



Installment 11 of “Creating a Sustainable Food Future”

# SHIFTING DIETS FOR A SUSTAINABLE FOOD FUTURE

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## SUMMARY

How can shifting diets—the type, combination, and quantity of foods people consume—contribute to a sustainable food future? Building on the United Nations Food and Agriculture Organization’s (FAO) food demand projections, we estimate that the world needs to close a 70 percent “food gap” between the crop calories available in 2006 and expected calorie demand in 2050.

The food gap stems primarily from population growth and changing diets. The global population is projected to grow to nearly 10 billion people by 2050, with two-thirds of those people projected to live in cities. In addition, at least 3 billion people are expected to join the global middle class by 2030. As nations urbanize and citizens become wealthier, people generally increase their calorie intake and the share of resource-intensive foods—such as meats and dairy—in their diets. At the same time, technological advances, business and economic changes, and government policies are transforming entire food chains, from farm to fork. Multinational businesses are increasingly influencing what is grown and what people eat. Together, these trends are driving a convergence toward Western-style diets, which are high in calories, protein, and animal-based foods. Although some of this shift reflects health and welfare gains for many people, the scale of this convergence in diets will make it harder for the world to achieve several of the United Nations Sustainable Development Goals, including those on hunger, healthy lives, water management, climate change, and terrestrial ecosystems.

Note: All dollars are US dollars. All tons are metric tons (1,000 kg). “GHG” = greenhouse gas. “CO<sub>2</sub>e” = carbon dioxide equivalent. “Kcal” = kilocalorie, also referred to as simply “calorie.”

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*Working Papers contain preliminary research, analysis, findings, and recommendations. They are circulated to stimulate timely discussion and critical feedback, and to influence ongoing debate on emerging issues. Working papers may eventually be published in another form and their content may be revised.*

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Efforts to close the food gap have typically focused on increasing agricultural production. However, relying solely on increased production to close the gap would exert pressure to clear additional natural ecosystems. For example, to increase food production by 70 percent while avoiding further expansion of harvested area, crop yields would need to grow one-third more quickly than they did during the Green Revolution. In short, yield increases alone will likely be insufficient to close the gap.

To help provide a more holistic approach, the World Resources Report, *Creating a Sustainable Food Future*, and a series of accompanying working papers propose a menu of production- and consumption-based solutions. In this paper, the last in the series, we assess the role of one consumption-based solution: shifting the diets of populations who consume high amounts of calories, protein, and animal-based foods. Specifically, we consider three interconnected diet shifts:

1. Reduce overconsumption of calories.
2. Reduce overconsumption of protein by reducing consumption of animal-based foods.
3. Reduce consumption of beef specifically.

For each shift, we describe the issue it addresses, why it matters, and the relevant trends. We use the GlobAgri model to quantify the land use and greenhouse gas consequences of different foods, and then analyze the per person and global effects of the three diet shifts on agricultural land needs and greenhouse gas emissions. We find that these diet shifts—if implemented at a large scale—can close the food gap by up to 30 percent, while substantially reducing agriculture’s resource use and environmental impacts. With the food industry in mind—particularly the retail and food service sectors—we introduce the Shift Wheel, a framework that harnesses marketing and behavioral change strategies to tackle the crucial question of how to shift people’s diets. We conclude with four recommendations to help shift diets and apply the Shift Wheel.

## What are the trends in calorie consumption and why do they matter?

There is a global trend toward overconsumption of calories, even though many people around the world remain hungry. In 2009, per capita calorie consumption exceeded average daily energy requirements in regions containing half of the world’s population. Globally, there are now two-and-a-half times more overweight than undernourished people. More than one in three adults are overweight. While per person calorie availability may be peaking in developed countries, it is rising across the developing world, particularly in emerging economies like China and Brazil. Once considered a high-income-country problem, the numbers of obese or overweight people are now rising in low- and middle-income countries, especially in urban areas.

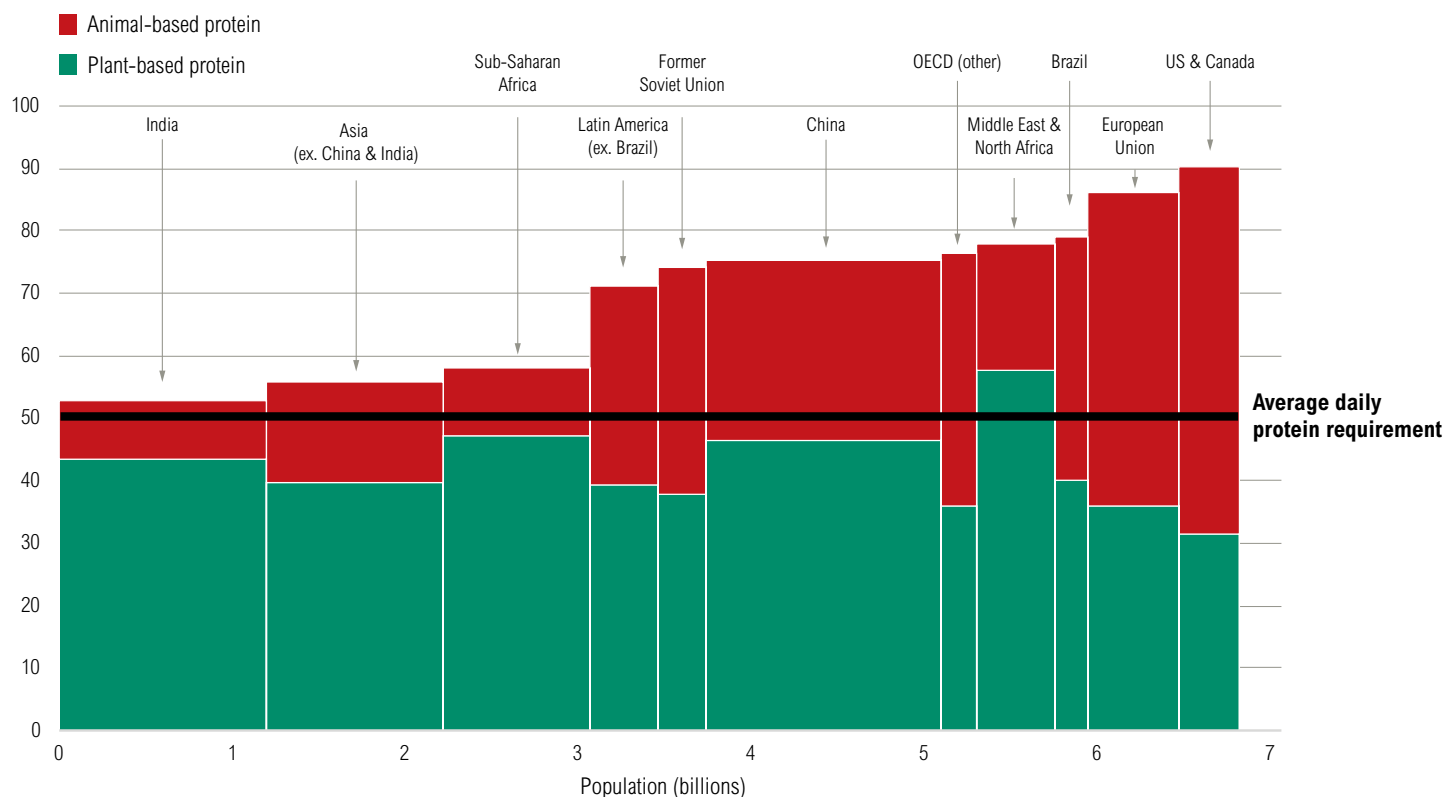
Overconsumption of calories widens the food gap and drives unnecessary use of agriculture inputs and unnecessary environmental impacts. It also contributes to people becoming overweight and obese, harming human health and contributing to rising healthcare costs and lost productivity. The related economic and healthcare costs are enormous. For example, the global economic cost of obesity was estimated to be around \$2 trillion in 2012, roughly equivalent to the global cost of armed conflict or smoking.

## What are the trends in protein consumption and why do they matter?

Overconsumption of protein occurs in all of the world’s regions, and it is rising in developing and emerging economies. In 2009, the average person in more than 90 percent of the world’s countries and territories consumed more protein than estimated requirements. Global average protein consumption was approximately 68 grams per person per day—or more than one-third higher than the average daily adult requirement. In the world’s wealthiest regions, protein consumption was higher still (Figure ES-1).

In addition, the share of animal-based protein is growing in people’s diets relative to that of plant-based protein. Between 1961 and 2009, global average per person availability of animal-based protein grew by 59 percent, while that of plant-based protein grew by only 14 percent. Looking forward, total consumption of animal-based food is expected to rise by nearly 80 percent between 2006

Figure ES-1 | **Protein Consumption Exceeds Average Estimated Daily Requirements in All the World's Regions, and is Highest in Developed Countries**  
g/capita/day, 2009



Source: GlobAgri model with source data from FAO (2015) and FAO (2011a). Width of bars is proportional to each region's population. Average daily protein requirement of 50 g/day is based on an average adult body weight of 62 kg (Walpole et al. 2012) and recommended protein intake of 0.8 g/kg body weight/day (Paul 1989). Individuals' energy requirements vary depending on age, gender, height, weight, pregnancy/lactation, and level of physical activity.

and 2050. Although per person animal-based food consumption may be peaking in developed countries where consumption is already high, it is projected to rise in developing countries, especially in emerging economies and in urban areas.

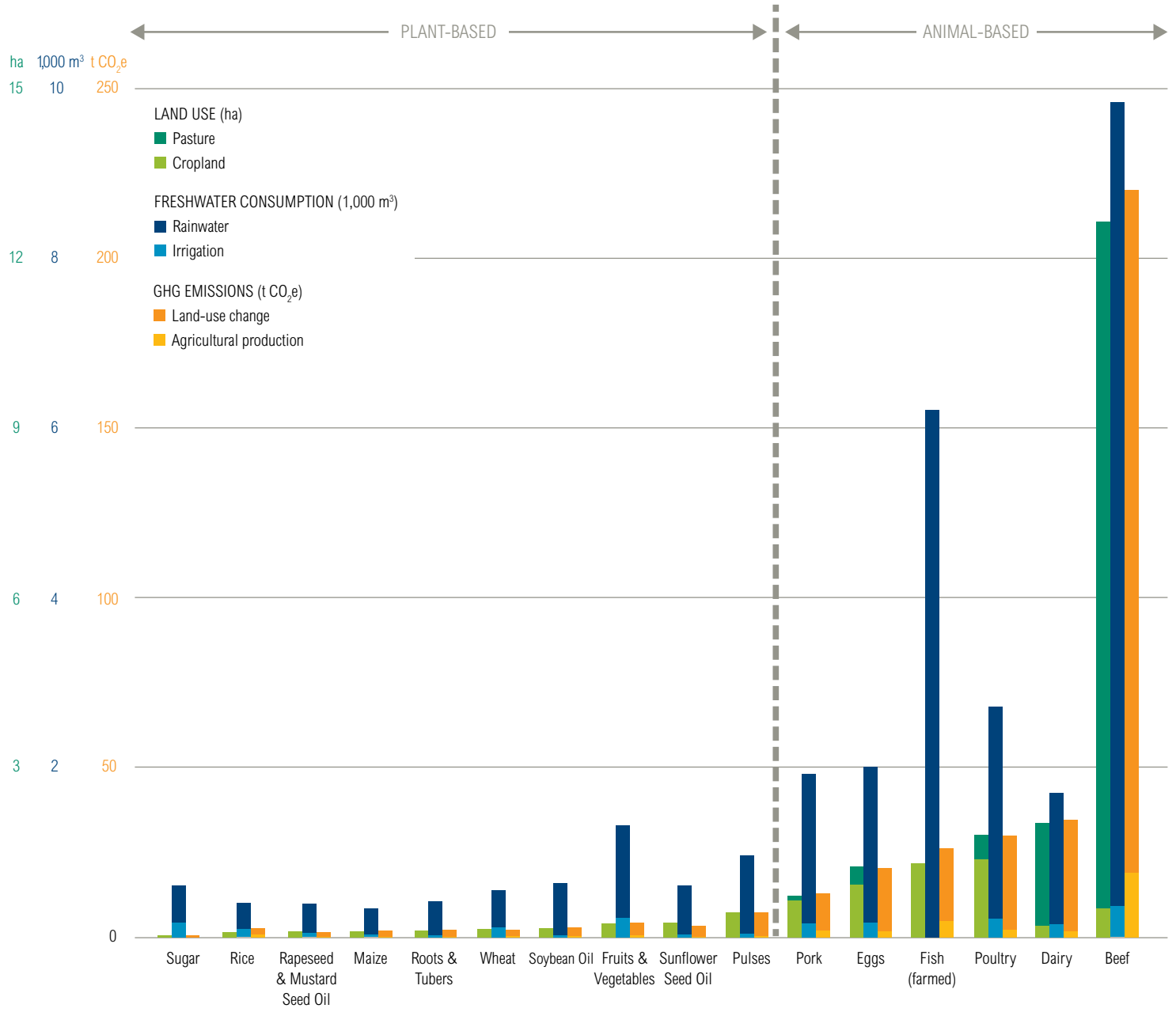
Like overconsumption of calories, overconsumption of protein widens the food gap. Furthermore, animal-based foods are typically more resource-intensive and environmentally impactful to produce than plant-based foods (Figure ES-2). Production of animal-based foods accounted for more than three-quarters of global agricultural land use and around two-thirds of agriculture's production-related greenhouse gas emissions in 2009, while only contributing 37 percent of total protein consumed by people in that year. Because many animal-based foods rely on crops for feed, increased demand for animal-based foods widens the food gap relative to increased demand for plant-based foods.

### What are the trends in beef consumption and why do they matter?

Beef consumption is rising in emerging economies and is showing signs of peaking in some developed countries. In Brazil, per person beef availability (and probably consumption) has increased steadily over the past decades, and is now more than three times the world average, having surpassed the United States in 2008. In China, per person beef availability is still only half of the world average, but is growing. In India, growing demand for dairy products is spurring an expansion in the cattle population, although beef consumption remains low. In the United States, per person annual beef consumption has declined 27 percent since the 1970s. Global demand for beef is projected to increase by 95 percent between 2006 and 2050, with much of this growth in countries where current per person consumption is low, such as China and India.

Figure ES-2 | **Production of Animal-Based Foods is Generally More Impactful on the Planet than Plant-Based Foods**

**PER MILLION KILOCALORIES CONSUMED**

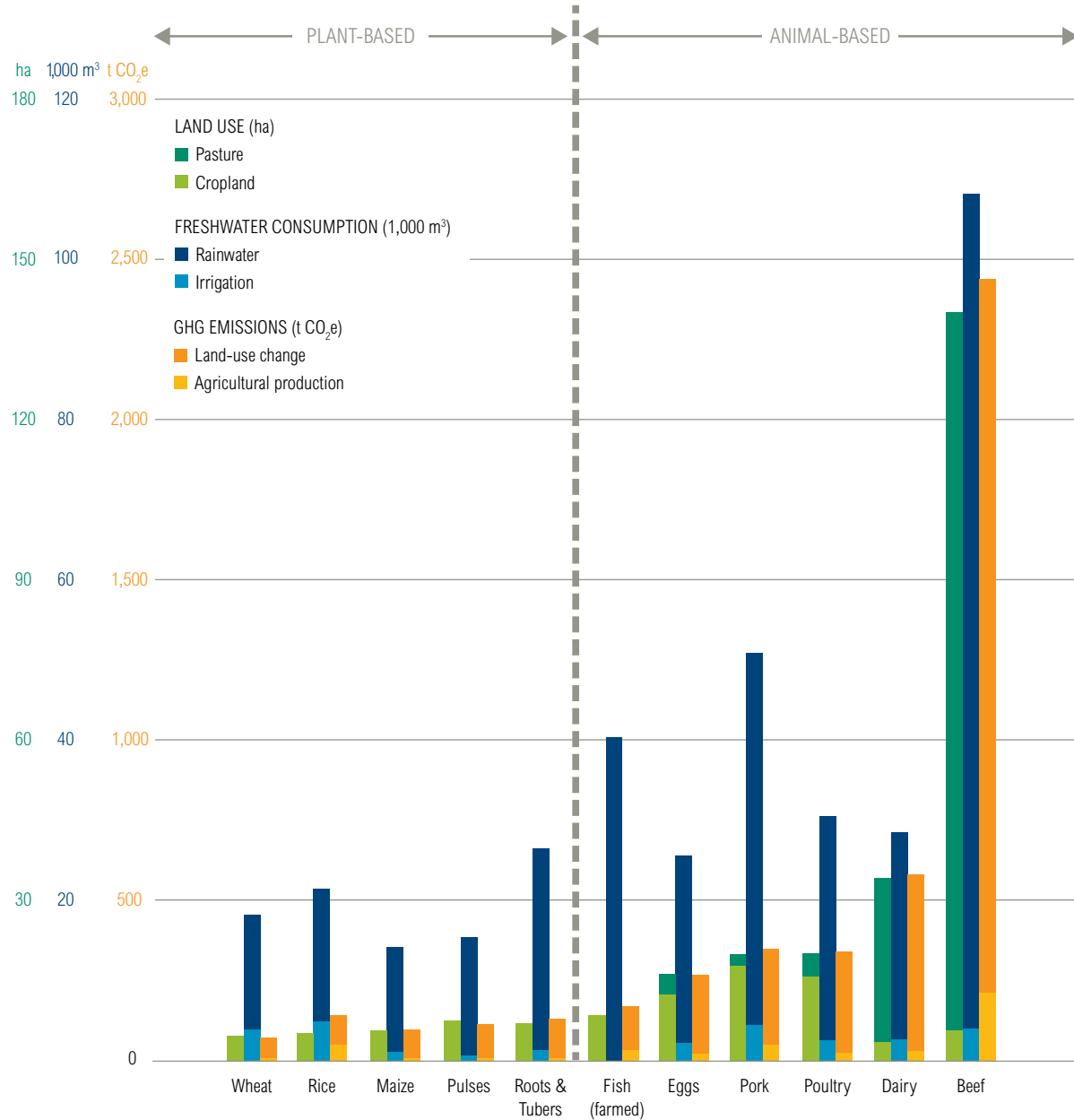


Sources: GlobAgri model (land use and greenhouse gas emissions), authors' calculations from Mekonnen and Hoekstra (2011, 2012) (freshwater consumption), and Waite et al. (2014) (farmed fish freshwater consumption).

Notes: Data presented are global means. Entries are ordered left to right by amount of total land use. Indicators for animal-based foods include resource use to produce feed, including pasture. Tons of harvested products were converted to quantities of calories and protein using the global average edible calorie and protein contents of food types as reported in FAO (2015). "Fish" includes all aquatic animal products. Freshwater use for farmed fish products is shown as rainwater and irrigation combined. Land use and greenhouse gas emissions estimates are based on a marginal analysis (i.e., additional agricultural land use and emissions per additional million calories or ton of protein consumed). Based on the approach taken by the European Union for estimating emissions from land-use change for biofuels, land-use change impacts are amortized over a period of 20 years and then shown as annual impacts. Land use and greenhouse gas emissions estimates for beef production are based on dedicated beef production, not beef that is a coproduct of dairy. Dairy figures are lower in GlobAgri than some other models because GlobAgri assumes that beef produced by dairy systems displaces beef produced by dedicated beef-production systems.

Figure ES-2 | **Production of Animal-Based Foods is Generally More Impactful on the Planet than Plant-Based Foods (continued)**

**PER TON PROTEIN CONSUMED**



Sources: GlobAgri model (land use and greenhouse gas emissions), authors' calculations from Mekonnen and Hoekstra (2011, 2012) (freshwater consumption), and Waite et al. (2014) (farmed fish freshwater consumption).

Notes: Data presented are global means. Entries are ordered left to right by amount of total land use. Indicators for animal-based foods include resource use to produce feed, including pasture. Tons of harvested products were converted to quantities of calories and protein using the global average edible calorie and protein contents of food types as reported in FAO (2015). "Fish" includes all aquatic animal products. Freshwater use for farmed fish products is shown as rainwater and irrigation combined. Land use and greenhouse gas emissions estimates are based on a marginal analysis (i.e., additional agricultural land use and emissions per additional million calories or ton of protein consumed). Based on the approach taken by the European Union for estimating emissions from land-use change for biofuels, land-use change impacts are amortized over a period of 20 years and then shown as annual impacts. Land use and greenhouse gas emissions estimates for beef production are based on dedicated beef production, not beef that is a coproduct of dairy. Dairy figures are lower in GlobAgri than some other models because GlobAgri assumes that beef produced by dairy systems displaces beef produced by dedicated beef-production systems.

Beef is one of the least efficient foods to produce when considered from a “feed input to food output” perspective. When accounting for all feeds, including both crops and forages, by one estimate only 1 percent of gross cattle feed calories and 4 percent of ingested protein are converted to human-edible calories and protein, respectively. In comparison, by this estimate, poultry convert 11 percent of feed calories and 20 percent of feed protein into human-edible calories and protein. Because of this low conversion efficiency, beef uses more land and freshwater and generates more greenhouse gas emissions per unit of protein than any other commonly consumed food (Figure ES-2).

At the global level, beef production is a major driver of agricultural resource use. One-quarter of the Earth’s landmass, excluding Antarctica, is used as pasture, and beef accounts for one-third of the global water footprint of farm animal production. Although some beef production uses native pasture, increases in beef production now rely on clearing forests and woody savannas. Ruminants, of which beef is the most commonly produced and consumed, are responsible for nearly half of greenhouse gas emissions from agricultural production. Given the environmental implications of rising demand for beef, reducing its consumption will likely be an important element to limiting the rise of global temperatures to 1.5 or 2 degrees Celsius, in line with international goals.

