals used in the production of plastic bowls on people's health will accelerate demand for plastic alternatives.

The market for food packaging is substantial at around USD 250 billion annually. While no company truly dominates at this stage, some of the largest providers of plastic packaging globally include Reynolds, Sealed Air, Berry Global and RPC Group. With demand for plastic food packaging alternatives growing strongly, Footprint believes that it has the potential to capture 10% of the overall market in the next ten years. The company's current growth is already strong, with contractual revenues set to double this year to around USD 600–700 million, according to the CEO. Footprint's view on market share is not only driven by a growing desire on the part of its customers to replace plastic with alternatives for environmental reasons, but also because its products are actually cheaper, so that it makes economic sense too.

We agree with Footprint's view on the outlook for plastic alternatives. This also creates possibilities for more traditional paper and packaging companies as they diversify their paper-based packaging technologies more toward food-related offerings.

Footprint's products reduce the need for plastic food packaging, which reduces waste and emissions associated with the production of plastic. Furthermore, Footprint's technologies allow for longer-term food storing, which therefore also aids the quest to reduce the food waste that typically occurs in the retail and domestic parts of the supply chain.

> "The lifespans of some plastic products can be hundreds of years

Source: Footprint

Photo: Credit Suisse

Solutions: Regulation and support for farmers

Our analysis shows that current food consumption patterns not only have serious health implications, but that they also put the ecological sustainability of our planet at risk and carry substantial economic costs. These challenges are only likely to become greater when we incorporate the likely increase in the world's population for the next few decades. In our view, all of this suggests a change toward a more sustainable food system is essential, although we see a number of roadblocks that will need to be overcome.

Regulation may be needed to bring about change

Despite the rise in diet-related illnesses such as diabetes, and the economic and social costs involved, we note that government legislation on food consumption has largely remained focused on educational programs. These measures, which place the responsibility for what food to eat with consumers, mainly focus on dietary guidelines and food labelling. Hence they ignore the fact that a person's dietary choice is a complex multi-faceted result of a range of different factors, most of which are outside the consumer's direct sphere of influence.

These factors can be sociocultural in nature (e.g. social and cultural norms), community-related (e.g. workplace or school environment, accessibility to supermarkets and local stores), driven by (local) agricultural or market factors (food safety, marketing and production and distribution incentives), or determined by government policies or global issues including food availability, trade agreements or international food standards, distribution or commodity pricing.

To date, most government policies have focused on the individual consumer rather than on food and beverage producers, despite the fact that the producers appear to show more consistent evidence of effectiveness (see Mozzaffarian and colleagues, "Role of government policy in nutrition – barriers to and opportunities for healthier eating"). One can only speculate as to the reasons why governments have so far failed to take a hard line with producers of unhealthy food. Industry lobbying, a timing mismatch between the impact of nutrition policies on corporate profits and employment versus longer-term health, or a lack of public support have all been identified.

The sugar tax as a regulatory example

To underline the resistance of various stakeholders to stricter regulation, we highlight some of the experiences related to the "sugar tax."

Mexico was one of the first countries to introduce a levy on soda containing sugar. In 2014, it added one peso per liter of soda as a tax. Currently, some 40 countries around the

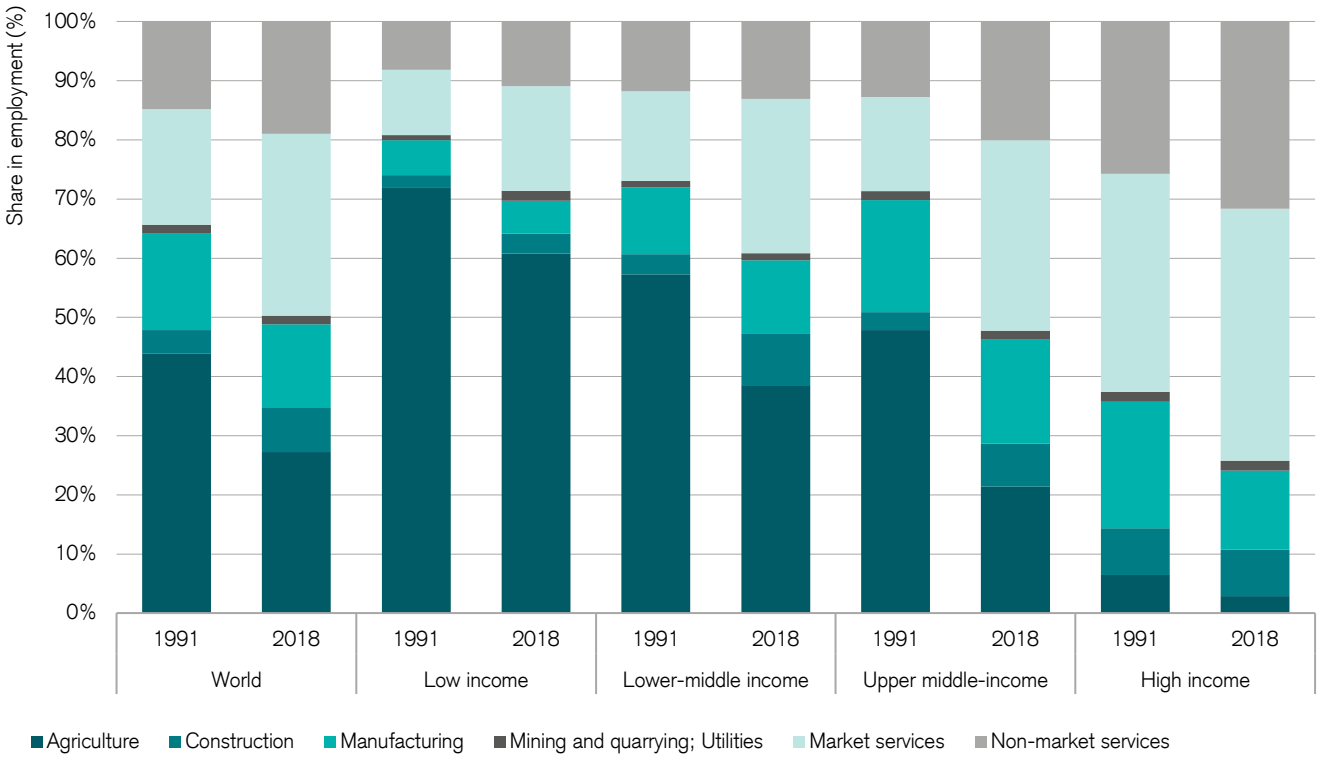
world have introduced taxes on sugar-sweetened beverages. The experience regarding the impact of a sugar tax on the sale of sweetened beverages appears supportive. In Mexico, consumption dropped by 5.5% in the first year after the tax was announced, followed by a 9.7% decline in the second year. A 2019 study published by the University of Otago ("Sugary drink taxes reduce consumption, major review shows." ScienceDaily. ScienceDaily, 25 June 2019) found that a 10% tax on sugary drinks cut the purchase and consumption of sugary drinks by 10% on average in places where it had been introduced. Despite these observations, there has been resistance to the sugar tax. The beverage industry has historically been critical and public support has also not been uniformly positive owing to an increased cost of living and the potential employment implications for local smaller businesses.