Table ES-1 | **Diet Shifts and Scenarios Modeled in this Paper**

SCENARIO NAME	SCENARIO DESCRIPTION	AFFECTED POPULATION (MILLIONS), 2009
<b>DIET SHIFT 1: Reduce overconsumption of calories</b>		
Eliminate Obesity and Halve Overweight	Recognizing that reducing overconsumption of calories can contribute to reducing overweight and obesity, this scenario eliminates obesity and halves the number of overweight people by reducing calorie consumption across all foods.	1,385
Halve Obesity and Halve Overweight	Similar to the above scenario, this scenario halves the number of obese and overweight people.	1,046
<b>DIET SHIFT 2: Reduce overconsumption of protein by reducing consumption of animal-based foods</b>		
Ambitious Animal Protein Reduction	In regions that consumed more than 60 grams of protein (from animal and plant sources combined) and more than 2,500 calories per person per day, protein consumption was reduced to 60 grams per person per day by reducing animal-based protein consumption (across all animal-based foods). Overall, global animal-based protein consumption was reduced by 17 percent.	1,907
Traditional Mediterranean Diet	In regions that consumed more than 40 grams of animal-based protein and more than 2,500 calories per person per day, half of the population was shifted to the actual average diet of Spain and Greece in 1980. Overall calorie consumption was held constant.	437
Vegetarian Diet	In regions that consumed more than 40 grams of animal-based protein and more than 2,500 calories per person per day, half of the population was shifted to the actual vegetarian diet as observed in the United Kingdom in the 1990s. Overall calorie consumption was held constant.	437
<b>DIET SHIFT 3: Reduce beef consumption specifically</b>		
Ambitious Beef Reduction	In regions where daily per person beef consumption was above the world average and daily per person calorie consumption was above 2,500 per day, beef consumption was reduced to the world average level. Overall, global beef consumption was reduced by 30 percent.	1,463
Shift from Beef to Pork and Poultry	In regions where daily per person beef consumption was above the world average, beef consumption was reduced by one-third and replaced by pork and poultry. Overall calorie consumption was held constant.	1,952
Shift from Beef to Legumes	In regions where daily per person beef consumption was above the world average, beef consumption was reduced by one-third and replaced with pulses and soy. Overall calorie consumption was held constant.	1,952

## What would be the effects of applying the three diet shifts to high-consuming populations?

Shifting the diets of high-consuming populations could significantly reduce agricultural resource use and environmental impacts. We used the GlobAgri model to analyze the effects of the three diet shifts on agricultural land use and greenhouse gas emissions in 2009. For each of the three shifts, we developed alternative diet scenarios, ranging from “realistic” to “ambitious” (Table ES-1). In each scenario, we assumed that crop and livestock yields and trade patterns remained constant at actual 2009 levels. We altered food consumption levels among the world’s high-consuming populations, but did not alter the diets of the world’s less wealthy. None of the scenarios sought to turn everyone into a vegetarian.

We conducted two types of analysis using 2009 food consumption data:

- First, we quantified the per person effects of applying the diet scenarios in Table ES-1 to the consumption pattern of a high-consuming country—the United States (Figure ES-3). This analysis shows how, among high-consuming populations, the three diet shifts could significantly reduce per person agricultural land use and greenhouse gas emissions.
- Second, we quantified the global effects of applying the diet scenarios to people currently overconsuming calories or protein, or who are high consumers of beef, to show the aggregate effects of the diet shifts across large populations. The scenarios affected the diets of between 440 million and 2 billion people (Figure ES-4).

Highlights of the results are summarized below.

The agricultural land use and greenhouse gas emissions associated with the average American diet were nearly double those associated with the average world diet, with 80 to 90 percent of the impacts from consumption of animal-based foods.

We found that producing the food for the average American diet in 2009 required nearly one hectare of agricultural land, and emitted 1.4 tons of carbon dioxide equivalent (CO<sub>2</sub>e), before accounting for emissions from land-use change. These amounts of land use and greenhouse gas emissions were nearly double those associated with the average world diet that year (Figure ES-3). Animal-based foods (shown in red, orange, and yellow in Figure ES-3) accounted for nearly 85 percent of the production-related greenhouse gas emissions and nearly 90 percent of agricultural land use. Beef consumption alone (shown in red) accounted for nearly half of the US diet-related agricultural land use and greenhouse gas emissions.

Furthermore, factoring land-use implications into agricultural greenhouse gas emissions estimates shows a fuller picture of the consequences of people’s dietary choices. For example, if an additional person eating the average American diet were added to the world population in 2009, the one-time emissions resulting from converting a hectare of land to agriculture to feed that person would be about 300 tons of CO<sub>2</sub>e. This amount is equal to 17 times the average US per person energy-related carbon dioxide emissions in 2009. In other words, the emissions from clearing additional land to feed an additional person eating the US diet are equal to 17 years’ worth of an average American’s energy-related CO<sub>2</sub> emissions.

Shifting the diets of high consumers of animal-based foods could significantly reduce per person agricultural land use and greenhouse gas emissions.

When applied to the average American diet in 2009, the *Ambitious Animal Protein Reduction* and *Vegetarian Diet* scenarios reduced per person land use and agricultural greenhouse gas emissions by around one-half—or down to around world average. The three scenarios that reduced consumption of beef—just one food type—reduced per person land use and greenhouse gas emissions by 15 to 35 percent. Figure ES-3 shows the effects of the three diet shifts on per person agricultural land use and greenhouse gas emissions when applied to the average American diet.



Figure ES-3 | **Shifting the Diets of High Consumers of Animal-Based Foods Could Significantly Reduce Per Person Agricultural Land Use and GHG Emissions**  
per capita values, 2009



Source: GlobAgri model.

Note: All "US" data are for United States and Canada. Land-use change emissions are amortized over a period of 20 years and then shown as annual impacts. Calculations assume global average efficiencies (calories produced per hectare or per ton of CO<sub>2</sub>e emitted) for all food types. "Other animal-based foods" includes pork, poultry, eggs, fish (aquatic animals), sheep, and goat.



**Figure ES-3 | Shifting the Diets of High Consumers of Animal-Based Foods Could Significantly Reduce Per Person Agricultural Land Use and GHG Emissions (continued)**  
per capita values, 2009



Source: GlobAgri model.

Note: All "US" data are for United States and Canada. Land-use change emissions are amortized over a period of 20 years and then shown as annual impacts. Calculations assume global average efficiencies (calories produced per hectare or per ton of CO<sub>2</sub>e emitted) for all food types. "Other animal-based foods" includes pork, poultry, eggs, fish (aquatic animals), sheep, and goat. The vegetarian diet scenario, which uses data from Scarborough et al. (2014), includes small amounts of meat, as "vegetarians" were self-reported.

Reducing animal-based food consumption results in significant savings in global agricultural land use.

When applied globally to populations overconsuming calories or protein, or who are high consumers of beef, the diet scenarios could spare between 90 million and 640 million hectares of agricultural land. The *Ambitious Animal Protein Reduction* scenario—which shifted the diets of nearly 2 billion people in 2009—spared 640 million hectares of agricultural land, including more than 500 million hectares of pasture and 130 million hectares of cropland. This area of land is roughly twice the size of India, and is also larger than the entire area of agricultural expansion that occurred globally over the past five decades. Notably, the *Ambitious Beef Reduction* scenario spared roughly 300 million hectares of pasture—an amount similar to the entire area of pasture converted from other lands since 1961.

These results suggest that reducing consumption of animal-based foods among the world’s wealthier populations could enable the world to adequately feed 10 billion people by 2050 without further agricultural expansion. Curbing agricultural expansion would also avoid future greenhouse gas emissions from land-use change. The *Ambitious Animal Protein Reduction* scenario, which spared the most land, could avoid 168 billion tons of emissions of CO<sub>2</sub>e from land-use change. To put this reduction in perspective, global greenhouse gas emissions in 2009 were 44 billion tons CO<sub>2</sub>e. Figure ES-4 shows the global effects of the three diet shifts on agricultural land use in 2009.

All three diet shifts could contribute to a sustainable food future, but the two shifts that reduce consumption of animal-based foods result in the largest land use and greenhouse gas reductions.

Our analysis of the three diet shifts, summarized in Figures ES-3 and ES-4, yields the following insights:

- 1. REDUCE OVERCONSUMPTION OF CALORIES.** While reducing overweight and obesity is important for human health, this diet shift contributed less to reducing agriculture’s resource use and environmental impacts than the other two shifts.
- 2. REDUCE OVERCONSUMPTION OF PROTEIN BY REDUCING CONSUMPTION OF ANIMAL-BASED FOODS.** This diet shift resulted in the largest benefits, as it applied to a relatively large population and across all animal-based foods.
- 3. REDUCE BEEF CONSUMPTION SPECIFICALLY.** This diet shift resulted in significant benefits, and would be relatively easy to implement, since it only affects one type of food. Additionally, some high-consuming countries have already reduced per person beef consumption from historical highs, suggesting that further change is possible.

The diet shifts can also help close the gap between crop calories available in 2006 and those demanded in 2050. With a projected 25 percent of all crops (measured by calories) dedicated to animal feed in 2050, we calculate that the *Ambitious Animal Protein Reduction* scenario could reduce the food gap by 30 percent—significantly reducing the challenge of sustainably feeding nearly 10 billion people by mid-century.

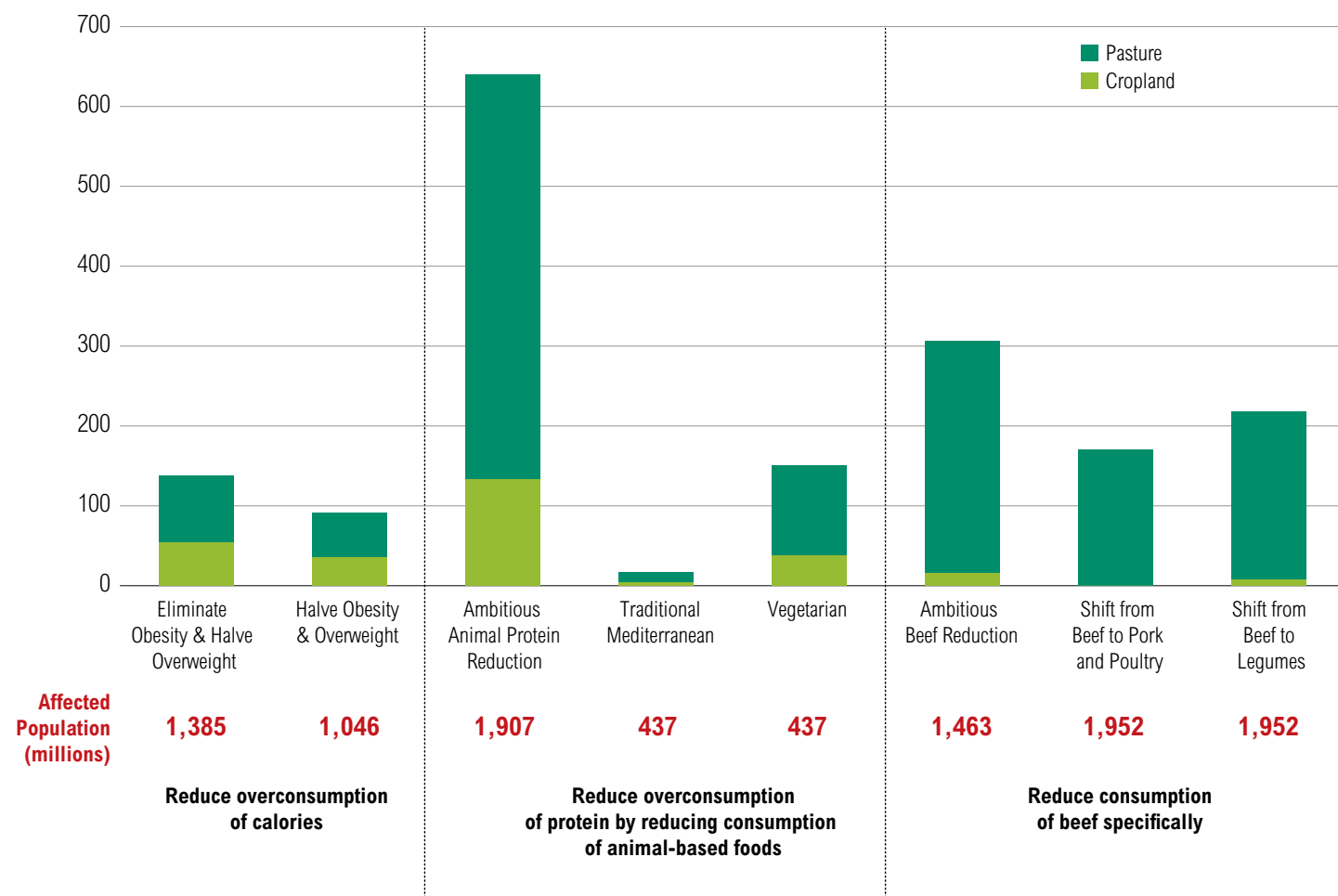
### Will the diet shifts adversely impact poor food producers and consumers?

The diet shifts do not call for the world’s poor to reduce consumption, and they preserve an abundant role for small livestock farmers. The three shifts target populations who are currently overconsuming calories or protein, or are high consumers of beef—or are projected to be by 2050. They do not target undernourished or malnourished populations. Nor do they aim to eliminate the livestock sector, which provides livelihoods to millions of poor smallholders, makes productive use of the world’s native grazing lands, and generates 40 percent of global agricultural income. Indeed, solutions to sustainably increase crop and livestock productivity are also critical to closing the food gap, and are covered in the *Interim Findings of Creating a Sustainable Food Future*.

### Would reducing beef consumption result in productive pastureland going to waste?

Reducing beef consumption is unlikely to result in “wasted” pastureland for two reasons. First, beef demand is projected to nearly double between 2006 and 2050, and pasture is likely to remain the dominant source of feed. Even with increased pasture productivity, it will be difficult to meet projected growth in demand without clearing more natural forests and savannas for pasture. Our beef

Figure ES-4 | **Reducing Animal-Based Food Consumption Results in Significant Savings in Global Agricultural Land Use**  
 millions of hectares saved relative to world reference, 2009



Source: GlobAgri model.

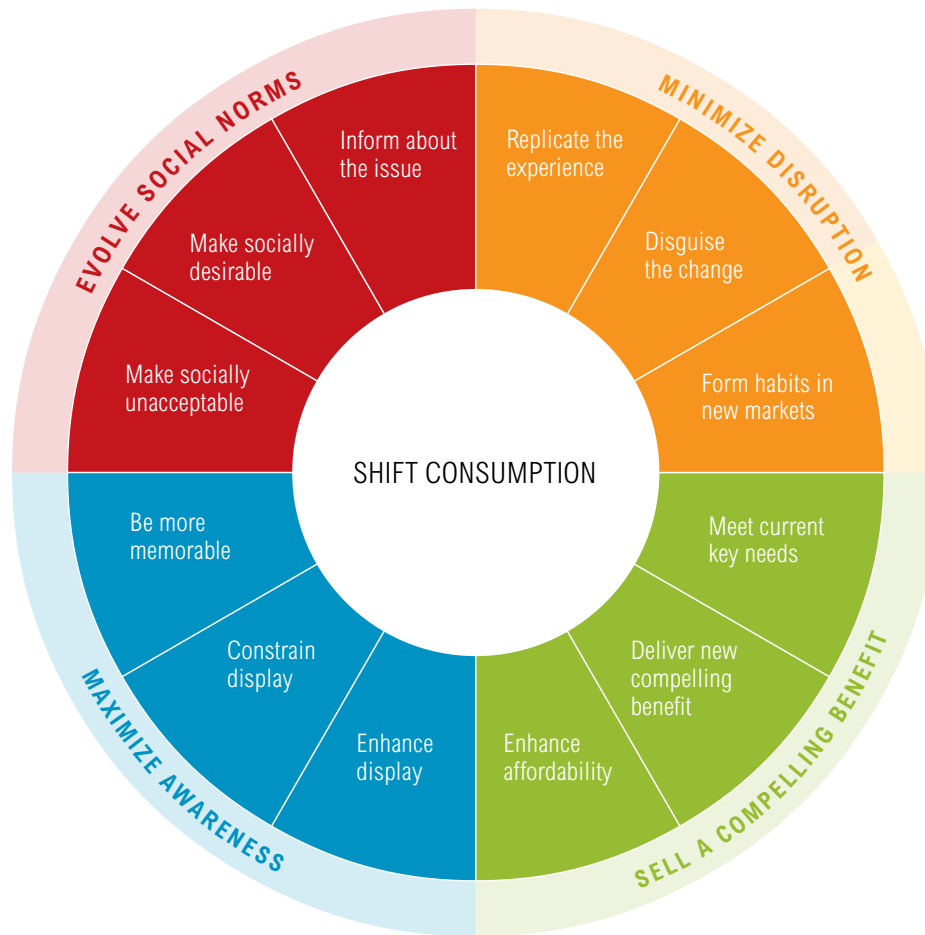
Note: The Shift from Beef to Pork and Poultry scenario includes a 196 Mha decrease in pasture, but a 26 Mha increase in cropland, for an overall 170 Mha "savings."

reduction scenarios do not eliminate beef consumption, but just reduce it. Given the projected growth in beef consumption, the proposed diet shifts are unlikely to reduce beef's global land use below today's levels. Accordingly, "reducing beef consumption" is about preventing further expansion, not creating a surplus of unused or "wasted" pastureland. Second, because native grazing land has few alternative uses, it is nearly always used for grazing. Even if there were large enough reductions in beef consumption to reduce total pasture area, the result would not be to stop grazing of native pasturelands but instead to free up lands that were naturally wooded and that are wet enough to meet the growing demand for crops or for regenerating forests.

### What can be done to shift people's diets?

There is no silver bullet solution. To date, efforts to encourage more sustainable eating have largely focused on consumer education, back-of-the-package labeling, and campaigns around abstinence (e.g., vegetarianism), with limited success. A more holistic approach is needed that works in step with how consumers make purchasing decisions. Purchases are typically based on habit and unconscious mental processing rather than on rational, informed decisions. Furthermore, attributes like price, taste, and quality tend to be more important than sustainability in purchasing decisions. Strategies that influence these factors and engage actors in food value

Figure ES-5 | **The Shift Wheel Comprises Four Strategies to Shift Consumption**



Source: Authors.

chains (e.g., food manufacturing companies, food service companies, supermarkets) are needed. The multinational businesses that are increasingly influencing consumers’ choices across the globe can play an important role in shifting consumers to more sustainable diets.

To help shift people’s diets, we propose a new framework based on proven private sector marketing tactics: the Shift Wheel (Figure ES-5). The development of the Shift Wheel was informed by a range of consumption shifts already successfully orchestrated by industry, nongovernmental organizations (NGOs), and government. These include shifts such as from caged to free-range eggs in the United Kingdom, from higher- to lower-alcohol beer in the United Kingdom, and away from shark fin in China.

The Shift Wheel comprises four complementary strategies:

- **MINIMIZE DISRUPTION.** Changing food consumption behavior typically involves changing ingrained habits. This strategy seeks to minimize the disruption to consumers’ habits caused by the shift. It can include minimizing changes associated with the shift, such as taste, look, texture, smell, packaging, and the product’s location within a store.
- **SELL A COMPELLING BENEFIT.** Selling a compelling benefit requires identifying and delivering product attributes (such as health or affordability) that will be sufficiently motivating to the consumer to stimulate a behavior change. As plant-based proteins can be less expensive than animal-based ones, companies may have an opportunity to sell reformulated products with a greater share of plant-based ingredients at a lower price and/or an increased profit.

- **MAXIMIZE AWARENESS.** The more consumers see or think of a product, the greater the chance they will consider purchasing it. Enhancing the availability and display of the more sustainable food choice, and creating memorable advertising campaigns, can increase a product's visibility and the chance that consumers will purchase it.
- **EVOLVE SOCIAL NORMS.** What people eat is highly influenced by cultural environment and social norms. Informing and educating consumers, along with efforts to make the preferred food more socially desirable or the food to be shifted from less socially desirable, can influence or change the underlying social and cultural norms that underlie people's purchasing decisions.

How can the Shift Wheel be applied to shift diets? The first step is to analyze the landscape of animal- and plant-based food consumption in a given geography or market. Who are the consumers? What are they eating? Where, when, why, and how is this consumption occurring? The answers to these questions will help identify the most promising intervention points. This might be a specific occasion (e.g., family evening meals), a product format (e.g., meatballs), a social perception (e.g., that plant-based protein is inferior to meat), a demographic group (e.g., millennials), or specific outlets (e.g., school or workplace cafeterias). The next step is to design approaches to achieve the chosen shift, drawing on relevant strategies from the Shift Wheel. The final steps are to test the selected approaches and scale up successes.

## What actions are needed to apply the Shift Wheel and shift diets?

We offer four recommendations to help the food industry apply the Shift Wheel and shift diets:

- **SET TARGETS, APPLY THE SHIFT WHEEL, LEARN FROM THE RESULTS, AND SCALE UP SUCCESSES**  
Companies and governments should set quantifiable targets to reduce the consumption of animal-based protein and beef specifically. They should use the Shift Wheel to drive progress toward these targets.
- **ENSURE GOVERNMENT POLICIES ARE ALIGNED WITH PROMOTING SUSTAINABLE DIET CHOICES**  
Governments should ensure coherence among agriculture, health, water, and environmental policies in relation to promoting sustainable diets.
- **INCREASE FUNDING FOR EFFORTS TARGETED AT SHIFTING DIETS**  
Governments and foundations should create funding mechanisms to support the development, testing, and rollout of evidence-based strategies to shift diets.
- **CREATE A NEW INITIATIVE FOCUSED ON TESTING AND SCALING UP STRATEGIES TO SHIFT DIETS**  
A new initiative should be established to apply the Shift Wheel to specific contexts and catalyze new approaches to shifting diets. Such an initiative could conduct pilot tests, build an evidence base, measure behavior change and its impacts on people and the environment, and share and scale up successes. Its goal should be to increase the share of plant-based protein in diets and reduce the consumption of beef specifically.