Strategies for a sustainable food system

The various stakeholders in the debate over healthy or sustainable food (producers, consumers, healthcare providers and the government) may have conflicting interests when it comes to changing the world's food system to a more sustainable structure. Government policies therefore need to be multi-faceted in order to have the greatest chance of success, in our view. While certain vested interests may resist change, we note that the food industry and society at large can, and are likely to, play a role in enabling the transition of the current food system.

> "Most government policies have focused on the individual consumer rather than on food and beverage producers

Figure 1: Employment by sector (1991 and 2018)



Source: Global Panel on Agriculture and Food systems for Nutrition, ILO 2019

Greater support for (small-scale) farmers needed

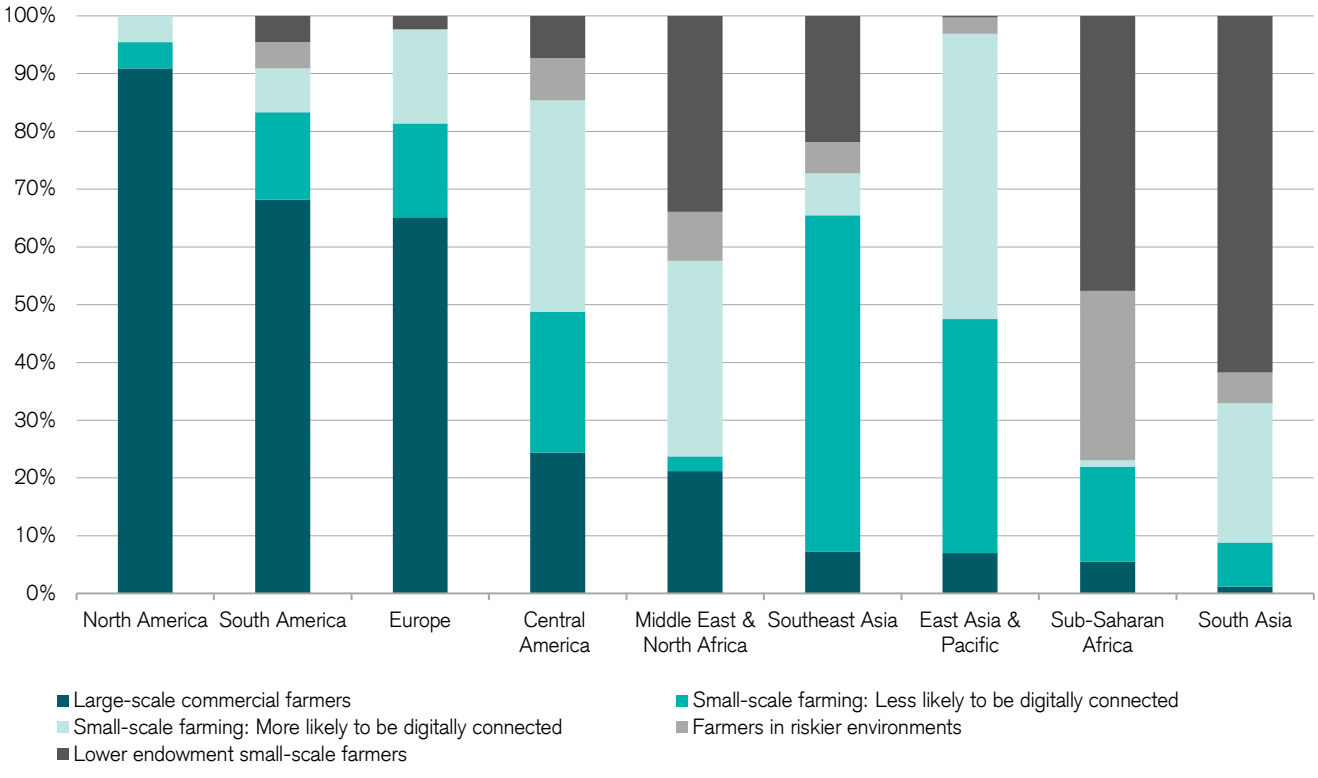
Putting widespread policies in place aimed at redirecting food consumption and production away from unhealthy, unsustainable products toward those that are more in line with desired health and ecological products is unlikely to be fully successful, in our view, unless the agricultural sector is also addressed.