## DIET MATTERS ON THE MENU

What we eat has a profound impact on our own health and the planet's health. In the World Resources Report's *Creating a Sustainable Food Future: Interim Findings* (Box 1), we describe how the world food system faces a great balancing act: feeding the population in 2050 while advancing economic development and reducing agriculture's pressure on the environment in a changing climate. The *Interim Findings* and an accompanying series of working papers explores a menu of solutions that could combine to achieve this balance.

Based on an adjusted FAO projection of food demand and production by 2050, the world needs to close a roughly 70 percent gap between the crop calories available in 2006 and expected calorie demand in 2050 (Figure 1).<sup>1</sup> Global population is projected to grow to 9.7 billion by 2050.<sup>2</sup> At least 3 billion more people are expected to enter the global middle class by 2030,<sup>3</sup> and two-thirds of the global population is projected to live in cities by mid-century.<sup>4</sup> A wealthier, more urban global population will likely demand more food per capita—and more resource-intensive foods such as meat and dairy.<sup>5</sup> Without successful measures to restrain the consumption of resource-intensive foods by the world's affluent or to reduce waste, sufficiently feeding the world will require worldwide annual crop production in 2050 to be more than 70 percent higher than 2006 levels.<sup>6</sup>

While overall food demand—as measured by crop calories (Box 2)—is projected to rise by roughly 70 percent between 2006 and 2050, demand for animal-based foods is projected to rise even faster. Based on the latest, most likely population projections, demand for meat and dairy is projected to grow by nearly 80 percent. Demand for beef specifically—one of the most resource- and greenhouse-gas-intensive foods—is projected to grow by 95 percent between 2006 and 2050.<sup>7</sup> Unless curbed, the demand for animal-based products will make it hard to achieve several of the United Nations Sustainable Development Goals, including those on hunger, healthy lives, management of water, consumption and production, climate change, and terrestrial ecosystems.

Efforts to feed a growing and increasingly affluent population have primarily focused on increasing food production, rather than addressing consumption. However, if the world were to rely solely on increased production to close

### Box 1 | The World Resources Report: *Creating a Sustainable Food Future*

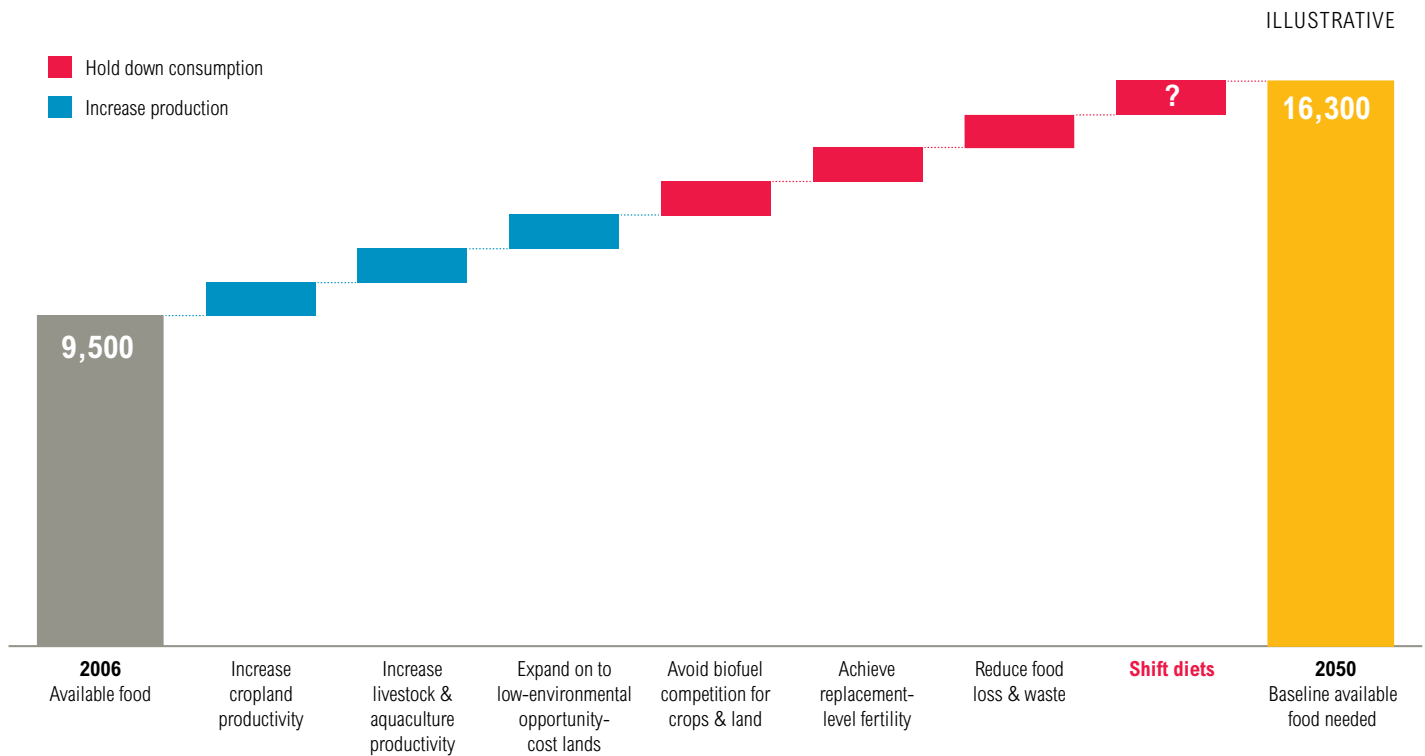
The world faces a great balancing act. How will the world adequately feed nearly 10 billion people by 2050 in a manner that advances economic development and reduces pressure on the environment, while adapting to climate change? This requires balancing three needs. First, the world needs to close a roughly 70 percent gap between the crop calories available in 2006 and those needed by 2050 (the “food gap”). Second, the world needs agriculture to contribute to inclusive economic and social development. Third, the world needs to reduce agriculture's impact on the environment.

This edition of the World Resources Report, *Creating a Sustainable Food Future*, proposes a menu of solutions that can achieve this balance. The menu includes production-focused solutions, such as sustainably increasing crop yields and livestock pasture productivity, and consumption-focused solutions, such as reducing food waste, achieving replacement-level fertility, and reducing demand for bioenergy that makes dedicated use of crops and land. This working paper focuses on a consumption-focused solution: shifting people's diets.

Since the 1980s, the World Resources Report has provided decision makers from government, business, and civil society with analyses and insights on major issues at the nexus of development and the environment. For more information about the World Resources Report and to access previous installments and editions, visit [www.worldresourcesreport.org](http://www.worldresourcesreport.org).

the food gap, there would be enormous pressure to clear the world's remaining tropical forests and other natural ecosystems to expand croplands and pasturelands. For example, to avoid further expansion of harvested area, the annual average increase in crop yields from 2006 to 2050 would need to be about one-third *more* than in the previous 44-year period (1962 to 2006)—a period that encompassed the Green Revolution.<sup>8</sup> In addition, increases in food production and the associated land-use changes would make it even more difficult to limit global warming to the internationally recognized goals of 1.5 to 2 degrees Celsius above preindustrial levels.<sup>9</sup> Agriculture and related land-use change accounted for nearly one-quarter of global greenhouse gas emissions in 2010. By 2050, they could consume 70 percent of the total allowable global emissions “budget” for limiting global warming to 2 degrees.<sup>10</sup>

Figure 1 | **A Menu of Solutions is Required to Sustainably Close the Food Gap**  
global annual crop production (kcal trillion)



Source: WRI analysis based on Bruinsma (2009) and Alexandratos and Bruinsma (2012).

Note: Includes all crops intended for direct human consumption, animal feed, industrial uses, seeds, and biofuels.

The world will need to do more than increase food production and the efficiency of production. Given the magnitude of the challenge and the environmental impacts associated with increased production, consumption-focused solutions will also be necessary. One consumption-focused solution is to shift diets—the type, combination, and quantity of food consumed by people. There are good reasons to shift diets aside from the need to close the food gap. One in two people worldwide currently consumes a nutritionally imbalanced diet as a result of overconsumption, hunger, or micronutrient deficiency.<sup>11</sup> Shifting to more nutritionally balanced diets could profoundly affect food security, human health, healthcare costs, natural resource use, the environmental impacts of agriculture, and animal welfare.

In this paper, we examine three interconnected diet shifts that can contribute to a sustainable food future:

1. Reduce overconsumption of calories.
2. Reduce overconsumption of protein by reducing consumption of animal-based foods.
3. Reduce consumption of beef specifically.

This paper is primarily tailored to businesses that can play a role in shifting diets. This includes actors in the food value chain, particularly food service companies and food retailers.



We do *not* suggest that everyone should become a vegan or vegetarian. Nor do we aim to reduce food consumption among undernourished or malnourished populations. We do not seek to eliminate the livestock sector, which provides livelihoods to millions of poor smallholders and generates 40 percent of global agricultural income.<sup>12</sup> Rather, we focus on reducing *overconsumption* of calories and protein, decreasing the share of animal-based protein in diets, and reducing the consumption of beef specifically.

For each of the three proposed diet shifts, we define the issues, explain why they matter, and review projected consumption trends. We then quantify the projected effects of the shifts on the land use and greenhouse gas impacts of agriculture in 2009, using the version of the GlobAgri model developed for *Creating a Sustainable Food Future* (Box 3). The greenhouse gas emissions estimates include both emissions from agricultural production and emissions from land-use change. Regarding land-use change emissions, we estimate the emissions that would occur from conversion of forests, savannas, and other lands to produce the additional foods<sup>13</sup> based on existing crop yields, livestock efficiencies, and patterns of trade (Box 4). We then assess the effects of the diet shifts in 2050, including their potential to help close the food gap.

Next, we outline a novel approach to address the crucial question of *how* to shift people's diets. We consider strategies beyond information and education campaigns, and draw on practices employed by the consumer goods industry that have successfully changed consumption patterns. We conclude with four recommendations for shifting diets.

In our assessment, the three proposed diet shifts meet the development and environmental criteria introduced in the World Resources Report's *Interim Findings* (Table 1). They reduce the pressure of agriculture on ecosystems, climate, and water, and offer potential benefits for human health.

## Box 2 | What Metric for Assessing Food Security and Nutritional Requirements?

There is no one perfect metric for assessing global food security or human nutritional requirements. FAO used economic value as a metric in its 2009 estimate of a 70 percent food gap between 2006 and 2050.<sup>a</sup> Given that food prices fluctuate, economic value does not provide a consistent unit of measure over time. Another metric that has been used is food weight or volume (for example, tons). Since this includes water, it does not provide a reliable metric of the nutritional content of food.

This paper—and others in the *Creating a Sustainable Food Future* series—measures the food gap between 2006 and 2050 in crop calories. Calories are consistent over time and avoid embedded water. Measuring the calories embedded in crops (production) rather than in foods (consumption) also has the advantage of counting not only crops intended for human consumption, but also animal feed, bioenergy, and other uses. However—critically for this paper—this metric does not capture the role of pastureland in supporting human food needs.

The analysis of the three diet shifts explored in this paper focuses on total calories and one important macronutrient (protein) because of their key role in nutritional health and the availability of globally consistent data. Each of the modeled diet scenarios in this paper was designed to ensure adequate amounts of calories and protein to the populations affected by the scenarios. Two of the scenarios—vegetarian and Mediterranean-style diets—were based on realistic diets that are high in nutrient-rich foods.

It should be noted, however, that other nutrients are needed for a balanced diet. A narrow focus on calories and protein could lead to nutritionally unbalanced diets. For example, an “environmentally sustainable diet” that sought only to maximize calories produced per hectare could inadvertently encourage production of high-yielding, energy-dense crops, such as sugars and cereals, in place of lower-yielding, but nutrient-rich crops, such as fruits, vegetables, and beans. As a result, “shifting diets” should be implemented with an eye to providing not only adequate amounts of calories and protein, but also all other nutrients essential to human health. This is particularly important given that micronutrient deficiencies—or “hidden hunger”—affected more than 2 billion people in 2010–12, with the most common deficiencies including iodine, iron, zinc, and vitamin A.<sup>b</sup>

### Notes:

a. Bruinsma (2009).

b. FAO, WFP, and IFAD (2012).

### Box 3 | An Overview of the GlobAgri-WRR Model

This paper uses the GlobAgri-WRR model (“GlobAgri”), which is a version of the GlobAgri model developed by the Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD), Princeton University, the Institut National de la Recherche Agronomique (INRA), and WRI. GlobAgri is a global biophysical model that quantifies the greenhouse gas emissions and land-use effects of agricultural production. It estimates emissions from agricultural production, primarily methane and nitrous oxide, and carbon dioxide from the energy used to produce fertilizers and pesticides or to run farm machinery. It also estimates emissions from land-use change (Box 4). It does not include emissions from food processing, transportation, retail, or cooking.

GlobAgri links food consumption decisions in each country or region (see Appendix A for list of countries and regions) to the production of the crops, meat, milk, or fish necessary to meet food demands after accounting for food loss and waste at each stage of the value chain from farm to fork. Its core data for production, consumption, and yields are based on data from FAO (2015). The model accounts for the multiple food, feed, and energy products that can be generated by each crop, and reflects the estimates of crop calorie content by region as estimated in FAO (2015). It estimates land use and greenhouse gas emissions related to agricultural production in each of the world’s countries in light of crop yields, population, diets, production methods,

and levels of food loss and waste—factors that can all be modified to examine future scenarios of agricultural production and food consumption.

To analyze the eight alternative diet scenarios explored in this paper, GlobAgri held all other consumption and production factors constant. For example, the model assumes additional food would be supplied at the same average crop yields, using the same average livestock production measures, and with the same rates of food loss and waste as in the 2009 reference scenario. The model similarly assumes that the role of imports and exports would remain the same; for example, if 20 percent of a crop in Country A is imported from Country B, that percentage would remain true under scenarios of altered demand for that crop.

The GlobAgri model differs from some other global agriculture and land-use models in that it does not incorporate economic feedback effects. For example, if people in one country were to increase food consumption, the prices of those foods would increase, potentially triggering changes in food production and consumption in other countries. Economic models can be used to simulate these feedback effects, but given the uncertainties associated with these interactions, they need to make a number of assumptions, making the results highly variable. Furthermore, it seems inappropriate—when evaluating the consequences of a resource-intensive diet (for example, one high in

animal-based foods)—to “credit” that diet for reduced food consumption by others.

Patrice Dumas (CIRAD) is the principal architect of the GlobAgri-WRR model, working in partnership with Tim Searchinger of Princeton University and WRI. Other researchers contributing to the core model include Stéphane Mançeron (INRA) and Richard Waite (WRI).

A major strength of the GlobAgri model is that it incorporates other biophysical submodels that estimate emissions or land-use demands in specific agricultural sectors. GlobAgri therefore benefits from other researchers’ work, incorporating the highest levels of detail available. Major subcomponents include a livestock model with lead developers Mario Herrero (CSIRO) and Petr Havlik (IIASA), with extra contributions from Stefan Wirsenius (Chalmers University); a land-use model with lead developer Fabien Ramos of the European Commission Joint Research Centre; a global rice model with lead developer Xiaoyuan Yan of the Chinese Institute for Soil Science; a nitrogen emissions model with lead developer Xin Zhang of Princeton University; and an aquaculture model with lead developer Mike Phillips of WorldFish and Rattanawan Mungkung of Kasetsart University. Each of these submodels had several contributors. Information on vegetarian diets was based on information provided by Peter Scarborough and Paul Appleby of the University of Oxford.

## Box 4 | How Does the GlobAgri Model Quantify the Land-Use-Related Greenhouse Gas Effects of Different Food Choices?

The GlobAgri model estimates the amount of agricultural land needed to produce a specific quantity of food required by a given diet assuming present crop yields, production systems, and trade. It assumes that any agricultural expansion triggered by a change in diet will come at the expense of forests, savanna, or some other native vegetation. The resulting loss of carbon in plants and soils provides the quantity of greenhouse gas emissions from land use attributed to the diet. Conversely, under scenarios of reduced food demand, GlobAgri estimates negative land-use-change emissions (or avoided future emissions), simulating the restoration of agricultural land to native vegetation. The model does not consider how economic feedbacks might alter other demands, production systems, or yields.

### How have other studies quantified the greenhouse gas effects of changes in agricultural land use?

Informed by Schmidinger and Stehfest (2012), we identified three broad approaches that life-cycle assessments of agriculture and/or alternative diets generally use to quantify the greenhouse gas effects associated with changes in land use:

**1. Land-use-change emissions are not estimated.** Most conventional life-cycle assessments of agriculture account for the land area required to produce the foods being studied, but do not assign any land-use-change-related greenhouse gas emissions to that land. Estimates of greenhouse gas emissions in such studies are limited to sources from agricultural production (not land-use change), such as methane from livestock and energy used to run farm machinery.

**2. Land-use-change emissions are averaged over total agricultural production and land use in the study period.** Under this approach, land-use-change emissions per unit of food produced are generally quite low—and can even be zero if land-use change did not occur during the study time frame. Some of these studies do this calculation just for a specific crop and in a specific country. For example, if soybean area is expanding in Brazil, but not in the United States, the emissions from this expanding soybean area are allocated to all the production of soybeans in Brazil, but none are assigned to soybean production in the United States. This approach would assign land-use-change emissions to a European pork producer who imports soybeans from Brazil, but not one who imports soybeans from the United States.

**3. Land-use-change emissions are attributed to marginal (additional) agricultural production.** This approach—employed by GlobAgri and most biofuel studies—focuses on the additional emissions from the additional land required to produce any additional amount of a crop or other food. Under this approach, land-use-change emissions per unit of food produced are much higher than in approach (2), and are never zero.

A hypothetical example illustrates the difference between approach (2) and approach (3). Assume that in 2009, soybeans occupied 5 million hectares of land in a country and produced 2 tons per hectare, for a total production of 10 million tons. Each ton of soybeans therefore required half a hectare of cropland. Now assume that in 2010, soybean area expanded by 100,000 hectares to 5.1 million hectares, while yields stayed

constant, meaning that production grew by 200,000 tons (from 10 million tons to 10.2 million tons). Suppose that these additional 100,000 hectares came from clearing forest that contained 400 tons of CO<sub>2</sub>e per hectare. In approach (2), the 100,000 hectares of land-use change and the resulting emissions of 40 million tons of CO<sub>2</sub>e would be assigned to all 10.2 million tons of soybeans, resulting in a small quantity of emissions per ton (around 4 tons of CO<sub>2</sub>e per ton of soybeans produced).

In fact, if we change this example and assume that soybean yields grew just enough in 2010 to produce 10.2 million tons of soybeans on the same 5 million hectares of land (in other words, with no expansion of the soybean area), this approach would attribute no land-use change (and no land-use-change emissions) to soybeans. Under approach (2), eating meat fed entirely by soybeans from this country has no land-use emissions cost.

What approach (2) does not tell us is how much extra land use was required for each additional ton of soybeans in 2010. In the first example above, if soybean demand had not gone up by 200,000 tons in 2010, soybean area would not have expanded at all. The increase of 200,000 tons required the extra 100,000 hectares. Approach (3) therefore assigns the land-use-change emissions from converting those 100,000 hectares only to the 200,000 additional tons of soybeans. In this example, therefore, each additional ton of soybeans is responsible for emitting 200 tons of CO<sub>2</sub>e. Recognizing that land converted into agricultural production can sustain crops or livestock over many years, we follow the approach taken by the European Union for estimating land-use-change emissions for biofuels, and amortize the land-use-change emissions over 20 years. In our example, this amortization therefore assigns emissions of 10 tons of CO<sub>2</sub>e per year per

## Box 4 | How Does the GlobAgri Model Quantify the Land-Use-Related Greenhouse Gas Effects of Different Food Choices? (continued)

additional ton of soybeans produced. GlobAgri applies this “marginal” approach (3) in this paper in order to gain a fuller picture of the land and greenhouse gas consequences of diet shifts, which by definition happen at the margin. For any given yield, each additional ton of food demanded requires a certain amount of additional land, which results in a certain amount of land-use-change emissions. The converse is also true—each ton of food no longer demanded (e.g., under scenarios that reduced consumption of animal-based foods and as a result reduced demand for crop-based feed) results in a decrease in agricultural land use and negative land-use-change emissions if agricultural land reverts to native vegetation. However, because global agricultural land is expanding—as food demand growth continues to outpace yield growth—the real-world consequences of reducing food demand under the scenarios modeled in this paper would be to avoid future land-use change. This avoided land-use change and associated greenhouse gas emissions are what GlobAgri estimates.

This approach reveals that each person’s diet matters quite a lot for agricultural land use and the associated greenhouse gas

emissions. Regardless of what anyone else does, individual dietary choices affect demand for land “at the margin” and therefore have a significant effect on greenhouse gas emissions.

### **Why does GlobAgri not consider the economic effects of changes in food supply and demand?**

The GlobAgri model is designed to answer the question of how much agricultural land would be required for a given level of food demand, crop yield, and livestock production efficiency. It does not assess whether and by how much an increase or decrease in food demand by one group of people leads to price changes and economic feedbacks that in turn shift other people’s demands, farmers’ yields, and/or production techniques. Such economic effects are highly complex and uncertain. As a result, there is limited underlying economic evidence that can be used to robustly estimate them.<sup>a</sup> In addition, economic assessments do not fully capture the land-use “opportunity costs” of diet choices. Consider, for example, a scenario in which a relatively wealthy person increases their beef consumption. This change in demand would likely lead

to an increase in beef and grain prices and could cause a poorer person elsewhere to consume less grain or beef as prices increase. This “crowding out” of the poorer person’s food demand does reduce global land-use demands relative to a world in which the poorer person’s grain demand is unaffected by the wealthier person’s beef demand. However, it seems inappropriate, when evaluating the consequences of a resource-intensive diet, to “credit” that diet for reduced food consumption by others, even if this does lead to potential overestimates of the greenhouse gas benefits of reducing consumption. By eliminating the economic feedback effects from the analysis, GlobAgri can more transparently estimate what combinations of diet shifts, yield gains, and other solutions would be necessary to achieve a sustainable food future.