While farming plays a central role, the current structure of the global agricultural sector needs to be adjusted in order to facilitate a move toward a global sustainable food system. Data from the International Labor Organisation (ILO) suggest that agriculture makes up almost 30% of employment globally in 2018 (**Figure 1**). However, this is heavily tilted toward the low- and middle-income countries. Despite a diversification achieved between 1991 and 2018, almost 40% of employment in middle-income countries took place in the agricultural sector in 2018, whereas this was around 60% for low-income countries.

A potential future shift in what we eat is obviously likely to require farmers around the world to make changes to what they produce. We believe this is likely to have a much more profound impact on farmers in developing countries than in developed ones. The reason for this relates firstly to the fact that farming in emerging markets is largely a "small-scale business."

> "The current structure of the global agricultural sector needs to be adjusted

Figure 2: Share of farmers by region



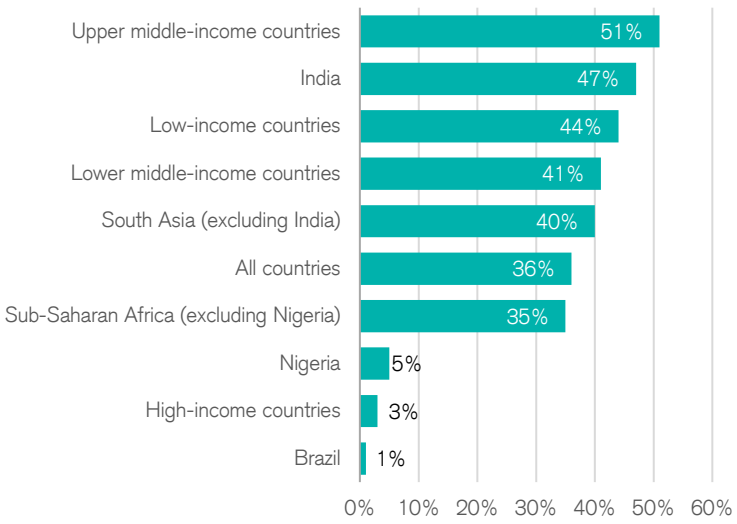
Source: CGIAR Research Program on Climate Change, Agriculture and Food Security, Credit Suisse Research

For example, in North America, more than 90% of farming enterprises are large-scale commercial enterprises (**Figure 2**). By contrast, this figure is less than 10% across Africa and Asia, while 85%–95% of farmers in South and Southeast Asia and Africa are small-scale and not likely to be digitally connected, operate in riskier environments or have to rely on lower endowments.

Based on the mix between small- and large-scale farmers across regions, we are not surprised to find that small-scale farming makes up more than 50% of total food production across developing countries, whereas this figure is just 3% for high-income regions according to the International Food Policy Research Institute (IFPRI, **Figure 3**). However, the reliance on small-scale farming in developing countries presents a clear risk to those economies if food consumption patterns change, given that small-scale farmers and especially those located in developing countries tend to operate under financially very challenging conditions.

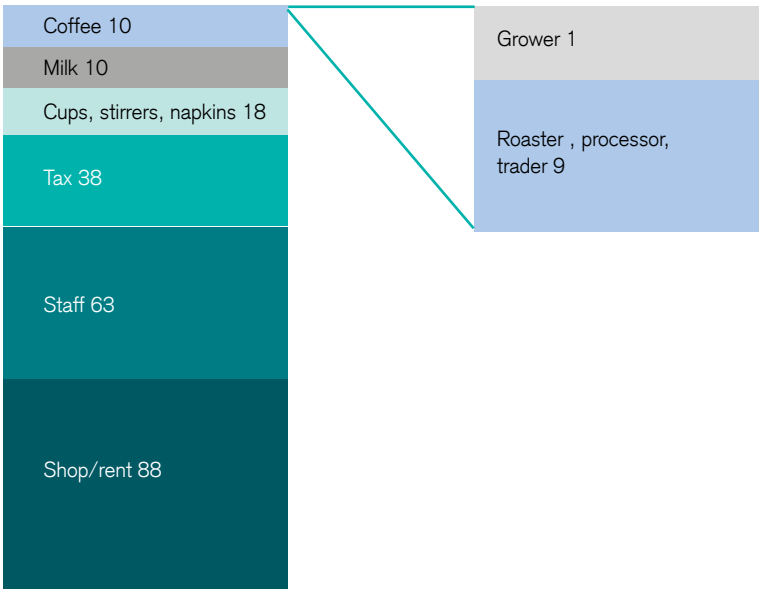
FAO data on average income levels for farmers across developing countries clearly show the financial challenge that small-scale farmers will face if they have to change their business model. Across the 37 countries shown in **Figure 5**, small-scale food producers recorded average incomes of just USD 1,100 per year.

Figure 3: Smallholder share in value of primary food production



Source: IFPRI (2020), Credit Suisse Research

Figure 4: A coffee grower might make 1 cent from every USD 2.50 cup of coffee sold



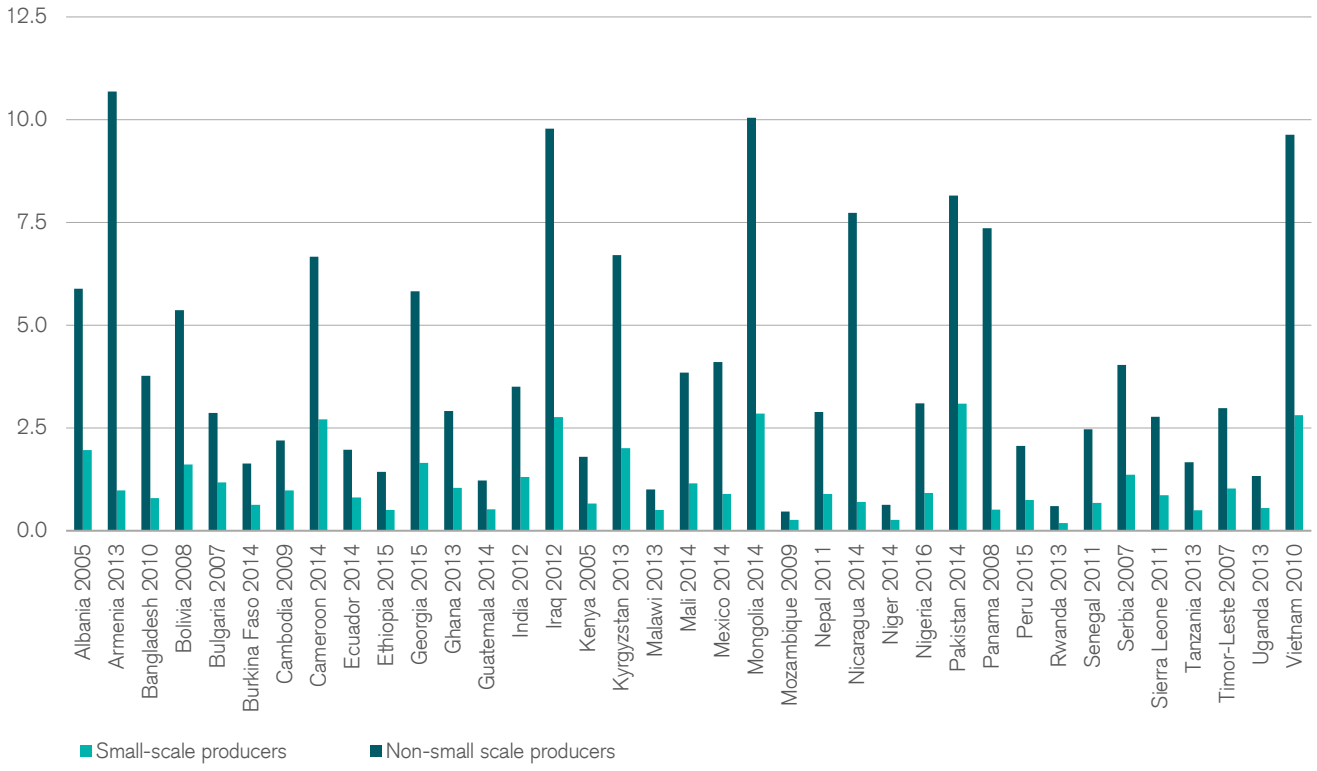
Note: Figures do not add up due to rounding
Source: FOLU, International Trade Centre, Allegra Strategies

> “Farmers in higher-income countries actually receive more support than those in emerging regions

Government support for farmers is too low and declining

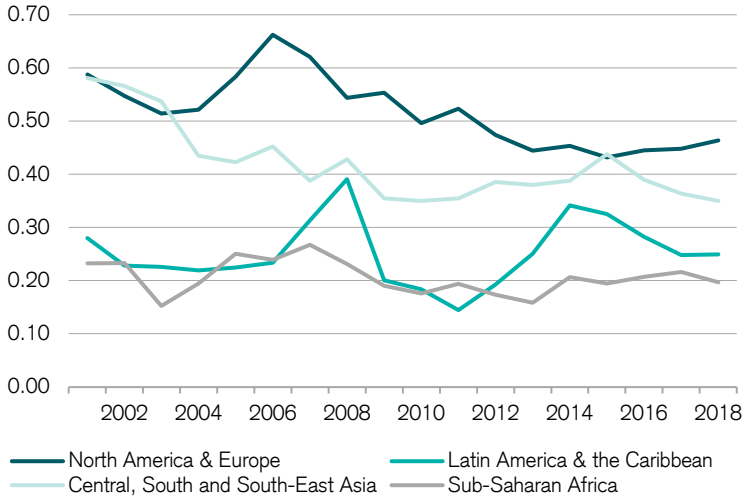
The challenging financial conditions for (small-scale) farmers, especially across developing countries, have so far not resulted in greater support from local governments. If anything, support has been declining. Furthermore,