Even without considering the economic interactions of changes in food supply and demand, there are still many other uncertainties in estimating both the type of lands that are likely to be converted and the quantity of carbon that conversion would release. All model estimates, including those of GlobAgri, should therefore be considered rough.

#### *Note:*

a. Searchinger et al. (2015) and supplement; Berry (2011).

Table 1 | How “Shifting Diets” Performs Against the Sustainable Food Future Criteria

● = positive      ○ = neutral/it depends

CRITERIA	DEFINITION	PERFORMANCE	COMMENT
<b>Poverty alleviation</b>	Reduces poverty and advances rural development, while still being cost effective	○	Careful policy choices would be needed to ensure that the diet shifts make food affordable to all, and do not adversely impact poor livestock farmers. <sup>a</sup>
<b>Gender</b>	Generates benefits for women	●	The diet shifts would provide health benefits for women.
<b>Ecosystems</b>	Reduces pressure for agricultural expansion and intensification on existing agriculture land	●	The diet shifts would reduce the land needed for food production. Reducing consumption of animal-based food products, particularly beef and dairy, would lower the pressure to convert forests and wooded savannas into pasturelands.
<b>Climate</b>	Reduces greenhouse gas emissions from agriculture to levels consistent with stabilizing the climate	●	The diet shifts would contribute to stabilizing the climate. <sup>b</sup> Shifting diets would reduce the need to convert forests to crop and pastureland, apply more fertilizers, and raise more livestock. Reducing overconsumption of calories would reduce the need for energy for producing, processing, transporting, and storing food.  Reducing beef consumption specifically would reduce methane emissions from enteric fermentation and manure and nitrous oxide (N <sub>2</sub> O) from excreted nitrogen and the chemical nitrogenous fertilizers used to produce feed for animals kept in feedlots.
<b>Water</b>	Reduces water consumption and pollution	●	The diet shifts would reduce the quantity of water needed for food production. They would also reduce the contribution of agriculture to water pollution.

Notes:  
a. USDA/HHS (2015).  
b. Hedenus et al. (2014).

## CONVERGING DIETS

Around the world, eating habits are converging toward Western-style diets high in refined carbohydrates, added sugars, fats, and animal-based foods. Consumption of pulses,<sup>14</sup> other vegetables, coarse grains, and fiber is declining.<sup>15</sup> Three interconnected global trends are associated with this convergence. First, rising incomes are associated with rising demand for animal-based foods, vegetable oils, and added sugars.<sup>16</sup> Second, increasing urbanization (also associated with rising incomes) provides easy access to supermarkets, restaurants, fast food chains, and foods that they supply, including meat, dairy, and processed foods and drinks.<sup>17</sup> Third, technological advances, business and economic changes, and government policies are transforming entire food chains, from farm to fork. Multi-national agribusinesses, food manufacturers, retailers, and food service companies increasingly influence what is grown and what people eat, a trend that is spreading from high-income to low- and middle-income countries.<sup>18</sup>

These trends—combined with more sedentary lifestyles— affect nutritional and health outcomes, including height, weight, and the prevalence of noncommunicable diseases.<sup>19</sup> Diet-related noncommunicable diseases include hypertension, type 2 diabetes, cardiovascular diseases, and certain types of cancer.<sup>20</sup>

FAO food supply data—adjusted downward from “per capita food availability” to “per capita food consumption”<sup>21</sup> to account for food loss and waste during the consumption stage of the food supply chain—indicate that the consumption of calories and protein is already above average requirements in the majority of developed countries. Per capita food consumption also is rapidly rising in emerging economies, including China and Brazil.<sup>22</sup> In this paper, we build on FAO’s projections<sup>23</sup> to estimate food consumption levels in 2050. We find that in 2050, emerging economies will likely exhibit per capita consumption levels—in terms of calories, protein, and consumption of animal-based foods—comparable to today’s developed countries.<sup>24</sup>

Why does this global convergence in diets matter? Foods differ vastly in terms of the quantity of land, water, and energy needed per unit of energy and protein ultimately consumed, and in terms of their greenhouse gas impacts (Figure 2).<sup>25</sup> Although the data in Figure 2 are global means for current agricultural production<sup>26</sup>—masking variations among locations, production systems, and farm management practices (Box 5)—they enable general comparisons across food types.

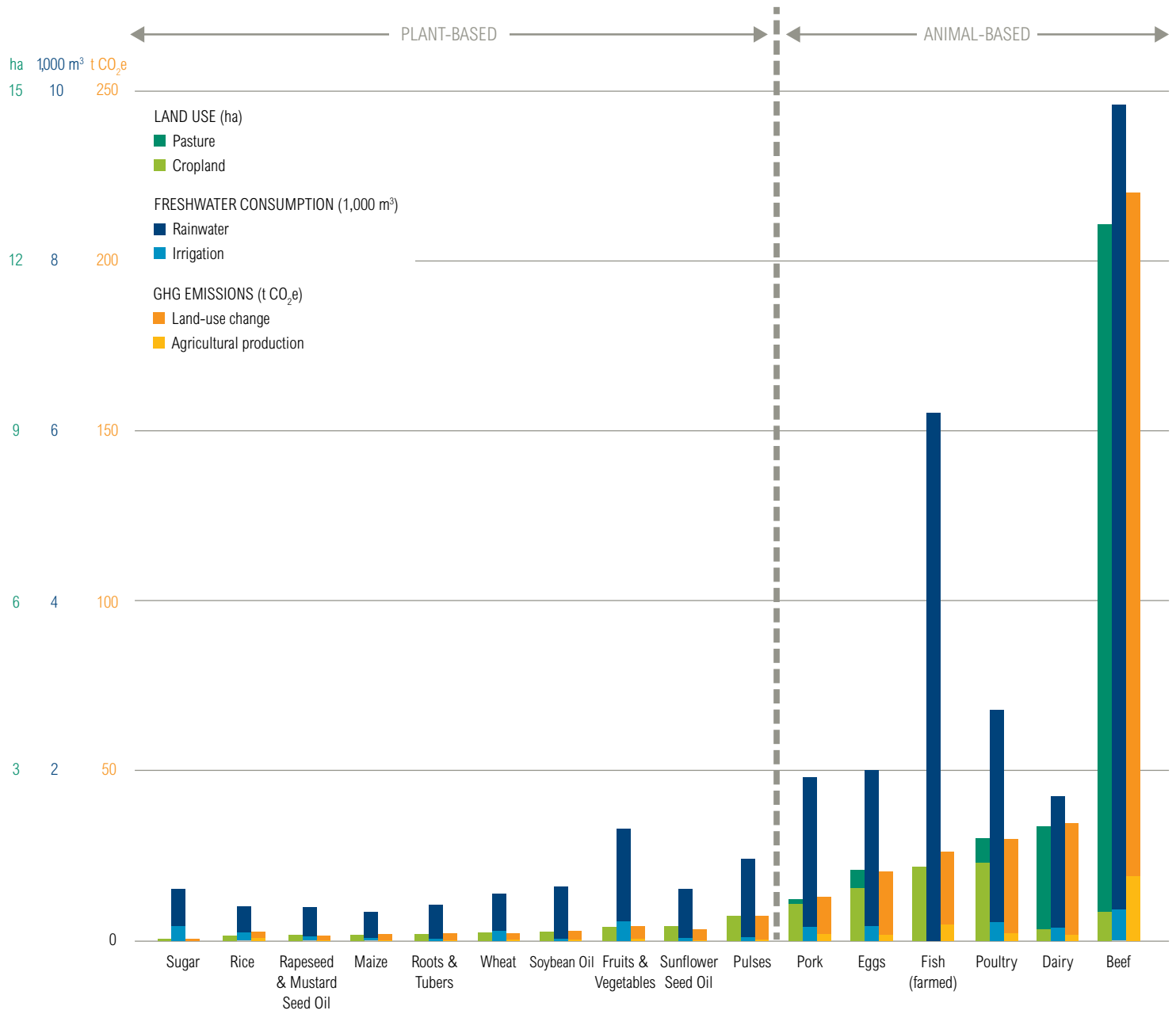
Unlike many other studies (Box 4), the comparison of food types in Figure 2 incorporates both land used for pasture and greenhouse gas emissions associated with changes in land use. Key findings from this more inclusive approach, using the GlobAgri model, include:

- Animal-based foods are generally more resource-intensive and environmentally impactful to produce than plant-based foods.
- Beef and other ruminant meats (sheep and goat) are by far the most resource-intensive of foods, requiring four to six times more land and generating that many times more greenhouse gas emissions than dairy per calorie or unit of protein ultimately consumed by people. Beef and other ruminants also require more than 20 times more land and generate more than 20 times more greenhouse gas emissions than pulses per unit of protein consumed.
- Dairy’s land use and greenhouse gas emissions are slightly higher than those of poultry per calorie consumed and significantly higher than those of poultry per unit of protein consumed.
- Poultry and pork have similar greenhouse gas emissions and land use per unit of protein consumed, but poultry’s land use and emissions are higher than pork’s per calorie consumed mainly because of the high energy content of pork fat.
- Pulses, fruits, vegetables, and vegetable oils are generally more resource-intensive to produce than sugars and staple crops, but still compare very favorably to animal-based foods.
- Factoring land-use implications into agricultural greenhouse gas emissions estimates shows a fuller picture of the consequences of people’s dietary choices. For all food types, the annualized emissions from land-use change (shown in orange in Figure 2) are far higher than emissions associated with agricultural production (shown in light orange). For example, when considering production emissions only, consumption of a million calories of beef would generate 19 tons of CO<sub>2</sub>e, while the same quantity of pulses would generate 0.4 tons of CO<sub>2</sub>e, a savings of 18.6 tons of CO<sub>2</sub>e. But when factoring in land use, emissions would fall from 201 tons of CO<sub>2</sub>e (for beef) to 7 tons of CO<sub>2</sub>e (for pulses), a savings of 194 tons of CO<sub>2</sub>e or more than 10 times the amount when considering only production-related emissions.



Figure 2 | Foods Differ Vastly in Resource Use and Environmental Impacts

PER MILLION KILOCALORIES CONSUMED



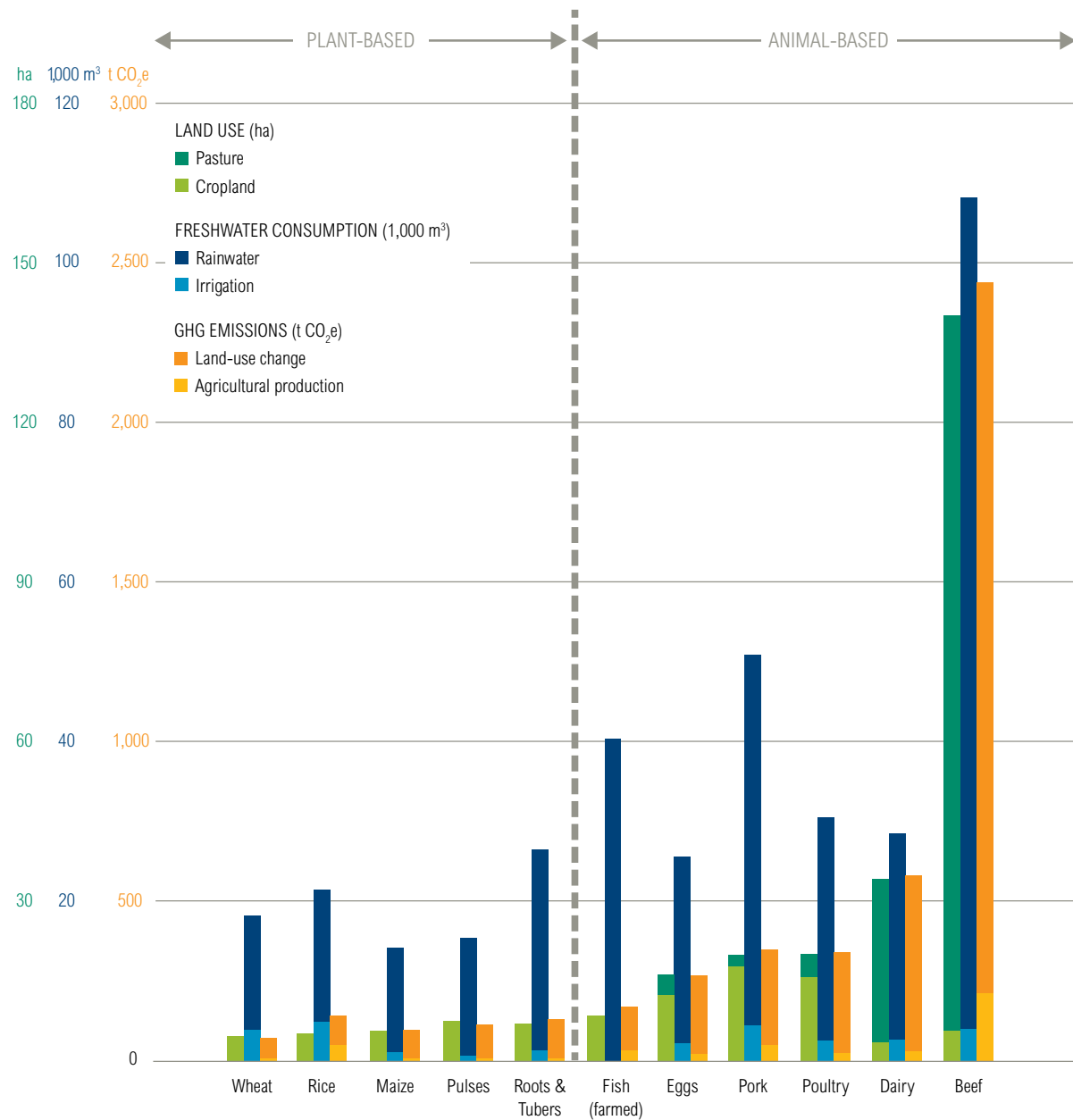
Sources: GlobAgri model (land use and greenhouse gas emissions), authors' calculations from Mekonnen and Hoekstra (2011, 2012) (freshwater consumption), and Waite et al. (2014) (farmed fish freshwater consumption).

Notes: Data presented are global means. Entries are ordered left to right by amount of total land use. Indicators for animal-based foods include resource use to produce feed, including pasture. Tons of harvested products were converted to quantities of calories and protein using the global average edible calorie and protein contents of food types as reported in FAO (2015). "Fish" includes all aquatic animal products. Freshwater use for farmed fish products is shown as rainwater and irrigation combined. Land use and greenhouse gas emissions estimates are based on a marginal analysis (i.e., additional agricultural land use and emissions per additional million calories or ton of protein consumed). Based on the approach taken by the European Union for estimating emissions from land-use change for biofuels, land-use change impacts are amortized over a period of 20 years and then shown as annual impacts. Land use and greenhouse gas emissions estimates for beef production are based on dedicated beef production, not beef that is a coproduct of dairy. Dairy figures are lower in GlobAgri than some other models because GlobAgri assumes that beef produced by dairy systems displaces beef produced by dedicated beef-production systems.



Figure 2 | Foods Differ Vastly in Resource Use and Environmental Impacts (continued)

PER TON PROTEIN CONSUMED



Sources: GlobAgri model (land use and greenhouse gas emissions), authors' calculations from Mekonnen and Hoekstra (2011, 2012) (freshwater consumption), and Waite et al. (2014) (farmed fish freshwater consumption).

Notes: Data presented are global means. Entries are ordered left to right by amount of total land use. Indicators for animal-based foods include resource use to produce feed, including pasture. Tons of harvested products were converted to quantities of calories and protein using the global average edible calorie and protein contents of food types as reported in FAO (2015). "Fish" includes all aquatic animal products. Freshwater use for farmed fish products is shown as rainwater and irrigation combined. Land use and greenhouse gas emissions estimates are based on a marginal analysis (i.e., additional agricultural land use and emissions per additional million calories or ton of protein consumed). Based on the approach taken by the European Union for estimating emissions from land-use change for biofuels, land-use change impacts are amortized over a period of 20 years and then shown as annual impacts. Land use and greenhouse gas emissions estimates for beef production are based on dedicated beef production, not beef that is a coproduct of dairy. Dairy figures are lower in GlobAgri than some other models because GlobAgri assumes that beef produced by dairy systems displaces beef produced by dedicated beef-production systems.

## Box 5 | Improving Agricultural Productivity for a Sustainable Food Future

It is not just the type of food consumed that determines the environmental and resource use impacts of agriculture, but also the way that food is produced. The GlobAgri model incorporates the wide diversity of crop, livestock, and aquaculture systems in all of the world's regions. For instance, it includes estimates for the quantity of nitrogen used by type of crop and region. It also incorporates regional estimates of the greenhouse gas emissions generated from the energy used to run farm machinery and to produce and apply pesticides.

World agricultural productivity has increased over time, as advances in farming technology and practices have boosted crop and pasture yields in some places. While those advances have generally increased chemical, water, and energy inputs, there have also been substantial improvements in input efficiency in recent decades.<sup>a</sup> Overall, modern livestock systems—particularly beef and dairy—generate fewer greenhouse gas emissions and use less land than traditional production systems, especially when coupled with gains in crop yield for animal feeds.<sup>b</sup>

As discussed in other *Creating a Sustainable Food Future* installments,<sup>c</sup> crop and livestock productivity can be significantly increased without increasing inputs or shifting to the most concentrated feedlot systems. For example, Brazil's National Plan for Low Carbon Emissions in Agriculture aims to increase input efficiency, boost productivity, and reduce agricultural greenhouse gas emissions and other environmental impacts by intensifying production on degraded pasturelands and through integrated crop-livestock-forest systems, no-till farming, and other practices.<sup>d</sup>

Still, although there are tradeoffs among production systems, and agricultural productivity will likely continue to increase, reducing overconsumption is likely to generate environmental, resource-use, health, and other benefits, regardless of the production systems employed. This is especially true for animal-based foods, which are resource intensive.

### Notes:

a. For a global overview, see Garnett et al. (2015). For progress in nitrogen use efficiency in some developed countries in recent years, see Lassaletta et al. (2014). For progress in water use efficiency in the US, see Schaible and Aillery (2012).

b. Herrero et al. (2013).

c. See, for example, installments on improving crop breeding (Searchinger et al. 2014), improving land and water management (Winterbottom et al. 2013), limiting crop expansion to lands with low environmental opportunity costs (Hanson and Searchinger 2015), reducing greenhouse gas emissions and water use from rice production (Adhya et al. 2014), improving productivity of aquaculture (Waite et al. 2014), and increasing productivity of pasture and grazing lands (Searchinger et al. 2013).

d. Marques (2013).

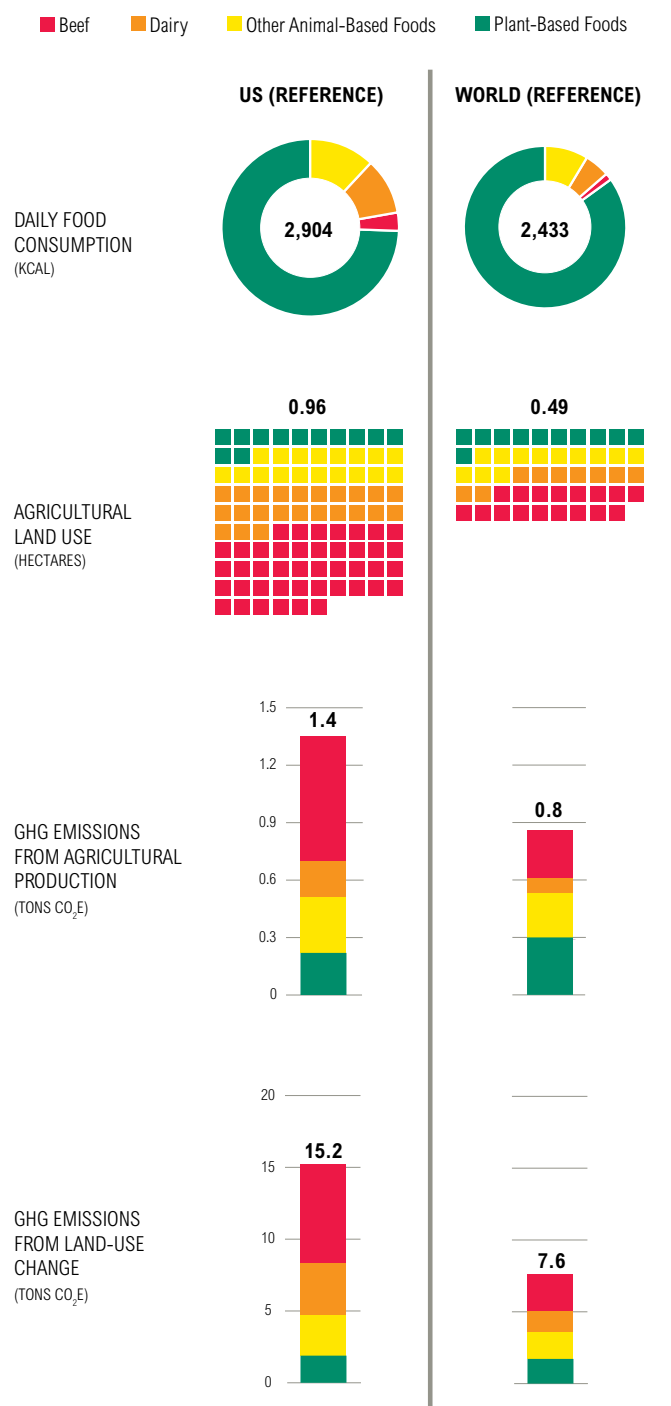
The global convergence toward Western-style diets, high in animal-based foods, has enormous implications for the resource needs and environmental impacts of agriculture. The average diet of the United States<sup>27</sup> is a case in point. Figure 3 compares the average daily diets of the world and the United States in 2009 based on the number of calories of each food type consumed, as well as the associated land-use needs and greenhouse gas emissions. In the United States, the average daily diet contained nearly 500 more calories than the average world diet, including nearly 400 additional animal-based calories. As a result, the agricultural land use and greenhouse gas emissions associated with the average daily US diet were almost double those associated with the average daily world diet.<sup>28</sup> Animal-based foods accounted for nearly 85 percent of the production-related greenhouse gas emissions and nearly 90 percent of agricultural land use associated with the average US diet.<sup>29</sup> Shifting the diets of people who currently consume high amounts of calories and animal-based foods, and those projected to by 2050, could therefore significantly reduce agriculture's impact on resources and the environment.

As noted above, factoring land-use implications into agricultural greenhouse gas emissions estimates shows a fuller picture of the consequences of people's dietary choices. For example, if an additional person eating the average daily US diet were added to the world population in 2009, the one-time emissions resulting from converting a hectare of land to agriculture to feed that person would be about 300 tons CO<sub>2</sub>e.<sup>30</sup> This amount is equal to 17 times the average US per person energy-related carbon dioxide emissions in 2009.<sup>31</sup> In other words, the emissions from clearing additional land to feed an additional person eating the US diet are equal to 17 years of that person's energy-related CO<sub>2</sub> emissions.

If diets around the world continue to converge, more people will be consuming more food that is more resource intensive and more environmentally impactful to produce, posing significant challenges to a sustainable food future. We examine three interconnected diet shifts<sup>32</sup> below that can address these challenges:

1. Reduce overconsumption of calories.
2. Reduce overconsumption of protein by reducing consumption of animal-based foods.
3. Reduce consumption of beef specifically.

**Figure 3 | Land Use and Greenhouse Gas Emissions Associated with the Average US Diet Were Nearly Twice the World Average per capita values, 2009**



Source: GlobAgri model.  
 Note: "US" data are for United States and Canada. Land-use change emissions are amortized over a period of 20 years and then shown as annual impacts. Calculations assume global average efficiencies (calories produced per hectare or per ton of CO<sub>2</sub>e emitted) for all food types. "Other animal-based foods" includes pork, poultry, eggs, fish (aquatic animals), sheep, and goat.

## DIET SHIFT 1: REDUCE OVERCONSUMPTION OF CALORIES

The first diet shift aims to reduce overconsumption of calories. Overconsumption of calories occurs when dietary calorie intake exceeds estimated energy requirements for an active and healthy life. Unnecessary calorie consumption results in unnecessary use of inputs (e.g., land, water, energy) and unnecessary environmental impacts related to the production of the excess calories. This diet shift targets countries and populations with high calorie intake now *and* those with high projected calorie intake by 2050. It would help reduce the number of obese and overweight people, and could result in significant potential savings in healthcare costs.

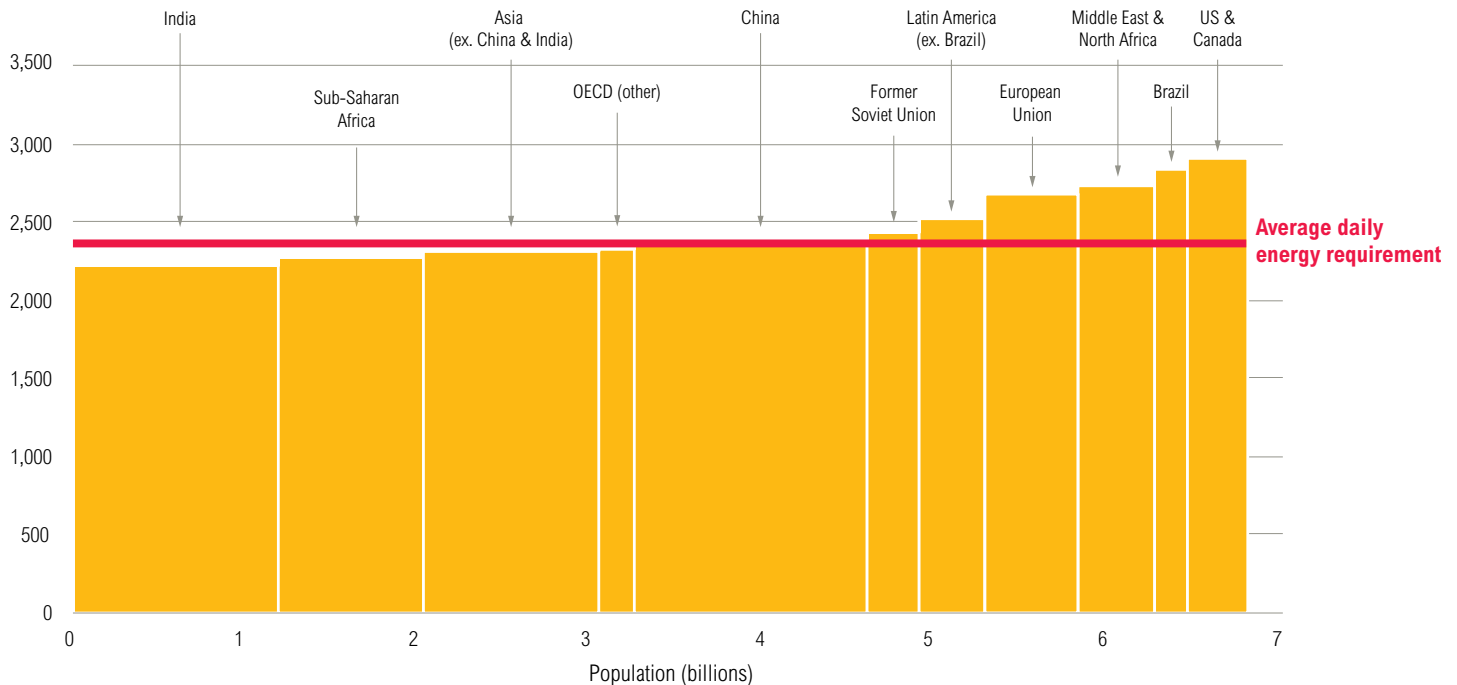
### What is the issue with overconsumption of calories?

The number of obese and overweight people is high and growing. In 2013, 2.1 billion people were overweight or obese<sup>33</sup>—more than two and a half times the number of chronically undernourished people in the world.<sup>34</sup> Globally, 37 percent of adults over the age of 20 were overweight in 2013 and 12 percent were obese.<sup>35</sup>

According to FAO, the global average daily energy requirement for an adult is 2,353 calories per day,<sup>36</sup> although individual energy requirements depend on age, sex, height, weight, level of physical activity, and pregnancy or lactation.<sup>37</sup> In 2009, however, per capita calorie consumption exceeded this average requirement in regions containing half of the world's population (Figure 4).<sup>38</sup> When people persistently overconsume calories, they can become overweight or obese.

A number of efforts have sought to explain the global rise in the number of people who are obese or overweight. Factors identified include increased consumption of energy-dense foods that are high in fat, decreased physical activity as a result of increasingly sedentary work, and changing modes of personal transportation, which are all associated with increasing urbanization.<sup>39</sup> These factors are compounded by increased access to low-cost convenience and processed foods and sugar-sweetened beverages, increased dining out, persuasive marketing by food and beverage companies, and government subsidies for food production that reduce the cost of food to consumers.<sup>40</sup>

**Figure 4 | Average Per Capita Calorie Consumption Exceeds Average Daily Energy Requirements in Regions Containing Half of the World's Population**  
kcal/capita/day, 2009



Source: GlobAgri model with source data from FAO (2015) and FAO (2011a). Width of bars is proportional to each region's population. Average daily energy requirement of 2,353 kcal/capita/day is given in FAO (2014). Individuals' energy requirements vary depending on age, sex, height, weight, pregnancy/lactation, and level of physical activity.

## Why does it matter?

The high and rising incidence of overconsumption of calories matters because it leads to “unnecessary” consumption of calories and the associated land, water, energy, chemicals, and other inputs that go into producing the calories.

Obesity and overweight also take a toll on human health. Obesity is a risk factor for several noncommunicable diseases, including hypertension, type 2 diabetes, cardiovascular diseases, and certain types of cancer (endometrial, breast, and colon).<sup>41</sup> Obesity also increases the risk of premature death.<sup>42</sup>

The health impacts of obesity and overweight drive up healthcare costs. According to one OECD study, obese people on average incur 25 percent higher healthcare costs than a person of normal weight.<sup>43</sup> In the United States, the healthcare costs of obesity accounted for 12 percent of the growth in health spending between 1987 and 2001.<sup>44</sup> In absolute terms, US obesity-related healthcare costs were approximately \$147 billion in 2008.<sup>45</sup> Spending on

type 2 diabetes alone (for which obesity is a risk factor) accounted for 13 percent of healthcare costs in China in 2010.<sup>46</sup>

Obesity and overweight can negatively impact productivity. Obese and overweight people have higher absenteeism rates than healthy people, and are at risk of loss of future income from premature death.<sup>47</sup> Direct costs (of obesity-related medical treatment) and indirect costs (related to lost productivity) accounted for EUR 32.8 billion in Europe in 2002.<sup>48</sup> In the United States alone, a 2006 medical expenditure panel survey and a 2008 national health and wellness survey estimated that the cost of obesity among full-time workers was \$73.1 billion per year as a result of decreased productivity, sick days, and general medical expenses.<sup>49</sup> In another study, the economic cost of lost productivity from obesity-related early mortality was estimated at \$49 billion per year in the United States and Canada.<sup>50</sup> A 2009 World Economic Forum survey of business executives identified noncommunicable diseases, such as those associated with diet, as a leading threat to global economic growth.<sup>51</sup>

Combining the costs of healthcare, lost productivity, and investments in obesity prevention and mitigation, the McKinsey Global Institute estimated the worldwide economic impact of obesity in 2012 to be around \$2.0 trillion, or 2.8 percent of global gross domestic product (GDP). This economic impact was roughly equivalent to the cost of armed conflict or smoking.<sup>52</sup>

## What are the trends?

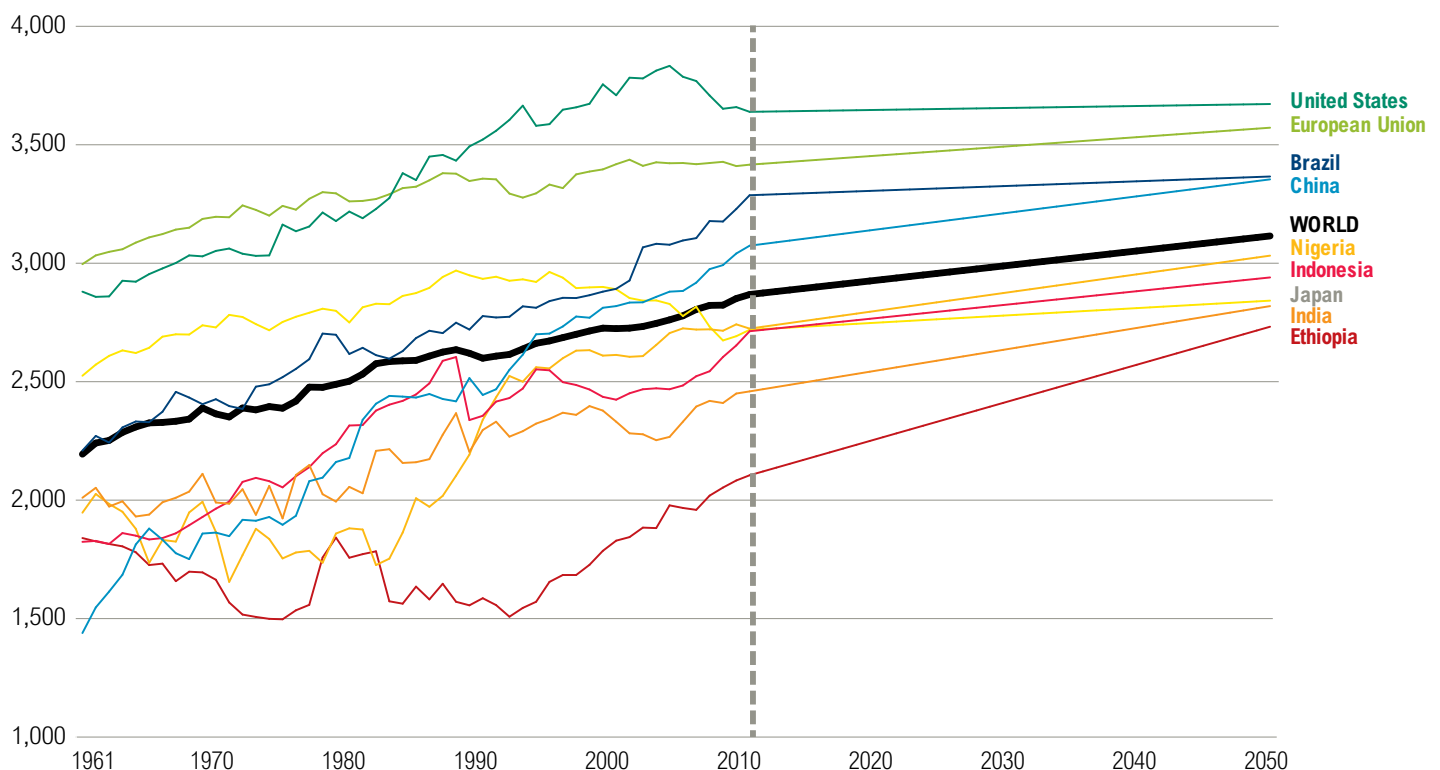
The global trend over the past five decades has been toward greater per capita availability of calories, meaning the calories available per person at the consumption stage without taking into account food wasted during the consumption stage. Figure 5 shows historical trends between 1961 and 2011, and projections to 2050, for a range of countries and regions.<sup>53</sup>

The number of people who are obese or overweight is rising globally and reaching epidemic proportions in some countries. Between 1980 and 2013, the number of adults worldwide with a BMI of 25 kg/m<sup>2</sup> or greater increased

from around 29 percent to 37 percent for men and from 30 percent to 38 percent in women.<sup>54</sup> The number of obese or overweight children and adolescents also grew in developed countries, with nearly one in four now obese or overweight. In Tonga, Samoa, and Kuwait, more than half of all adults were obese in 2013. More than half of the world's obese individuals lived in 10 countries in 2013: the United States, China, India, Russia, Brazil, Mexico, Egypt, Germany, Pakistan, and Indonesia.<sup>55</sup>

Emerging economies like China and Brazil have shown growth in caloric availability over several decades, climbing above the world average and surpassing some developed countries. Looking out to 2050, caloric availability is projected to continue rising, though more strongly in China than in Brazil.<sup>56</sup> Once considered a high-income country problem, the numbers of obese or overweight people is now rising in low- and middle-income countries, particularly in urban areas—although obesity is on the rise in rural areas and among poor populations as well.<sup>57</sup> In China, the obesity rate tripled from 1991 to 2006. The rate

Figure 5 | **Per Capita Calorie Availability is on the Rise**  
kcal/capita/day



Sources: FAO (2015) for historical data 1961–2011, Alexandratos and Bruinsma (2012) for 2050 projection, linear interpolation from 2012–2050.

of increase in overweight adults in China has been one of the most rapid in the world, faster even than in the United States.<sup>58</sup> In China, roughly 350 million people—more than a quarter of the adult population—are overweight or obese. This is twice as many as those who are undernourished.<sup>59</sup> In Brazil, obesity rates tripled among men and almost doubled among women from 1973 to 2003.<sup>60</sup> In addition, rates of obesity in Brazil have increased disproportionately among low-income groups.<sup>61</sup>

Obesity can increase even in countries that continue to have high levels of child stunting from insufficient nutrition. In Egypt, South Africa, and Mexico, adult obesity rates of more than 30 percent coexist with child stunting rates of 30 percent, 23 percent, and 15 percent, respectively.<sup>62</sup>

Obesity rates typically grow with a country's wealth until annual incomes reach roughly \$5,000 per person.<sup>63</sup> After that, other factors drive further rises in obesity. In China, for example, over the period 1989–2006, low socioeconomic status was associated with women being overweight, while high socioeconomic status remained a risk factor for men being overweight.<sup>64</sup> Globally, the rate of increase of overweight and obesity slowed between 2003 and 2013 relative to the previous decade, especially in developed countries, offering hope that obesity rates may have peaked in some countries.<sup>65</sup> One study in the United States found evidence that, among certain populations, further income increases (above approximately \$30,000 per person) were associated with declining obesity rates, possibly due to the ability to afford healthier foods and increase physical activities.<sup>66</sup>

Although the global trend is toward overconsumption of calories, many people remain hungry; an estimated 795 million people in 2014–16 were chronically undernourished.<sup>67</sup> Sub-Saharan Africa had the highest prevalence of chronic hunger at 23 percent. The highest absolute number of undernourished people—more than half a billion—was concentrated in Asia.<sup>68</sup> For example, Ethiopia's per capita calorie availability in 2011 was barely more than 2,000 calories. Because this number is below the average daily energy requirement—and because “availability” figures include food loss and waste that are not ultimately consumed—this low level suggests significant levels of hunger in Ethiopia. Data suggest that 36 percent of Ethiopia's population was undernourished in 2010–12.<sup>69</sup> Looking out to 2050, Ethiopia is predicted to have more than 2,700 calories available per person per day. This exceeds the average daily energy requirement, but not by much when food loss and waste

at the consumption stage are excluded.<sup>70</sup> In 2009, the average daily per capita food energy consumption in 79 countries and territories was lower than average energy requirements; the majority of these countries and territories were in sub-Saharan Africa and Asia.<sup>71</sup>

## What would be the land and greenhouse gas benefits of reducing overconsumption of calories?

Reducing overconsumption of calories could reduce agricultural resource use and environmental impacts. We used the GlobAgri model to determine the effects of reducing overconsumption of calories on agricultural land use and greenhouse gas emissions in 2009. By modifying food consumption data for 2009 (the “reference” scenario), we conducted two types of analysis. First, we quantified the per person effects of applying two calorie-reduction scenarios (described below) to the consumption pattern of a high-consuming country—the United States (Figure 6). Second, we quantified the global effects of the two calorie-reduction scenarios across all of the world's regions (Table 2).<sup>72</sup> When applied at the global level, the two calorie-reduction scenarios altered the diets of the 680 million people who were obese and the 1.4 billion people who were overweight in 2009.<sup>73</sup>

- **ELIMINATE OBESITY AND HALVE OVERWEIGHT SCENARIO.** Relative to the reference scenario, obesity is eliminated and the number of people overweight is halved. Informed by FAO (2004) and Hall et al. (2011a), this scenario assumes that an obese person on average consumes 500 more calories per day than a person eating the average daily energy requirement, and that each overweight person on average consumes 250 more calories per day than the average daily energy requirement of people with sedentary lifestyles.<sup>74</sup>
- **HALVE OBESITY AND OVERWEIGHT SCENARIO.** Relative to the reference scenario, the number of people that are obese and overweight are both halved, using the same assumptions as the *Eliminate Obesity and Halve Overweight* scenario.

In both scenarios, calorie consumption was reduced across all food types by equal proportions—that is, if in a given region cereal consumption was reduced by 3 percent, the consumption of all other food types (such as sugars, vegetable oils, and animal-based foods) was also reduced by 3 percent. At the global level, calorie consumption was



**Figure 6 | Reducing Overconsumption of Calories Reduces the Agricultural Land Use and Greenhouse Gas Emissions Associated with the Average US Diet by 4 to 6 Percent per capita values, 2009**



Source: GlobAgri model.

Note: "US" data are for United States and Canada. Land-use change emissions are amortized over a period of 20 years and then shown as annual impacts. Calculations assume global average efficiencies (calories produced per hectare or per ton of CO<sub>2</sub>e emitted) for all food types. "Other animal-based foods" includes pork, poultry, eggs, fish (aquatic animals), sheep, and goat.



reduced by 3 percent under the *Eliminate Obesity and Halve Overweight* scenario and by 2 percent under the *Halve Obesity and Overweight* scenario.



The effects of the two scenarios on the agricultural land use and greenhouse gas emissions associated with the average diet of a high-consuming country—the United States—are shown in Figure 6. The US (Reference) bars show the agricultural land use and greenhouse gas emissions associated with the average daily US diet in 2009. The other two bars show how the two scenarios would reduce per capita calorie consumption—as well as the associated greenhouse gas emissions—by 6 percent relative to reference under the *Eliminate Obesity and Halve Overweight* scenario and by 4 percent under the *Halve Obesity and Overweight* scenario.

Table 2 shows the global-level effects of the two scenarios on agricultural land use and greenhouse gas emissions in 2009. Relative to the 2009 reference, land use would

decrease by 90 million hectares in the *Halve Obesity and Overweight* scenario and by 140 million hectares in the *Eliminate Obesity and Halve Overweight* scenario. Greenhouse gas emissions from agricultural production would decrease by 2 percent in the *Halve Obesity and Overweight* scenario and 3 percent in the *Eliminate Obesity and Halve Overweight* scenario. In addition, the avoided future emissions from land-use change—assuming diet changes were sustained over time—would be 19.9 billion tons CO<sub>2</sub>e in the *Halve Obesity and Overweight* scenario and 34.6 billion tons CO<sub>2</sub>e in the *Eliminate Obesity and Halve Overweight* scenario.<sup>75</sup> To put this reduction in perspective, global greenhouse gas emissions in 2009 were 44 billion tons CO<sub>2</sub>e.<sup>76</sup>

Although not quantified here, reducing overconsumption of calories would likely generate significant human health benefits by contributing to a reduction in the incidence of overweight and obesity in the population.

Table 2 | **Global Effects of Reducing Overconsumption of Calories on Agricultural Land Use and Greenhouse Gas Emissions in 2009**

SCENARIO <sup>A</sup>	REDUCTION IN AGRICULTURAL LAND USE <sup>B</sup> (MILLION HA)	AVOIDED FUTURE GHG EMISSIONS FROM AGRICULTURAL LAND-USE CHANGE <sup>C</sup> (MILLION TONS CO <sub>2</sub> E)	REDUCTION IN GHG EMISSIONS FROM AGRICULTURAL PRODUCTION (MILLION TONS CO <sub>2</sub> E)
<b>ELIMINATE OBESITY AND HALVE OVERWEIGHT</b> APPLIED TO 1,385 M PEOPLE 	<b>84 Pastureland</b> <b>54 Cropland</b> TOTAL 138	34,564	194
<b>HALVE OBESITY AND OVERWEIGHT</b> APPLIED TO 1,046 M PEOPLE 	<b>56 Pastureland</b> <b>36 Cropland</b> TOTAL 92	19,908	126

Source: GlobAgri model.