Figure 5: Average income for small scale farmers across global emerging markets is very low
Average income from agriculture for selected countries by size of food producers PPP (constant 2011 international USD '000)



Source: FAO, Credit Suisse Research

Figure 6: Agriculture Orientation Index for Government Expenditure



Source: FAO, Credit Suisse Research

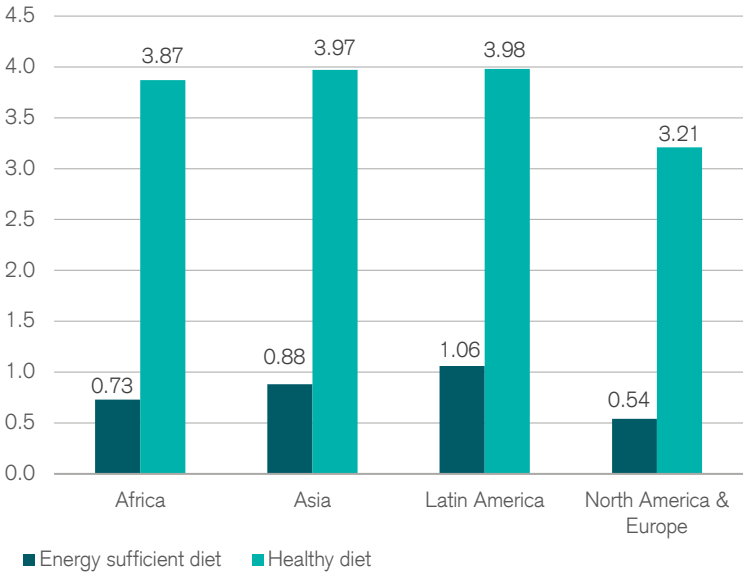
farmers in higher-income countries actually receive more support than those in emerging regions. Evidence for this can be seen in **Figure 6**:

- The Agriculture Orientation Index (AOI) for Government Expenditure remains substantially below 1 for developing countries and has even shown signs of weakening during the past few years. In addition, the index reading for emerging countries is lower than for North America and Europe. In other words, the agriculture share of government spending across developing regions is much lower than the share of agriculture in GDP. Given the relatively high contribution of agriculture to GDP across developing economies and the need to adjust business models to account for a necessary long-term shift in food consumption and production, we believe that support levels need to rise.
- Farmers across lower-income regions not only suffer from a relative lack of government spending, but also suffer more from trade policies than their counterparts in middle- or high-income countries. The nominal rate of protection (NRP) compares farm prices with international reference prices. It is considered to be the undistorted price that would prevail in the absence of government policies and under perfect market conditions. The NRP

for low-income countries is negative, which suggests that local farmers receive less for their products than the international reference price. While some might argue that this is done to support consumers, we do not believe that this argument holds given that low prices discourage local production, which not only impacts employment, but may also increase consumer prices for the products. Since this sector is largely made up of small-scale farmers and tends to make up more than 50% of employment across developing countries, we tend to think it is a net negative for lower-income countries.

- In addition to the misalignment of protection between low- and higher-income countries, we note that another aspect needs to be considered, especially with an eye on a move toward a healthier and sustainable food system. At the product level, government support globally appears strongest for products that do not feature prominently in healthy diets such as sugar and various forms of meat, while production of more nutrient-rich food such as fruit and vegetables appears to be penalized across a range of countries (**Table 1**). Furthermore, data from the FAO and the Global Panel on Agriculture and Food Systems for Nutrition indicates that a significant mismatch exists in the supply of vegetables across regions. For a large part of the developing world, supply is well below levels needed to provide the daily recommended intake per capita, whereas it is well above them in central and eastern Asia.
- Finally, we would note that a better alignment of government support and agricultural policies might help to make healthy food more affordable. Analysis by Herforth et al. (2020) indicates that the cost of a healthy diet per person in Africa, Asia, Latin America and the Caribbean is higher than for a consumer in North America and Europe. Furthermore, a healthy diet can be up to five times more expensive than a diet that merely provides sufficient energy (**Figure 7**).

Figure 7: USD cost/capita/day of reference diets (2017, PPP); affordability is lower in developing regions