Notes:

a. Reference scenario included a world population of 6.8 billion, agricultural land use of 5 billion hectares (3.4 billion hectares of pastureland and 1.6 billion hectares of cropland), and 6.9 billion tons of greenhouse gas emissions from agricultural production.

b. "Cropland" includes land for aquaculture farms.

c. These estimates assume that the diet changes are sustained over time. If other improvements to the food system (e.g., yield gains) allowed the world to avoid future land-use change, these scenarios would allow some existing agricultural lands to revert to native vegetation and sequester the equivalent amount of carbon.

## DIET SHIFT 2: REDUCE OVERCONSUMPTION OF PROTEIN BY REDUCING CONSUMPTION OF ANIMAL-BASED FOODS

The second diet shift aims to reduce overconsumption of protein by reducing consumption of animal-based foods and increasing the proportion of plant-based protein in diets. Overconsumption of protein occurs when consumption exceeds estimated dietary requirements. As with overconsumption of calories, overconsumption of protein results in unnecessary use of inputs and unnecessary environmental impacts related to the production of the excess protein.

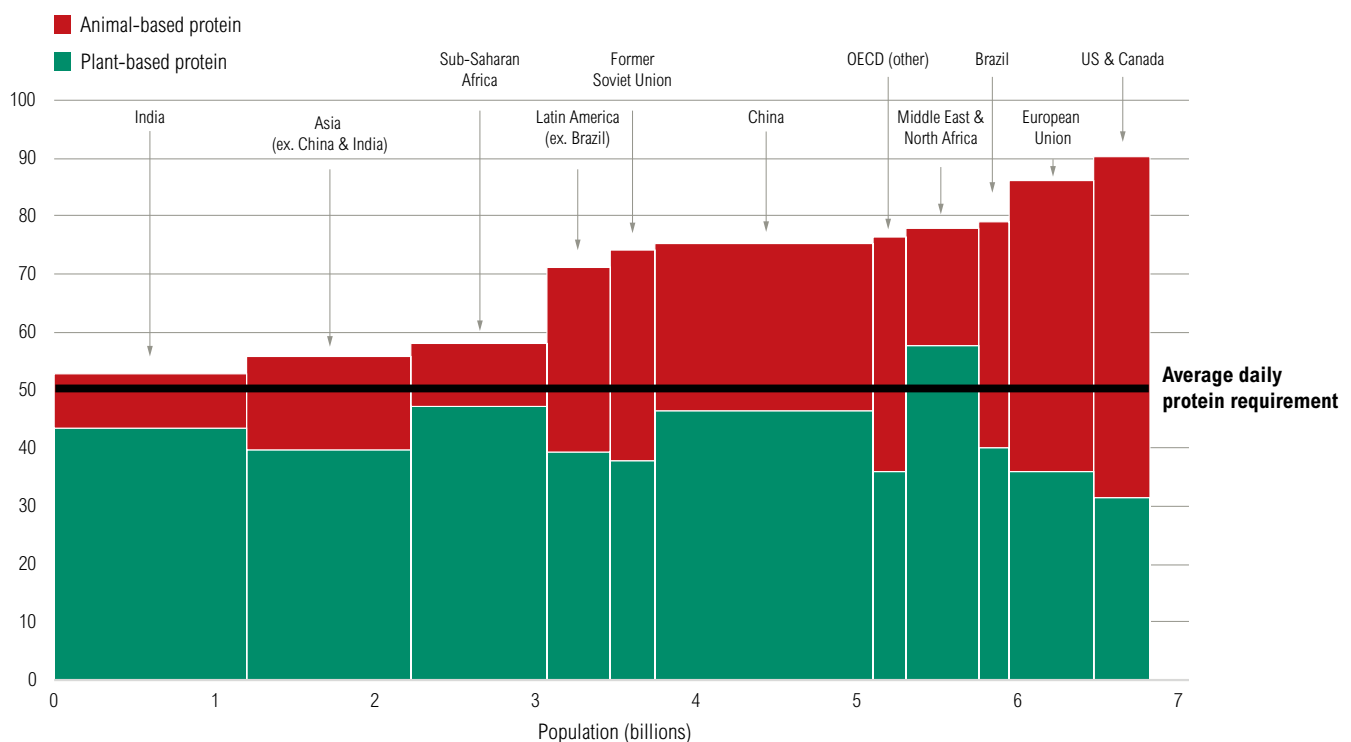
This diet shift targets countries and populations that currently overconsume protein and consume high amounts of animal-based protein—or are projected to by 2050. It does not target undernourished or malnourished people, nor does it seek to eliminate animal-based food consumption, recognizing that livestock production is an important source of livelihood and income.

### What is the issue with overconsumption of protein?

Many people—especially in rich countries—consume more protein than they need. Furthermore, the share of animal-based protein—including meats, dairy, fish, and eggs—is growing in diets.<sup>77</sup> Animal-based protein sources are generally more environmentally impactful and resource intensive to produce than plant-based sources (Figure 2).<sup>78</sup>

In much of the world, protein consumption exceeds estimated dietary requirements. The average daily protein requirement for adults is around 50 grams per day,<sup>79</sup> although individual requirements vary, as they do for energy.<sup>80</sup> However, in 2009, global average per capita protein consumption was approximately 68 grams per day—or 36 percent higher than the average daily adult requirement.<sup>81</sup> In the world's wealthiest regions, protein consumption was higher still (Figure 7). In more than 90 percent of the world's countries and territories, average daily per capita protein consumption exceeded estimated requirements in 2009.<sup>82</sup>

Figure 7 | **Protein Consumption Exceeds Average Estimated Daily Requirements in All the World's Regions, and is Highest in Developed Countries**  
g/capita/day, 2009



Source: GlobAgri model with source data from FAO (2015) and FAO (2011a). Width of bars is proportional to each region's population. Average daily protein requirement of 50 g/day is based on an average adult body weight of 62 kg (Walpole et al. 2012) and recommended protein intake of 0.8 g/kg body weight/day (Paul 1989). Individuals' energy requirements vary depending on age, gender, height, weight, pregnancy/lactation, and level of physical activity.

In addition to overall overconsumption of protein, the dietary share of animal-based protein relative to plant-based protein is growing globally (Figure 8). Meat and protein are often considered more desirable than plant-based food sources, although misconceptions about the importance of meat and protein in diets are common (Box 6). As incomes rise and people move to urban areas, people typically shift from low-cost plant-based foods to higher-cost diets more heavy in animal-based food sources.<sup>83</sup> Changes across food value chains—including high investment in the animal-food sector and feed crops, increases in livestock productivity, improvements in milk pasteurization and cold chains, and a drop in prices of animal-based foods relative to plant-based foods—have also contributed to the rise in animal-based food consumption.<sup>84</sup>

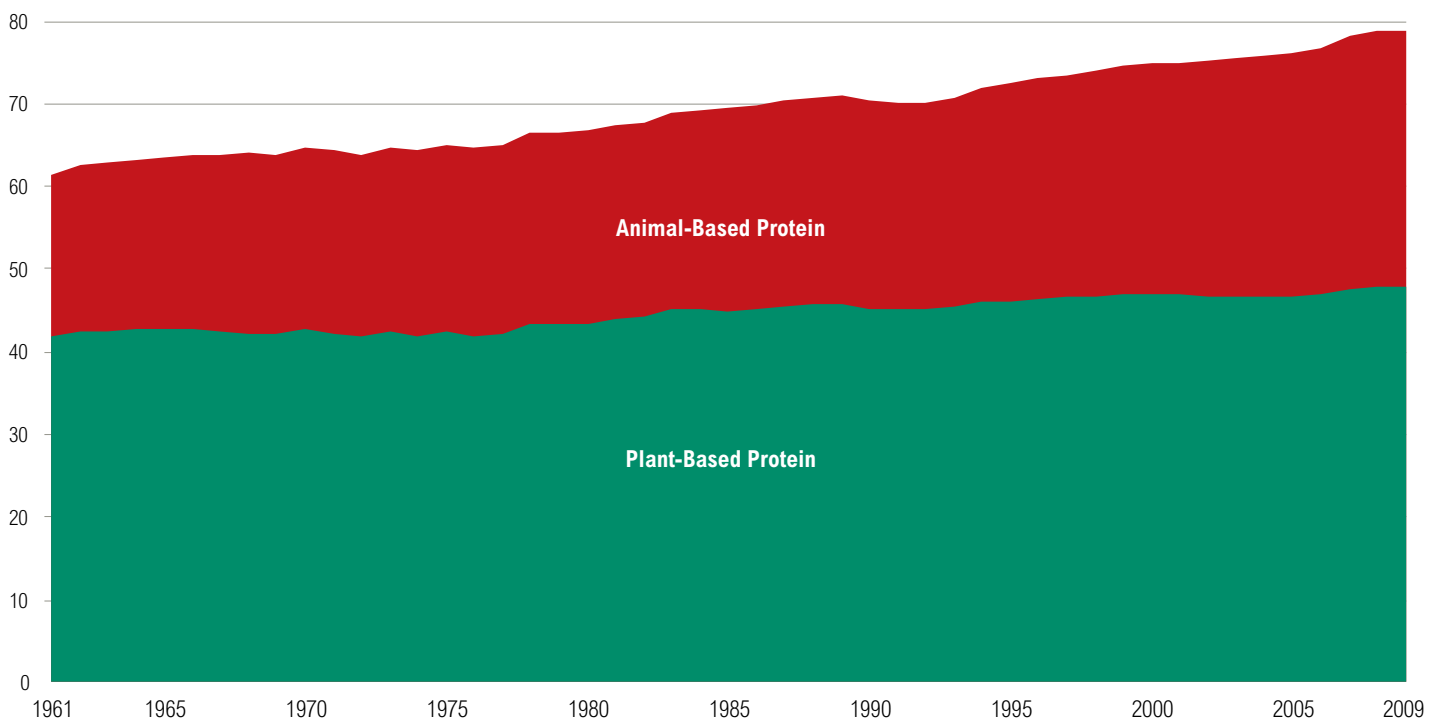
Global average per capita availability of animal-based protein grew faster (59 percent) than that of plant-based protein (14 percent) over the period 1961 to 2009 (Figure 8). Given that the average per capita consumption of protein already greatly exceeds estimated dietary requirements in the world's wealthiest regions, it is possible to reduce consumption of

animal-based protein in overconsuming populations without risk that diets will be deficient in protein.

However, reducing consumption of animal-based foods should not be a goal for people who are underconsuming. Animal-based foods provide a concentrated source of some vitamins and minerals that are particularly valuable to young children in developing countries whose diet is otherwise poor.<sup>85</sup> Studies have demonstrated large benefits from modest increases in meat in the diets of the poor in sub-Saharan Africa.<sup>86</sup>

Given that consumption of animal-based foods will likely continue to grow in developing countries, this diet shift preserves an abundant role for the world's small livestock farmers.<sup>87</sup> In one survey of low-income countries, nearly two-thirds of rural households kept livestock. Another survey of 13 low-income countries in Asia, Latin America, and Africa found that livestock provided 10–20 percent of the average income of rural households in each of the lowest three of five income categories.<sup>88</sup> For these reasons, the analysis in this paper focuses on reductions in animal-based protein consumption only in regions with high levels of consumption.<sup>89</sup>

Figure 8 | **Per Capita Availability of Animal-Based Protein has Grown Faster than Plant-Based Protein over the Past 50 Years**  
g/capita/day, 2009



Source: FAO (2015).

Box 6 | **Debunking Protein and Meat Myths**

Protein is an essential macronutrient for building, maintaining, and repairing the human body's tissues. Nine of the 20 amino acids that are used to make protein cannot be produced by the human body and must be obtained from food. However, several myths overstate the importance of protein in diets, especially from animal-based sources.

■ **MYTH: More protein is better**

More protein is not necessarily better, unless an individual is malnourished or undernourished. Although the word “protein” comes from the Greek *proteios*, meaning “of prime importance,” protein is no more important than the other nutrients required for good health. While protein is an essential part of a healthy diet, people may not need as much as they think. For instance, the average American adult consumed 66 percent more protein per day in 2012 than the average estimated daily requirement, but 21 percent of adults still considered themselves deficient in protein in a 2014 survey.<sup>a</sup> The World Health Organization suggests that only 10–15 percent of the daily calorie requirement needs to come from protein.<sup>b</sup> A balanced plant-based diet can easily meet this need. Overconsumption of protein is linked to some health problems, including kidney stones and the deterioration of kidney function in patients with renal disease.<sup>c</sup>

■ **MYTH: Animal-based foods are better sources of protein than plant-based foods**

This myth stems from the fact that animal-based foods provide a complete source of the essential amino acids that humans need, while plant-based foods—with the exception of a few such as soy and quinoa—lack some amino acids. However, plant-based foods can be readily combined to provide the full set of essential amino acids, as with rice and beans or peanut butter and bread. And while meat also contains high levels of essential micronutrients, including iron, A and B vitamins, and zinc, a diverse plant-based diet can also provide an adequate supply of micronutrients.<sup>d</sup> However, people following a strictly plant-based diet must take care to get enough Vitamin B12, which only occurs naturally in animal-based foods but is available in supplements.<sup>e</sup>

■ **MYTH: Plant-based foods need to be combined in single meals to meet protein nutritional needs**

It is not necessary to ensure that plant-based protein sources are combined to produce a complete set of essential amino acids at every meal sitting. Separate consumption of amino acids during different meals still ensures the nutritional benefits of complementarity.<sup>f</sup> Once consumed, both animal- and plant-based proteins are broken down during digestion into separate amino acids. These amino acids are then stored for later use by the body.<sup>g</sup>

Notes:

a. USDA (2014), French (2015).

b. WHO (2003).

c. WHO, FAO, and UNU (2007).

d. Craig and Mangels (2009).

e. Antony (2012).

f. Young and Pellett (1994).

g. Tufts University Health & Nutrition Letter (2012).

## Why does it matter?

Overconsumption of protein and the increasing share of animal-based protein in diets pose a significant threat to achieving a sustainable food future. The production of animal-based foods accounted for more than three-quarters of global agricultural land use and around two-thirds of agriculture's production-related greenhouse gas emissions in 2009, while only contributing 37 percent of total protein consumed by people in that year.<sup>90</sup> Furthermore, because many animal-based foods (e.g., pork and poultry) rely on crop-based feed, increased demand for these foods will widen the food gap relative to increased demand for plant-based foods.

Modern livestock systems that concentrate animals for all or part of their lives can increase production efficiencies, but with tradeoffs for other sustainability objectives.<sup>91</sup> They tend to concentrate manure, which can lead to odor and water pollution problems.<sup>92</sup> They can also give rise to animal welfare concerns.<sup>93</sup> The use of antibiotics to prevent infections in concentrated livestock production systems also raises indirect human health concerns. Studies have linked the use of antibiotics in livestock production to rising antimicrobial resistance—a serious health threat to people.<sup>94</sup>

In terms of the direct impacts of animal-based food consumption on human health, there is conflicting evidence about whether high consumption of some animal-based foods is linked to noncommunicable diseases. Some studies have linked red meat consumption with cardiovascular disease, type 2 diabetes, and colorectal cancer.<sup>95</sup> Red meat also has been associated with increases in total mortality by 10–44 percent,<sup>96</sup> cardiovascular disease mortality by 18–28 percent,<sup>97</sup> and cancer mortality by 10–32 percent.<sup>98</sup> Other research has highlighted the importance of distinguishing between unprocessed red meats (e.g., beef, veal, pork, lamb) and processed meats (e.g., bacon, bologna, sausages, salami) when linking health outcomes with meat consumption.<sup>99</sup> The International Agency for Research on Cancer, for example, has classified processed meat (Box 7) as “carcinogenic to humans,” while listing red meat as “probably carcinogenic.”<sup>100</sup> Generally, it is difficult to distinguish the effects of consuming an individual food from the effects of the rest of the diet on human health, and of course correlation is not necessarily causation.

## What are the trends?

Globally, per capita consumption of animal-based protein has been rising since 1961.<sup>101</sup> Figure 9 shows how per capita animal-based protein availability has changed over time for a range of countries and regions. Looking forward, we project a 79 percent increase in total consumption of animal-based foods (measured in calories) between 2006 and 2050.<sup>102</sup>

Countries with high average per capita availability of animal-based protein in 2011 were typically high-income countries, such as the United States, Western European countries, and Japan. As shown in Figure 7, in the United States, Canada, and the European Union, consumption of animal-based protein alone (after adjusting availability figures downward for food loss and waste during the consumption stage) exceeded estimated daily requirements for protein from all sources in 2009.<sup>103</sup> In some high-consuming countries, availability has plateaued and even declined. Possible factors for peaking or declining availability include market saturation, slowing income growth, moral and ethical concerns, and health concerns.<sup>104</sup>

The variation in current levels of animal-based protein consumption among developed countries suggests that lowering per capita consumption is possible. For example, per capita meat consumption in the United Kingdom is one-third less than in the United States.<sup>105</sup>

## Box 7 | Are Processed Foods Relevant to a Sustainable Food Future?

Food processing occurs across a spectrum, running from unprocessed and minimally processed foods (e.g., peeled or frozen vegetables, fresh milk, white rice) through moderately processed foods with added flavors (e.g., salted peanut butter, sweetened yogurt, whole-grain breads), to highly processed foods whose original food sources are unrecognizable (e.g., soups, potato chips, chicken nuggets, fish fingers, crackers, frozen pizza, soft drinks, candy).<sup>a</sup> Globally, processed foods are a growing portion of people’s diets at all income levels.<sup>b</sup>

Food processing can contribute to a sustainable food future. In countries with limited food processing, for instance, losses in food storage and retailing tend to be high. Processing can be an important means of reducing food losses, preserving food, and contributing to a safe and abundant food supply.<sup>c</sup> In countries that consume high amounts of animal-based foods, food processors can play a critical role in holding down demand for those foods by reformulating products high in animal-based ingredients to contain a larger share of plant-based ingredients, or by introducing vegetarian substitutes (as discussed later in this paper).

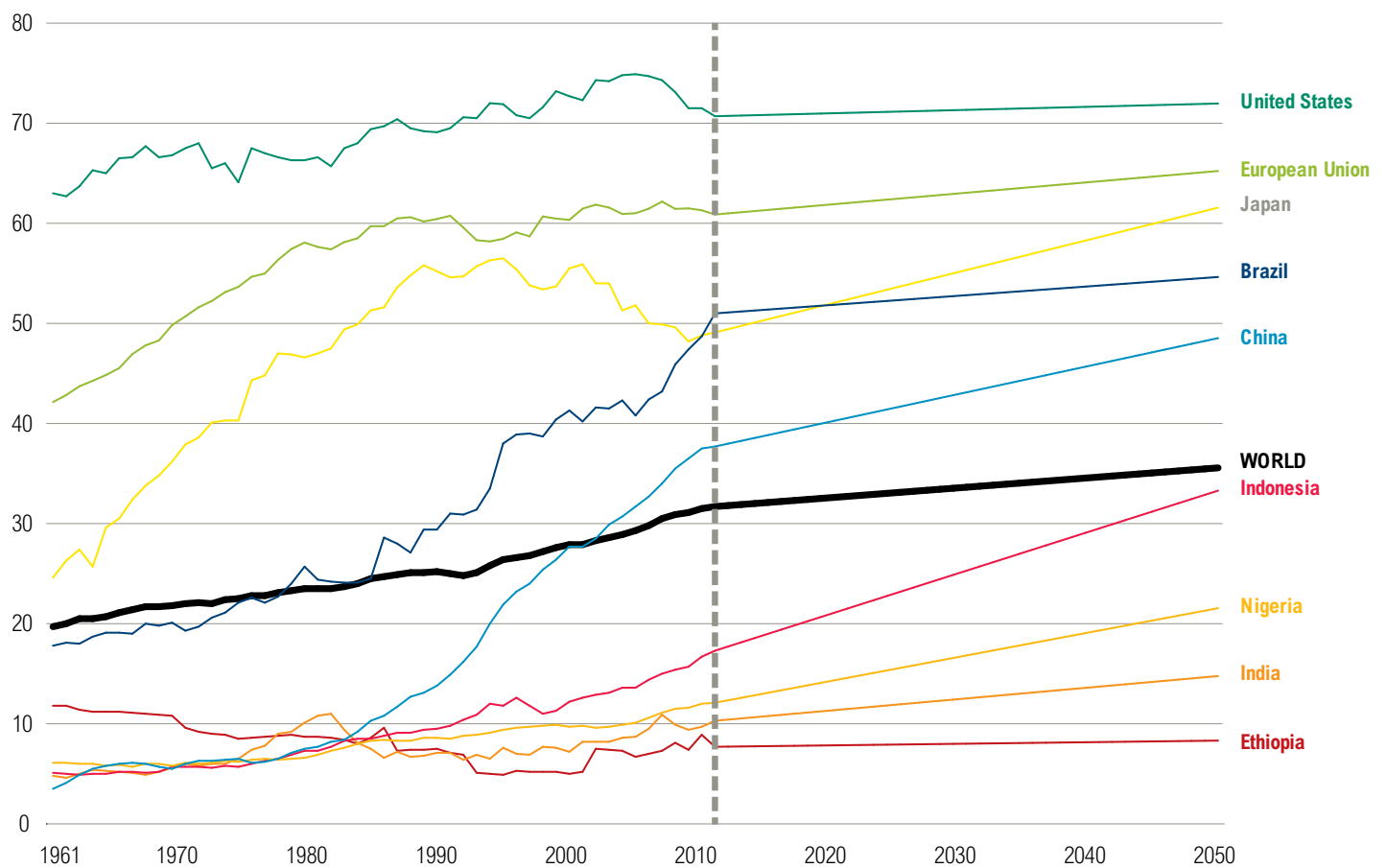
However, excessive consumption of processed foods may also contribute to adverse health impacts, such as those arising from obesity and poor dietary quality.<sup>d</sup> This is because some highly processed foods contain higher levels of sugars, sodium, and fats; lower levels of fiber; and are of overall lower nutritional value than unprocessed or minimally processed foods.<sup>e</sup>

This paper focuses on greenhouse gas emissions and land use at the farm level, and not in food processing, because the bulk of emissions and nearly all of the land use demands occur on the farm. The majority of greenhouse gas emissions from farm to fork—in the case of animal-based products, between 60 and 90 percent—tend to occur during agricultural production.<sup>f</sup> Processing, retail, and cooking can make up a large share of emissions in wealthy countries and for some highly processed food products, such as tomato ketchup.<sup>g</sup> Still, because greenhouse gas emissions related to processing, transportation, retail, and household consumption primarily result from energy use, these emissions can best be addressed through mitigation in the energy sector rather than the agriculture sector.