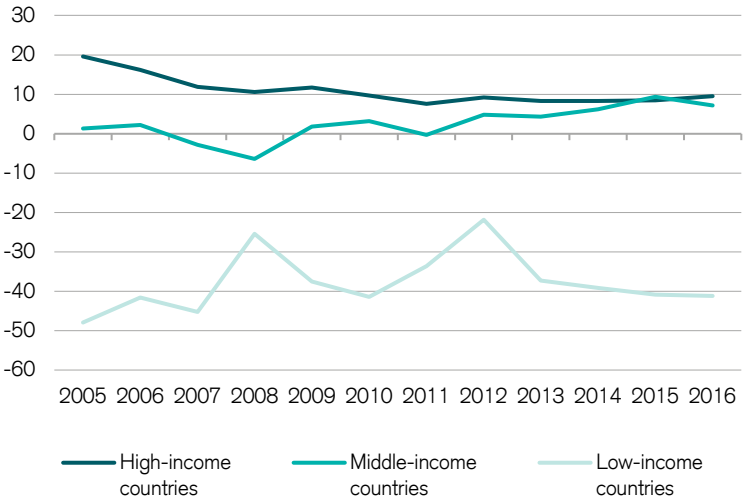
Source: FAO, Herforth, A., Bai, Y., Venkat, A., Mahrt, K., Ebel, A. & Masters, W.A. 2020. Cost and affordability of healthy diets across and within countries

Table 1: Government support appears strongest for sugar, rice and meat

Ten most incentivized products				Ten most taxed products			
	No. of countries	Weighted NRP	Unweighted NRP		No. of countries	Weighted NRP	Unweighted NRP
Sugar	27	19	29.9	Tomatoes	8	–2.2	0.8
Rice	36	17.6	39.8	Soybeans	13	–3.4	47.9
Poultry meat	35	15.4	64.7	Groundnuts	9	–3.5	1
Grapes	6	12.4	27.1	Cocoa beans	4	–5.4	–6
Pig meat	30	12.2	40.7	Sunflower seeds	8	–5.6	–3
Sheep meat	15	11.8	16.8	Palm oil	4	–7.2	–3.8
Bovine meat	38	11.8	21.6	Cashew nuts	4	–11.8	–6.3
Cassava	8	8.5	20.2	Sorghum	8	–21.3	–3.3
Rapeseed	6	6	23.8	Mango	4	–23.9	–8.7
Apples	6	4.5	15.5	Bananas	12	–32.5	–5.2

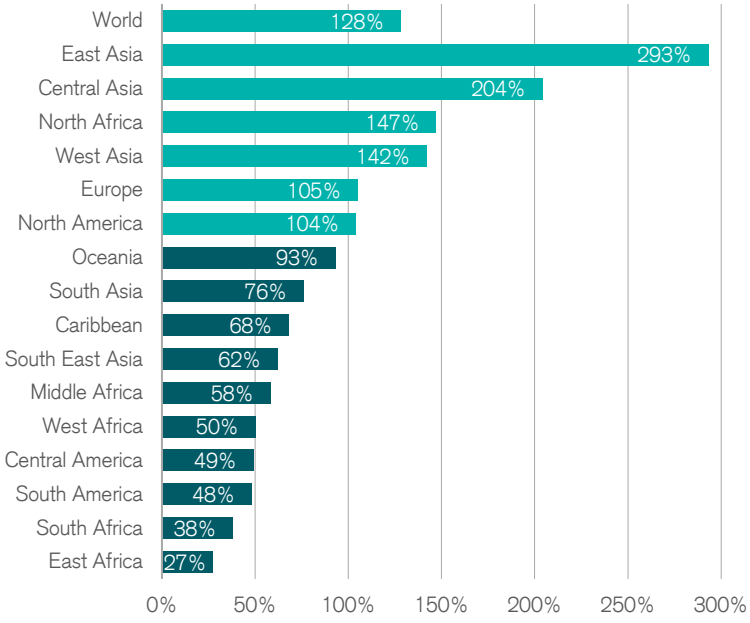
Source: Ag-Incentives. 2020. Nominal rate of protection. In: Ag-Incentives [online]. Washington, DC. [Cited 26 April 2020]

Figure 8: Agricultural production across low income countries is penalized while elsewhere it is supported



Source: IFPRI, AG-Incentives 2020, FAO

Figure 9: Vegetable supply per capita per day
Expressed as a percentage of a 300 gram recommendation; intake per capita is expected to be lower than supply.



Source: FAO, GAIN, Credit Suisse Research

Figures 8 and 9 suggest that the production of key food groups might be concentrated in only a few areas globally as this would create pricing power, which, combined with transportation costs, might be an explanation as to why healthy food is expensive in other areas. We have estimated the market share of food groups by country and our calculations seem to support this hypothesis. Using data from the FAO for 15 key food groups, we find that production of most of the key healthy food groups is concentrated in only a few countries. The countries that have the highest market shares across most of the 15 food categories are mainland China, India, the USA, Mexico, Indonesia and Brazil.
The analysis in this chapter shows that a change in what food is produced, what is eaten and how much is eaten is required to bring the global food system and human health on a more sustainable path. This would also have the benefit of substantial economic cost savings. However, a number of headwinds need to be addressed in order to achieve this goal, including the need for more regulation and, importantly, a rethink of the structure of the global agricultural sector.

> “
>
> A better alignment of government support and agricultural policies might help to make healthy food more affordable

Appendix 1: Assessing the economic costs of malnutrition

Our estimation of the global economic costs of malnutrition builds on available sources on the topic and merges them into a continuum. This includes bridging some gaps through additional assumptions and widening the scope to a larger number of countries. We express our estimates as an average yearly cost over the period 2020–35 in 2010 US dollars based on purchasing power parity (PPP).

Undernutrition

Our estimation of the economic costs of undernutrition is based on the research of Horton and Steckel (2013) for the Copenhagen Consensus on Human Challenges, who analyze the impact of poor nutrition over the 20th century with projections up to 2050 on a global scale. Given the lack of worldwide data on calorie availability and distribution over the past century as well as on the micronutrient status of children, the estimation approach builds on the relationship between body height and nutrition. Anthropometric studies show that individuals who are undernourished as young children tend to be underdeveloped as adults. Height is therefore a good indicator of long-run nutritional status. For this project, the authors assembled a database of adult heights from cohorts of males aged 18 or over since 1900 and developed a model of height and life expectancy to project height trends in the future. In a second step, they modeled the effects of nutrition as approximated by height on economic productivity and growth, with the impact being captured by the effects of height on wages. The resulting loss function of GDP with height finally allows computation of the annual loss in GDP associated with inadequate nutrition. For consistency with the estimate of the global impact of overweight, we based our calculation on the same GDP series and forecasts.

Overweight and obesity

To measure the economic cost of overweight, we drew on estimates from the Organisation for Economic Co-operation and Development (OECD), which quantify the effect of these forms of malnutrition on life expectancy, health expenditure and labor-market productivity (Cecchini and Vuik (2019)). The overall impact on the economy is expressed as the average yearly percentage loss of real GDP for 46 countries worldwide over the period 2020–50. The key idea of the OECD approach is to compare real GDP under the current conditions in terms of overweight prevalence with a counterfactual "non-overweight" GDP scenario. The model builds on the OECD real GDP forecasts, which are based on trend input components on efficiency, employment and the productive capital stock. For the counterfactual scenario, trend inputs are defined under the assumption that no overweight exists.

The difference between the two scenarios corresponds to the loss in GDP due to overweight. Since the OECD analysis only covers 46 countries, we had to expand the model to include the remaining world countries in order to assess the global cost of overweight. To do so, for each country not covered by the OECD analysis, we selected a proxy country, matching the most similar one from

the group of available countries. To find the best possible match, we used the following three dimensions: prevalence of overweight, geographical distance between countries weighted according to population densities, and development status, using data from the World Health Organization (WHO), the Centre d'Études Prospectives et d'Informations Internationales (CEPII) and the United Nations. With this approach, we were able to extend our analysis to 179 countries, an equivalent of approximately 98% of the world's population in 2019. With regard to the underlying GDP forecasts, we accounted for the impact of the COVID-19 pandemic assuming that the global economy will recover from the shock in 2021, albeit not fully returning GDP to pre-crisis levels.

Impact on the environment

To assess the impact of malnutrition on the environment, we drew on a study by Magkos et al. (2020), which calculates the extra CO2 emissions resulting from increased oxidative metabolism, increased food intake and increased fuel use in transportation for a person with obesity compared with a person of normal weight. To include all forms of malnutrition, we expanded the analysis to persons with overweight ($25 \leq BMI < 30$) and also took account of persons being underweight ($BMI < 18.5$). We inferred the total burden of malnutrition by using insights from the literature on nutrition and assumptions on average energy intake of a person belonging to the above-mentioned BMI categories. For the projection up to 2035, we made assumptions about future developments in the prevalence of underweight, overweight and obesity using data from the FAO and WHO.

To translate the extra carbon emissions into a cost measure, we put a price tag on them, drawing on the commonly used concept of social costs. This concept illustrates the economic cost of an additional ton of CO2 or the equivalent and is often used by policymakers, for instance, when determining the optimal level of carbon tax. The social cost not only depends on the potential damages resulting from an additional ton of CO2 emitted, but also on various assumptions about decision variables, including the discount rate, risk aversion and inter-generational inequality aversion. The wide range of estimates for social costs – ranging from single-digit USD figures to three hundredfold – reflects the uncertainties surrounding CO2 emissions, their costs to the climate and the choice of decision variables. Following Cai et al. (2016), we opted for average social costs of USD 186.8 per ton of CO2 equivalent (in 2010 US dollars) between 2020 and 2035, an estimate which includes the so-called "tipping points," i.e. irreversible changes in the Earth's climate systems, in the equation of potential damage. It is important to mention, nonetheless, that the estimate of Cai et al. (2016) does not include further large-scale second-round socioeconomic effects to climate change, such as conflicts, migration or the flight of capital investment. Therefore, our estimate can be regarded as a lower bound for actual social costs.

Appendix 2: Alternative food companies

Table 1: List of companies present in the alternative food sector

Cell culture products

Company	Main product	Country
Aleph Farms	Beef	Israel
Artemys Foods	Beef	USA
Avant Meats	Fish	Hong Kong
Biotech Foods	Pork	Spain
Biofood Systems	Beef	Israel
BlueNalu	Seafood	USA
Cell Farm Food Tech	Beef	Argentina
Clearmeat	Chicken	India
Cubiq foods	Fat	Spain
Finless Foods	Seafood	USA
Fork & Goode	Pork	USA
Future Meat Technologies	All meat	Israel
Gourmey	Foie gras	France
Higher Steaks	Pork	UK
Hoxton Farms	Fats	UK
Innocent Meat	Beef	Germany
Integriculture	Foie Gras	Japan
Eat Just	Chicken, beef, eggs	USA
Lab Farm Foods	Beef	USA
Meatable	Pork and beef	Netherlands
Meat Tech 3D	3D printed meat	Israel
Memphis meat	Beef, chicken, duck	USA
Mirai Foods	Beef	Switzerland
Mission Barns	Duck and pork fat	USA
Mosa Meat	Beef	Netherlands
Mzansi Meats	Antelope, beef	South Africa
New Age Meats	Pork	USA
Peace of Meat	Foie gras, duck fat	Belgium
Shiok Meats	Shrimp	Singapore
Supermeat	Chicken	Israel
Vow	Kangaroo	Australia
Wildtype	Salmon	USA