### Notes:

- a. Poti et al. (2015).
- b. Popkin (2014).
- c. Floros et al. (2010).
- d. Poti et al. (2015).
- e. Moubarac et al. (2013).
- f. Arcand et al. (2012), Foster et al. (2006).
- g. Andersson et al. (1998).

Figure 9 | **Per Capita Availability of Animal-Based Protein is on the Rise**  
g/capita/day



Sources: FAO (2015) for historical data 1961–2011, authors' calculations based on Alexandratos and Bruinsma (2012) for 2050 projection, linear interpolation from 2012–2050.

Countries with rapidly rising per capita availability of animal-based protein as of 2011 have typically experienced increased per capita income, urbanization, and access to supermarkets and restaurants.<sup>106</sup> These include China and Brazil. India is an exception as its per capita availability of animal-based protein has remained relatively low even as incomes have risen. India's lower consumption level likely results from cultural and religious factors. Within developing countries and emerging economies, per capita consumption of animal-based foods tends to be highest in urban areas. For example, in China in 2011, per capita animal-based food consumption was nearly twice as high in urban areas as in rural areas.<sup>107</sup>

Strong growth in per capita animal-based protein availability is projected to continue to 2050 in China and Indonesia, with slower growth projected in Brazil.

Growth in animal-based protein consumption has been driven by rising demand for poultry, which has increased at around three times the rate of population growth over each of the past five decades.<sup>108</sup> This trend will likely continue, with total global poultry consumption projected to grow by nearly 130 percent (i.e., more than doubling) between 2006 and 2050, outpacing growth in all other animal product sectors.<sup>109</sup>

Low-income countries typically have low per capita availability of animal-based protein. For example, in Ethiopia, animal-based protein availability has stayed below 10 grams per person per day for decades, even as the world average grew to more than 30 grams per person by 2011 (Figure 9). Solutions to sustainably increase livestock and fish production are discussed in other papers in the *Creating a Sustainable Food Future* series.<sup>110</sup>



Looking forward, our projections (based on FAO projections adjusted upward to ensure adequate caloric availability) estimate an increase in per capita availability of animal-based foods in sub-Saharan Africa of 34 percent between 2006 and 2050 (measured by calories). However, even with this 34 percent increase, animal-based protein availability across sub-Saharan Africa would still only be 13 grams per person per day in 2050—the equivalent of just one-and-a-half cups of whole milk and less than half of world average animal-based protein availability in 2011. Because FAO projects that more than 2 billion people in sub-Saharan Africa will continue to consume low amounts of animal-based foods in 2050, our overall food demand estimates for 2050 (leading to the 70 percent food gap) are arguably conservative. Studies that assume animal-based food consumption will rise in ways that match the global patterns for increases in income project greater growth in animal-based food consumption than the FAO.<sup>111</sup>

### What would be the land and greenhouse gas effects of reducing overconsumption of protein by reducing consumption of animal-based foods?

Reducing overconsumption of protein by reducing consumption of animal-based foods could reduce agricultural resource use and environmental impacts. Using the GlobAgri model, we ran three scenarios of diet shifts away from animal-based foods. For each scenario, we examined the per person effects in one high-consuming country (the United States) and then aggregate effects across high-consuming segments of the global population.<sup>112</sup>

We applied the *Ambitious Animal Protein Reduction* scenario (see below) to all regions overconsuming both protein and calories, home to nearly 2 billion people or 28 percent of world population in 2009. The scenario, the most ambitious of the three, was designed to be an “upper bound” for what might be achieved by altering the diets of a vast population. Two other scenarios—the *Traditional Mediterranean Diet* and *Vegetarian Diet* scenarios—were based on actual diet patterns in Mediterranean countries in 1980 and among UK vegetarians in the 1990s. We applied these two more “realistic” scenarios over a much smaller number of people (only 440 million) for two reasons. First, for the latter two scenarios we only altered diets of regions and countries consuming high amounts of animal-based protein in 2009—namely Europe, the United States, and Canada. Second, noting that a 100 percent shift of a region’s population to a Mediterranean or vegetarian diet was unlikely, we only altered the diets of half of those regions’ populations.

■ **AMBITIOUS ANIMAL PROTEIN REDUCTION SCENARIO.** This scenario modified average per capita animal-based protein consumption levels in regions where average daily per capita consumption (of all foods, both plant- and animal-based) was above 60 grams of protein and 2,500 calories in 2009—indicating overconsumption.<sup>113</sup> These regions<sup>114</sup> were home to 1.9 billion people in 2009. In each overconsuming region, protein consumption was reduced to exactly 60 grams per capita per day by reducing consumption of only animal-based foods.<sup>115</sup> Overall, this scenario reduced animal-based protein consumption in 2009 by about half in the United States, Canada, and Brazil; by about one-quarter in the European Union; and by 17 percent globally.<sup>116</sup> Because this scenario reduced animal-based food consumption in regions overconsuming protein, and did not increase consumption of any other foods, overall world calorie consumption was reduced by 2.4 percent.<sup>117</sup>

■ **TRADITIONAL MEDITERRANEAN DIET SCENARIO.** This scenario modified the diets of the European Union, the United States, and Canada—regions that consumed more than 2,500 calories and 40 grams of animal-based protein per person per day in 2009. We modified diets to reflect the food consumption patterns in Spain and Greece in 1980 as given in FAO (2015). We chose the year 1980 to more closely mimic what people probably think is the “traditional Mediterranean diet,” before the rise in obesity in these countries. The “traditional Mediterranean diet” promoted and studied by health experts is defined as high in fruits, vegetables, pulses, whole grains, fish, and poultry; but low in red meats, sugars, and whole-fat dairy.<sup>118</sup> It is true that the Spanish/Greek diet in 1980 (compared to the European, US, and Canadian diets in 2009) contained smaller shares of sugars, dairy, and most meats (including beef), as well as larger shares of fish, pulses, fruits, and vegetables. However, the Spanish/Greek diet in 1980 also contained larger shares of eggs and sheep and goat meat than the European, US, and Canadian diets in 2009,<sup>119</sup> meaning that the overall proportion of animal-based foods consumed did not change much under this scenario. In each region modified, we modified the diets of half of the population,<sup>120</sup> or around 440 million people in all. We held overall calorie consumption constant from 2009 reference levels to isolate the effect of the diet shift.



- **VEGETARIAN DIET SCENARIO.** As in the *Traditional Mediterranean Diet* scenario, consumption was modified in the European Union, the United States, and Canada only, shifting half of the population (around 440 million people) to the actual average vegetarian diet as observed in the EPIC-Oxford cohort study, conducted in the United Kingdom between 1993 and 1999.<sup>121</sup> For purposes of this scenario, a vegetarian diet may contain eggs or dairy, but no meat. Overall calorie consumption was held constant from 2009 reference levels to isolate the effect of the diet shift away from animal-based foods.

We first examine the effects of applying the three scenarios to the average consumption pattern of one high-consuming country—the United States. The results are shown in Figure 10. The “US (Reference)” bars show the average US daily diet in 2009, and the associated agricultural land use and greenhouse gas emissions. The “World (Reference)” bars show the average world daily diet, and the associated land use and emissions, for comparison’s sake. The findings from applying these three scenarios to the average US daily diet in 2009 are summarized below:<sup>122</sup>

- The land use and greenhouse gas impacts of the US diet are overwhelmingly driven by consumption of animal-based foods. Almost 90 percent of the agricultural land used to produce the average US diet stemmed from animal-based food production (shown in red, orange, and yellow in Figure 10), including both cropland and pasture. Similarly, almost 85 percent of the greenhouse gas emissions associated with producing the food for the average US diet were related to animal-based foods.
  - The *Ambitious Animal Protein Reduction* scenario reduced per person agricultural land use and production-related greenhouse gas emissions by 40 to 45 percent relative to reference.
  - Shifting to a *Traditional Mediterranean Diet* had a modest effect, reducing per person agricultural land use and production-related greenhouse gas emissions by just over 10 percent relative to reference.
  - The *Vegetarian Diet* scenario reduced per person agricultural land use and production-related greenhouse gas emissions by around 50 percent relative to reference, with emissions shrinking by more than one-half. These reductions were achieved even with a four-fold increase in the consumption of fruits and vegetables.
- The effects of eliminating meat consumption<sup>123</sup> dwarfed the smaller effects from increased consumption of plant-based foods.<sup>124</sup>
- Both the *Ambitious Animal Protein Reduction* scenario and the *Vegetarian Diet* scenario reduced the per person land use and greenhouse gas emissions associated with the US diet to around those associated with the world average diet. In fact, the *Ambitious Animal Protein Reduction* scenario when applied to the United States was strikingly similar to the 2009 world average diet.
- The global effects of applying the three scenarios to food consumption in 2009 are shown in Table 3 and summarized below:
- The *Ambitious Animal Protein Reduction* scenario delivered the greatest land use and greenhouse gas reduction benefits, because it delivered large per person benefits (Figure 10) and was also applied across the diets of 1.9 billion people. Total agricultural land use declined by 13 percent (nearly 650 million hectares)—equivalent to an area of land roughly twice the size of India, or greater than the entire area of land converted to agriculture between 1961 and 2006.<sup>125</sup> Pastureland declined by 15 percent (about 500 million hectares) and cropland declined by about 9 percent (130 million hectares) thanks to the reduced need for animal feed. Greenhouse gas emissions from agricultural production declined by 10 percent. Sparing this large land area from agricultural use could also avoid future greenhouse gas emissions from land-use change. Assuming diet changes were sustained over time, this scenario would avoid 168 billion tons of emissions of CO<sub>2</sub>e. To put this reduction in perspective, global greenhouse gas emissions in 2009 were 44 billion tons CO<sub>2</sub>e.<sup>126</sup>
  - The *Traditional Mediterranean Diet* scenario, when applied to half of the population of high-consuming regions, had only minor impacts on land use and greenhouse gas emissions. Total agricultural land use and production-related greenhouse gas emissions declined by less than 0.5 percent.<sup>127</sup> As noted above, this minor impact is due to the fact that overall animal-based food consumption did not actually drop by much in this scenario relative to reference. In particular, consumption of ruminant meats (i.e., beef, sheep, and goat) in Spain and Greece in 1980 was lower than in the United States and Canada in

**Figure 10 | Reducing Consumption of Animal-Based Foods Reduces the Agricultural Land Use and Greenhouse Gas Emissions Associated with the Average US Diet by up to Half per capita values, 2009**



Source: GlobAgri model.




Note: All "US" data are for United States and Canada. Calculations assume global average efficiencies (calories produced per hectare or per ton of CO<sub>2</sub>e emitted) for all food types. The vegetarian diet scenario, which uses data from Scarborough et al. (2014), includes small amounts of meat, as "vegetarians" were self-reported.

2009, but actually higher than in the European Union in 2009.<sup>128</sup> As a result, the modest land use and greenhouse gas reductions from this scenario when applied to the US diet (Figure 10) were mostly canceled out when the scenario was applied more broadly to include a region with a lower level of ruminant meat consumption.

- The *Vegetarian Diet* scenario, which shifted half of the population of high-consuming regions to vegetarian diets, reduced land use and greenhouse gas emissions by a greater amount than the *Traditional Mediterranean Diet* scenario, but a lesser amount than the *Ambitious Animal Protein Reduction* scenario. Total agricultural land use declined by 150 million hectares, and greenhouse gas emissions declined

by 4 percent. If the diet changes were sustained over time, this scenario also would avoid 37 billion tons of emissions of CO<sub>2</sub>e from future land-use change—an amount approaching total greenhouse gas emissions in 2009.<sup>129</sup> It is important to note, however, that the much smaller global benefits of the *Vegetarian Diet* scenario, relative to the benefits of the *Ambitious Animal Protein Reduction* scenario, were due primarily to the lower level of ambition of the *Vegetarian Diet* scenario. The *Vegetarian Diet* scenario was applied to a smaller number of people (only 440 million versus 1.9 billion) for the reasons discussed above. However, per person environmental benefits of the *Vegetarian Diet* and the *Ambitious Animal Protein Reduction* scenarios were similar (Figure 10).

Table 3 | **Global Effects of Reducing Overconsumption of Protein by Reducing Consumption of Animal-Based Foods on Agricultural Land Use and Greenhouse Gas Emissions in 2009**

SCENARIO <sup>a</sup>	REDUCTION IN AGRICULTURAL LAND USE <sup>b</sup> (MILLION HA)	AVOIDED FUTURE GHG EMISSIONS FROM AGRICULTURAL LAND-USE CHANGE <sup>c</sup> (MILLION TONS CO <sub>2</sub> E)	REDUCTION IN GHG EMISSIONS FROM AGRICULTURAL PRODUCTION (MILLION TONS CO <sub>2</sub> E)
<b>AMBITIOUS ANIMAL PROTEIN REDUCTION</b> APPLIED TO 1,907 M PEOPLE 	<b>508 Pastureland</b> <b>133 Cropland</b> TOTAL 641	168,206	715
<b>TRADITIONAL MEDITERRANEAN DIET</b> APPLIED TO 437 M PEOPLE 	<b>14 Pastureland</b> <b>4 Cropland</b> TOTAL 18	-4,066	10
<b>VEGETARIAN DIET</b> APPLIED TO 437 M PEOPLE 	<b>113 Pastureland</b> <b>37 Cropland</b> TOTAL 150	36,532	287

Source: GlobAgri model.

Notes:

a. Reference scenario included a world population of 6.8 billion, agricultural land use of 5 billion hectares (3.4 billion hectares of pastureland and 1.6 billion hectares of cropland), and 6.9 billion tons of greenhouse gas emissions from agricultural production.

b. "Cropland" includes land for aquaculture farms.

c. These estimates assume that the diet changes are sustained over time. If other improvements to the food system (e.g., yield gains) allowed the world to avoid future land-use change, these scenarios would allow some existing agricultural lands to revert to native vegetation and sequester the equivalent amount of carbon.

Taken together, this analysis suggests that reducing overconsumption of protein by reducing consumption of animal-based foods could make a significant contribution to a sustainable food future. Moreover, these findings are in line with those of other researchers (Box 8). Benefits include deep per person savings in land use and greenhouse gas emissions among high-consuming populations, and dramatic reductions in agricultural land use—and

greenhouse gas emissions associated with land-use change—at the global level, provided that a large number of people shift their diets. Large reductions in land use resulting from a reduction in animal-based food consumption could free up enough land to meet future growth in animal-based food consumption for those who are currently low consumers—without net agricultural expansion.

## Box 8 | Summary of Findings from Previous Studies

Several publications have used models to estimate the effects of reducing consumption of animal-based foods on resources and the environment.<sup>a</sup> In particular, models that account for all sources of animal feed—including both human-edible grains and human-inedible grasses—have found that large reductions in animal-based protein consumption could more than offset the increased land-use demands arising from projected growth in food demand to 2050, even if some decreases in animal-based foods were replaced with increases in plant-based foods. These reductions in agricultural land use result from the significant share of crops and land that goes to livestock production; one-quarter to one-third of all crops were used for livestock feed in 2006,<sup>b</sup>

and more than twice as many hectares of land are used for grazing by livestock as are used for the production of all crops combined.<sup>c</sup>

The GlobAgri model builds on previous studies and addresses some of their limitations. Some studies have analyzed only broad and likely unrealistic dietary shifts. For example, Stehfest et al. (2009) analyzed a scenario in which poultry consumption was reduced to 44 percent of projected 2050 levels and beef to 52 percent, with shifts to pulses replacing the animal-based protein. Other studies overestimate the potential land gains from reducing animal-based food consumption by assuming that if people ate fewer animal-based foods, they would replace

them with the maize, wheat, and soybeans that would otherwise have been fed to livestock.<sup>d</sup> In reality, people are more likely to switch to pulses, fruits, and vegetables.<sup>e</sup> The land and emissions savings of these alternative foods, while still significant, are less than the savings that would be achieved if people ate animal feeds (Figure 2). Still other studies are based not on one consistent model, but on average results from multiple studies (often by multiple authors) of the efficiency of various food products. Such an approach can introduce inconsistencies due to different underlying methods and assumptions.<sup>f</sup> GlobAgri, in contrast, applies a consistent methodology to all foods across the world.<sup>g</sup>

Eshel et al. (2009)	Found that a US diet based on animal products required 3–4 times as much land and 2–4 times as much nitrogen fertilizer as a vegetarian alternative.
Stehfest et al. (2009)	Modeled a “healthy diet” scenario, based on recommendations by the Harvard Medical School for Public Health, that included reducing consumption of beef, poultry/eggs, and pork to 52 percent, 44 percent, and 35 percent of global projected consumption levels (respectively) in 2050. The scenario freed up enough existing agricultural land to allow substantial reforestation and sequestering of carbon, and reduced greenhouse gas mitigation costs by more than 50 percent for the period 2005–50.
Bajzelj et al. (2014)	Examined the effects of shifting to “healthy diets” that reduce consumption of sugar, oil, meat, and dairy while increasing consumption of fruits and vegetables. Found that shifting to “healthy diets” reduced global cropland demand by 5 percent, pastureland demand by 25 percent, greenhouse gas emissions by 41 percent, and irrigation water demand by 3 percent relative to 2050 baseline projections.
Hedenus et al. (2014), Bryngelsson et al. (2016)	Found that reducing ruminant meat and dairy consumption—in addition to improving agricultural productivity and efficiency, and reducing greenhouse gas emissions from fossil fuels and deforestation—is a necessary strategy to meet European Union and global emissions targets to limit global warming to 2 degrees Celsius.

## Box 8 | Summary of Findings From Previous Studies (continued)

Scarborough et al. (2014)	Analyzed the greenhouse gas impacts of UK diets and found that relative to an average UK meat-eater diet, vegetarian diets produce one-third fewer greenhouse gases and vegan diets produce one-half fewer greenhouse gases.
Tilman and Clark (2014)	Predicted that global-average per capita dietary greenhouse gas emissions would increase by nearly one-third between 2009 and 2050 as incomes rose. Estimated that, relative to the projected 2050 global-average diet, per capita dietary greenhouse gas emissions would be 30 percent, 45 percent, and 55 percent lower under Mediterranean, pescetarian (vegetarian diet with fish), and vegetarian diets respectively.
Tyszler et al. (2014)	Modeled a diet for the Netherlands that both met nutritional requirements and reduced environmental impacts by reducing consumption of meat, cheese, and milk to 30 percent, 40 percent, and 84 percent (respectively) relative to the average Dutch diet, while raising consumption of fruits, vegetables, nuts, and seeds. The modeled diet provided a 38 percent reduction in greenhouse gas emissions and a 40 percent reduction in land use relative to the average Dutch diet.
Westhoek et al. (2014, 2015)	Predicted that halving consumption of meat, dairy, and eggs in the EU would reduce nitrogen emissions by 40 percent and greenhouse gas emissions by 25–40 percent. Also predicted a 23 percent reduction in domestic cropland needed to feed each EU citizen.
Tom et al. (2015)	Found that shifting from the current US diet to one that reduced overall caloric intake and also followed US dietary guidelines actually <i>increased</i> energy use by 38 percent, blue water footprint by 10 percent, and greenhouse gas emissions by 6 percent. However, the scenario modeled included not only a 25 percent decrease in meat consumption but also a 78 percent <i>increase</i> in dairy consumption—leading to an overall 13 percent <i>increase</i> in animal-based food consumption.

**Notes:**

- a. Because each of the studies discussed in this box uses a different approach, and because some include greenhouse gas emissions from food processing and retail and not merely production-related emissions at the farm, their results are not directly comparable to each other or to GlobAgri results.
- b. Foley et al. (2011) calculates that one-third of all crops are used for animal feed while data used for Alexandratos and Bruinsma (2012) suggest that figure is 25 percent calculated on a caloric basis.
- c. FAO (2011b), FAO (2015).
- d. Foley et al. (2011).
- e. Stehfest et al. (2009), Eshel et al. (2009), Tyszler et al. (2014).
- f. For example, Tom et al. (2015) conducted a meta-analysis of data from life-cycle analyses of energy use, water use, and greenhouse gas emissions of more than 100 food types in industrialized countries, but note that “various climates, transport modes and distances, food-related technology, and production methods are reflected among the data compiled,” not to mention the fact that different studies used different boundaries (e.g., “farm to farm gate” versus “farm to fork”). Because of this, results across the studies averaged might reflect not only true differences in environmental performance among food types but also differences in methods and assumptions among underlying studies.
- g. This methodological consistency enables GlobAgri to analyze issues regarding diets, livestock production systems, emissions, trade, transformations between finished and raw agricultural products, and losses and wastes with great detail.