Plant-based companies

Company	Main product	Country
Alpha Foods	Cheese, chicken, beef	USA
Alchemy foodtech	Alchemy fiber	Singapore
The better meat co	Plant protein	USA
Beyond Meat	Beef, pork, chicken	USA
Perdue/Chicken plus	Chicken	USA
Climax foods	Plant-based cheese	USA
Daring foods	Chicken	USA
Impossible foods	Beef and pork	USA
Good Catch	Plant-based tuna	USA
Green Monday	Plant-based group	Hong Kong
The Meatless Farm	Plant-based food	UK
New Wave Foods	Shrimp	USA
No Evil Foods	Pork, chicken	USA
Novameat	Beef, pork, chicken	Spain
Noquo	Plant-based cheese	Sweden
Notco	Plant-based food	Chile
Parabel	Water-lentil based drinks	USA
Planted	Chicken	Switzerland
Rebbl	Herbal drinks	USA
Rebellyous Foods	Chicken nuggets	USA
Rebel Kitchen	Plant-based drinks	UK
Redefine meat	Steak	Israel
Simulate	Chicken	USA
This	Chicken, pork	UK
Veestro	Vegan meal delivery	USA
Zhenmeat	Pork, beef	China

Air fermentation protein

Company	Main product	Country
Air Protein	Air protein	USA
Deep Branch Biotech	Proton compound feed	UK
Novonutrients	Fish feed	USA
Solar Foods	Solein	Finland

Cell culture growth media

Company	Main product	Country
Back of the yards algae sciences	Algae-based media	USA
Biftek	Serum-free cell media	Turkey
Cultured Blood	Blood	Netherlands
Future Fields	Media	Canada
Heuros	Media	Australia
Luyef Biotechnologies	Media	Chile
Multus Media	Media	UK
Scinora	Media	Germany

Fermentation – dairy

Company	Main product	Country
Better Dairy	Cultivated dairy	UK
Biomilq	Cultivated human breast milk	USA
Califia Farms	Plant-based milk	USA
Legendairy foods	Cheese	Germany
New culture	Cheese	USA
Perfect day	Dairy proteins	USA
Turtletree labs	Human breast milk	Singapore

Ingredients

Company	Main product	Country
Afineur	Proteins	USA
Arzeda	Proteins	USA
Bioscienz	Egg proteins, pesticide alternatives	Netherlands
Clara Foods	Eggs	USA
Geltor	Collagen	USA
Motif Foodworks	Proteins, cheese	USA
Puris	Pea protein	USA
Ripple food	Pea-based dairy alternative	USA
The Protein Brewery	Fermotein	Netherlands

Bioreactors/ 3D cell culture support

Company	Main product	Country
Applikon Biotechnology	Bioreactors	Netherlands
Atlast Food	Bioreactors	USA
Biocellion	Biomodelling	USA
Biomimetic solutions	Bioreactors	UK
Celltainer Biotech	Bioreactors	Netherlands
Cellularrevolution	Peptide coating, biorector design	UK
Cellular Agriculture	Bioreactors	UK
Corning life sciences	Biotech equipment	USA
Incuvers	Incubators	Canada
Kerafast	Reagents	USA
Kuhner shaker	Industrial shakers	Germany
Matrix meats	Scaffolding	USA
Merck Millipore	Bioreactors	USA
Ospin	Modular bioprocessing	Germany
Sartorius	Biopharmaceutical equipment	Germany
Sunp biotech	3D printers	USA
Thermo Fisher Scientific	Biopharmaceuticals	USA
Vivex bio	3D bioprinting	USA

Cell cultured pet food

Company	Main product	Country
Bond Pet Foods	Chicken	USA
Because Animals	Mouse	USA
Hownd	Pet care, dog treats	UK
Wild Earth	Dog food	USA

Biofabrics

Company	Main product	Country
Ananas Anam	Plant-based leather alternative	UK
Bolt Threads	Mycelium materials	USA
Ecovative design	Mycelium replacement for plastic	USA
Furoid	Cell-based fur, wool	Netherlands
Galy	Cotton	USA
Modern Meadow	Leather	USA
Mycoworks	Mycelium leather	USA
Spiber	Synthetic protein materials	Japan
Vitrolabs	Leather	USA

Source: Moo's law, Credit Suisse Research

Photo: GettyImages, Evgeniia Siiankovskaia

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Eugène Klerk is a Managing Director of Credit Suisse in the Securities Research Division, based in London.

Following a career of more than 20 years in investment banking, fund management and research, he is currently responsible for Credit Suisse's Global ESG research product. Prior to this, Eugene was responsible for the firm's Global Thematic Research and European Small and Mid-Cap Research. In addition, Eugene is a frequent leading author in a range of publications from the Credit Suisse Research Institute.

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