## DIET SHIFT 3: SHIFT FROM BEEF SPECIFICALLY

The third diet shift focuses on reducing beef consumption or shifting consumption to other animal- and plant-based foods. It targets countries and populations that are high consumers of beef, relative to the world average over the past 50 years, or are projected to be high consumers by 2050. This diet shift focuses on reducing rather than eliminating beef consumption; it recognizes that some beef consumption supports the livelihoods of cattle-dependent pastoralists, makes use of the productive capacity of native grazing lands, or is an offshoot of dairy production.

The term “beef” includes cattle, bison, African buffalo, water buffalo, yak, and the four-horned and spiral-horned antelopes. This shift focuses on cattle because they are the most significant beef source in terms of quantity consumed by people. Cattle are widely consumed around the world, except in countries such as India and Nepal, where they are considered sacred by most Hindus.

### What is the issue with beef?

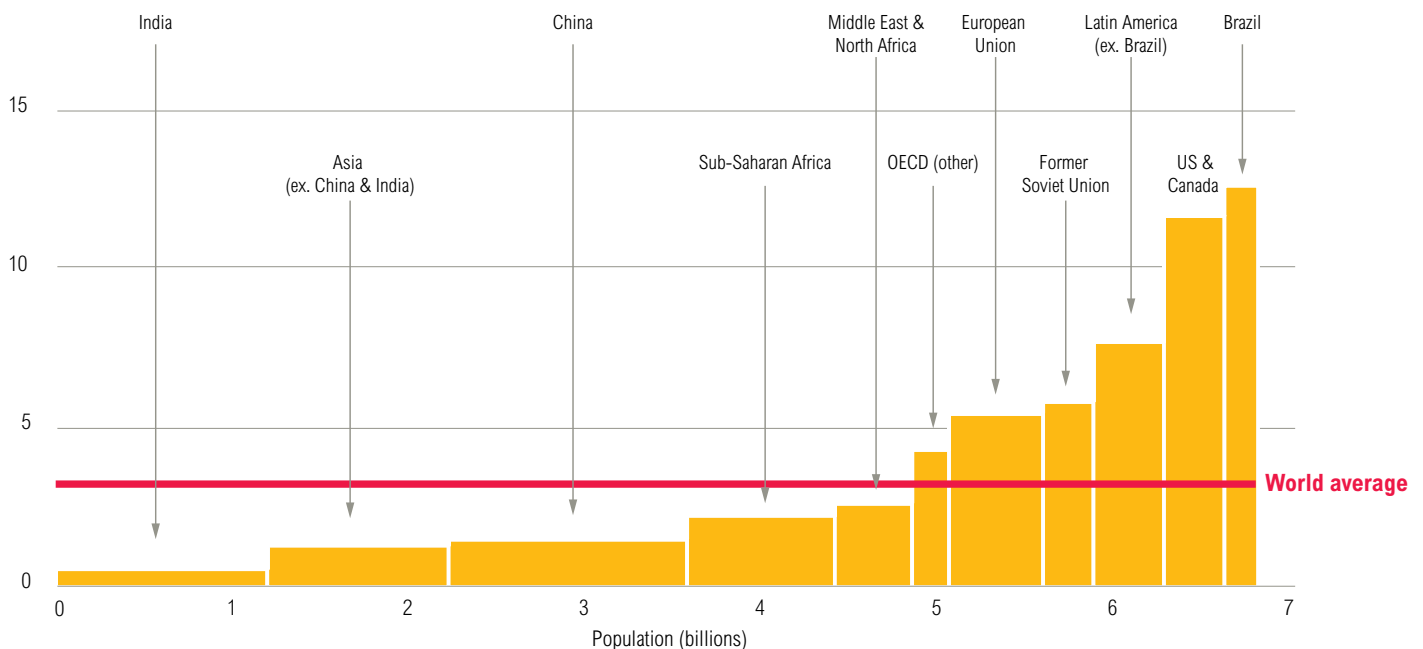
The previous diet shift called for a reduction in overconsumption of protein, of which beef is a source. This diet shift

underscores the importance of reducing beef consumption specifically for two reasons. First, demand for beef is expected to nearly double between 2006 and 2050. Second, cattle have one of the lowest energy conversion efficiencies of all animal-based foods, leading to very high resource use and environmental impacts per unit of beef produced.

Beef is not the primary source of animal-based protein in most regions today, but consumption varies widely by region. World average beef-based protein consumption was 3.2 grams of protein per capita per day in 2009, while in the United States, Canada, and Latin America (including Brazil), people consumed more than twice that amount (Figure 11).<sup>130</sup>

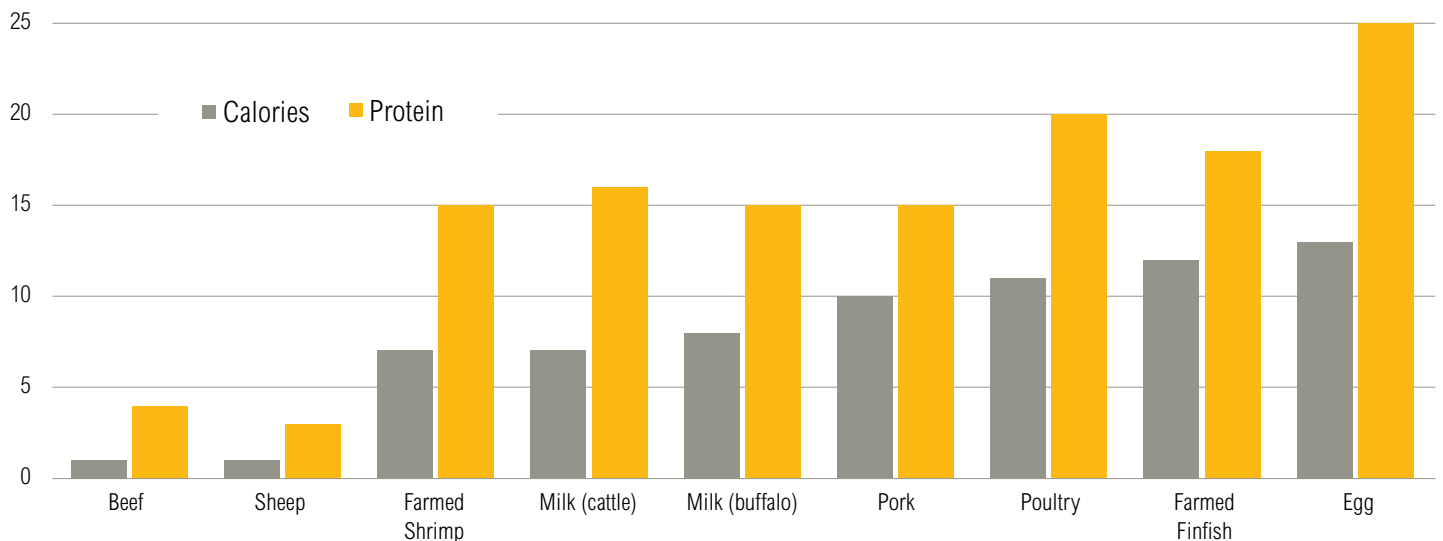
Total demand for beef, however, is projected to increase by 95 percent between 2006 and 2050.<sup>131</sup> This growth will in turn drive increased production. The global population of cattle is projected to increase from 1.5 billion to 2.6 billion head between 2000 and 2050.<sup>132</sup> While traditional pastoralists, in general, use dry, native grazing lands with great efficiency, they manage only a fraction of the world’s cattle. Without significant increases in productivity on remaining pastureland,<sup>133</sup> there is a risk that growing demand for beef, if left unchecked, will drive further expansion of pastureland into natural forests and savannas.

Figure 11 | **Beef Consumption Varies Widely by Region**  
g protein/capita/day, 2009



Source: GlobAgri model with source data from FAO (2015) and FAO (2011a). Width of bars is proportional to each region’s population. World average per capita consumption was 3.2 g of beef-based protein/capita/day.

**Figure 12 | Beef is Inefficient in Creating Human-Edible Calories and Protein**  
Percent or “Units of Edible Output Per 100 Units of Feed Input”



Sources: Terrestrial animal products: Wirsenius et al. (2010), Wirsenius (2000). Finfish and shrimp: WRI analysis based on USDA (2013), NRC (2011), Tacon and Metian (2008), Wirsenius (2000), and FAO (1989).

Notes: “Edible output” refers to the calorie and protein content of bone-free carcass. “Feed input” includes both human-edible feeds (e.g., grains) and human-inedible feeds (e.g., grasses, crop residues).

A near-doubling in beef production would have high environmental impacts, because, as Figure 12 shows, beef is a particularly inefficient animal product. Wirsenius et al. (2010) estimate that only 1 percent of gross cattle feed energy is converted into human-edible calories. In terms of protein, the conversion efficiency from “protein in” to “protein out” is a mere 4 percent. In contrast, by this estimate, milk, pork, poultry, farmed finfish and shrimp, and eggs convert animal feed to edible food at 6 to 13 times the efficiency of beef.<sup>134</sup> While sheep and goat are also highly inefficient—with similar conversion efficiencies to beef—they are consumed in smaller quantities globally. Beef represented 12 percent of global animal-based protein consumption in 2009 versus only 2 percent for sheep and goat combined.<sup>135</sup>

Beef’s conversion efficiency is lower than often assumed. Measures of the conversion efficiency of inputs to human-edible outputs for livestock typically compare quantities of “feed in” with quantities of “food out.” Calculations of “feed in” usually include only human-edible feeds, leaving out feeds that are not edible by people, such as grasses, crop residues, and food processing wastes, even though they constitute roughly 80 percent of livestock feed globally as measured by digestible energy, and an even greater share when measured by weight.<sup>136</sup>

However, in a world where native grasslands are nearly all used, and further expansion of pastureland would convert natural forests and savannas, limiting the “feed in” parameter to human-edible animal feed ignores the large environmental impacts associated with land conversion into pastureland. Given the expected growth in beef demand, these environmental impacts are very relevant. A more complete way to measure conversion efficiencies across livestock products is to count all “feed in” at each stage of production and then compare “energy or protein out” versus “energy or protein in,” as in Figure 12. This more inclusive approach results in lower conversion efficiencies than typically assumed for ruminants such as cattle, sheep, and goat.

### Why does it matter?

Beef consumption has by far the greatest impact on resource use and the environment of all commonly consumed foods (Figure 2), stemming from its low efficiency in converting feed inputs to human edible calories and protein (Figure 12). According to one US study, beef production required 28 times more land per calorie consumed than the average of other livestock categories.<sup>137</sup> One-quarter of the Earth’s landmass, excluding Antarctica, is used as pastureland.<sup>138</sup> Beef production consumes two to four times more freshwater than other livestock categories, and up to 7.5 times more freshwater than plant-based foods, per unit of



protein delivered.<sup>139</sup> Overall, beef accounts for one-third of the global water footprint of farm animal production, more than any other animal category.<sup>140</sup>

Beef also has a disproportionate impact on climate change. Cattle production generates more greenhouse gas emissions per unit of human-edible output than every other commonly eaten animal-based food. Greenhouse gas emissions from cattle production originate from five main sources:

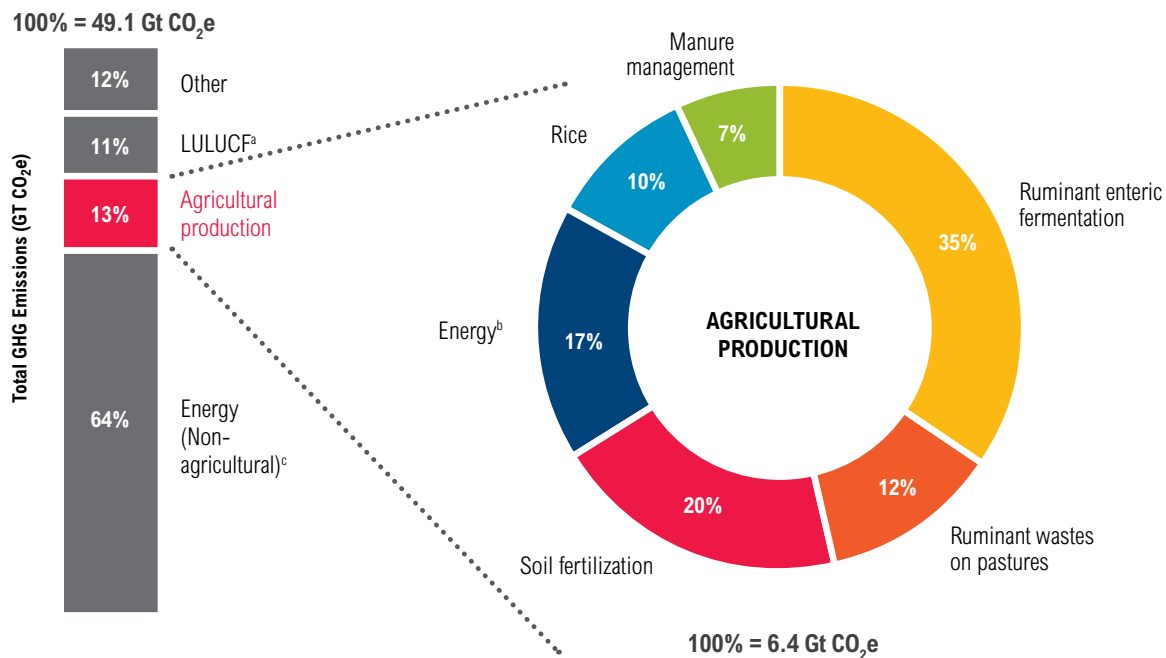
- Methane from the ruminant digestive process (known as “enteric fermentation”)
- Methane from manure management
- Nitrous oxide from excreted nitrogen in manure
- Nitrous oxide from the chemical nitrogenous fertilizers used to produce feed for cattle
- Carbon dioxide and nitrous oxide from deforestation and conversion of grassland into pastureland.

Ruminants such as cattle were responsible for 47 percent of production-related greenhouse gas emissions from agriculture in 2010, without taking land-use impacts into account (Figure 13).<sup>141</sup> Because total greenhouse gas emissions from agricultural production represented 13 percent of global greenhouse gas emissions in 2010, ruminants contributed about 6 percent of total global greenhouse gas emissions in 2010, before accounting for land-use change.<sup>142</sup>

### What are the trends?

Figure 14 shows changes in per capita beef availability over time for a range of countries and regions. By 2050, FAO projects that on a per capita basis, global availability of beef will approach that of the European Union in 2011. Per capita demand growth will be especially strong in China, more than doubling between 2011 and 2050. In Brazil and the United States, two of the world’s top beef consumers as of 2011, per capita consumption is projected to slightly rise and to decline, respectively.<sup>143</sup>

Figure 13 | **Ruminants Contributed Nearly Half of Global Greenhouse Gas Emissions from Agricultural Production in 2010**



Source: WRI analysis based on UNEP (2012), FAO (2012a), EIA (2012), IEA (2012), and Houghton (2008) with adjustments.

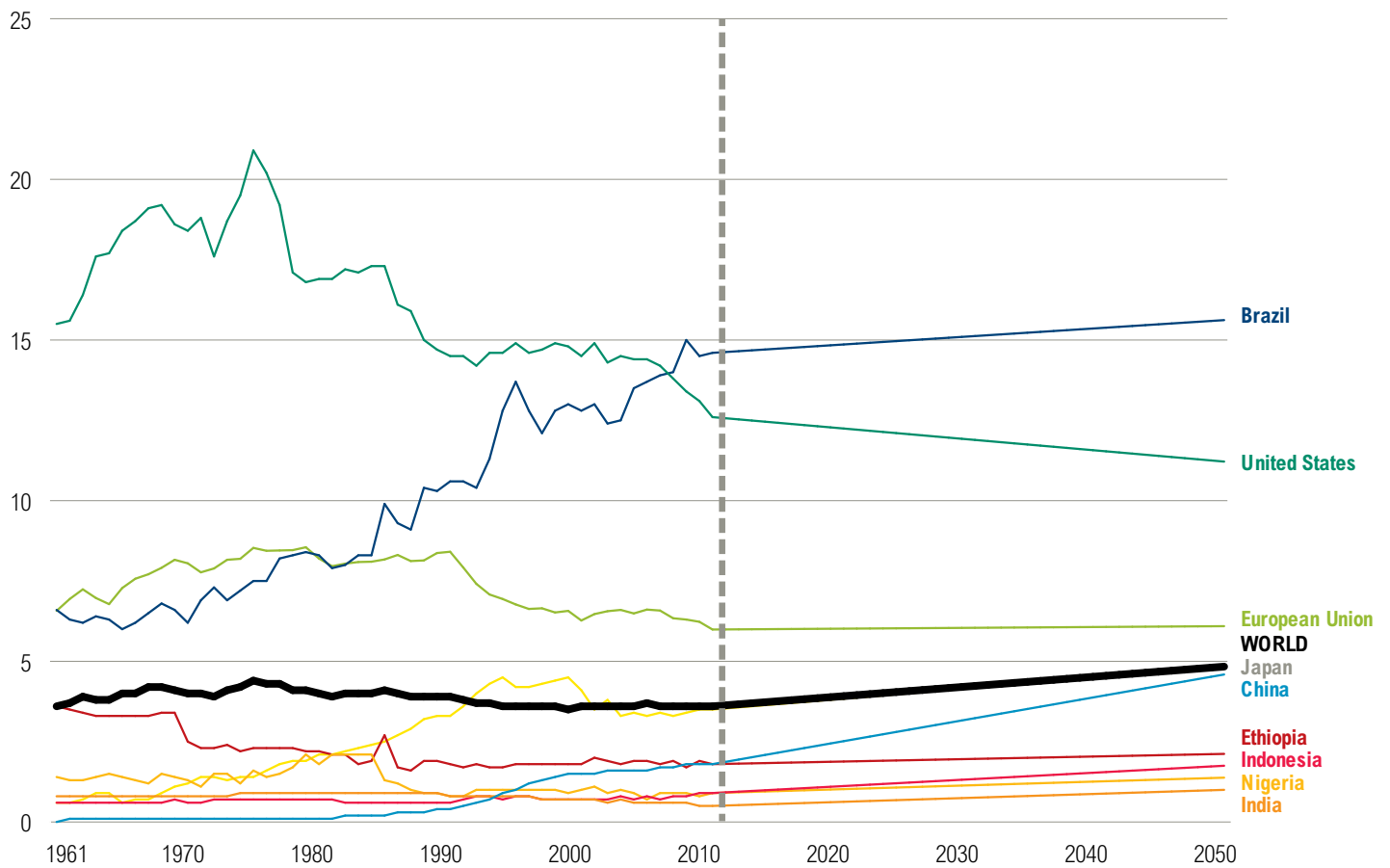
Notes: Figures may not equal 100 percent due to rounding.

a. LULUCF = Land Use, Land-Use Change, and Forestry.

b. Includes emissions from on-farm energy consumption as well as from manufacturing of farm tractors, irrigation pumps, other machinery, and key inputs such as fertilizer. It excludes emissions from the transport of food.

c. Excludes emissions from agricultural energy sources described above.

Figure 14 | **Per Capita Beef Availability is Projected to Rise to 2050**  
g/capita/day



Sources: FAO (2015) for historical data 1961–2011, authors' calculations based on Alexandratos and Bruinsma (2012) for 2050 projection, linear interpolation from 2012–2050.

In the United States and Europe, per capita beef consumption has already receded from historical highs. United States per capita annual beef consumption has declined 27 percent since the 1970s.<sup>144</sup> Reasons postulated for declining beef consumption include health concerns, an increase in women in the workforce (beef takes longer than chicken to prepare), increased availability of low-cost ready-to-cook chicken products, and more families eating in restaurants where other meat choices are available.<sup>145</sup> In Europe, per capita beef availability declined by 29 percent between 1991 and 2011, and is expected to remain relatively stagnant to 2050.<sup>146</sup>

In Brazil, per capita beef availability has increased steadily over the past decades, and is now more than three times the world average, having surpassed the United States

in 2008.<sup>47</sup> In Brazil, Argentina, and other parts of Latin America, beef has become a cultural staple because of abundant grazing land.<sup>148</sup> Nevertheless, Latin America has begun to adopt modern chicken and pork production. It is plausible that a combination of health concerns, increased availability of other livestock products, and public campaigns could help reduce beef consumption in Latin America.

In China, per capita beef availability is still only half of the world average, but it is growing and is expected to continue to grow. In India, growing demand for dairy products, together with higher prices, is spurring an expansion in the cattle population, even while beef consumption remains quite low.<sup>149</sup>

## What would be the land and greenhouse gas benefits of reducing beef consumption?

Reducing beef consumption could reduce agricultural resource use and environmental impacts. Using the GlobAgri model, we ran three scenarios to examine the effects of reducing beef consumption on agricultural land use and greenhouse gas emissions. For each scenario, we examined the per person effects in one high-consuming country (the United States) and the aggregate effects across high-consuming segments of the global population.<sup>150</sup>

- **AMBITIOUS BEEF REDUCTION SCENARIO.** Beef consumption levels were modified in regions where daily per capita beef consumption in 2009 was above the world average of 3.2 grams of protein, and where per capita average calorie consumption was above 2,500.<sup>151</sup> In each of these regions—together home to 1.5 billion people in 2009—per capita beef consumption was reduced to the world average.<sup>152</sup> This scenario led to a 20 percent reduction in beef in Latin America (excluding Brazil); 40 percent in Europe; and more than 70 percent in Brazil, Canada, and the United States. Globally, the scenario led to a 30 percent reduction in beef consumption.<sup>153</sup>
- **SHIFT FROM BEEF TO PORK AND POULTRY SCENARIO.** In countries such as the United States, recent reductions in beef consumption have been accompanied by increases in pork and poultry consumption, suggesting that consumers are substituting pork and poultry for beef. Beef consumption levels were modified in regions where daily per capita beef consumption in 2009 was above the world average, regardless of caloric consumption level—together home to nearly 2 billion people.<sup>154</sup> The scenario reduced per capita beef consumption by 33 percent in these regions<sup>155</sup> and fully replaced the reduced beef consumption with pork and poultry. Overall calorie consumption remained unchanged relative to the 2009 reference.
- **SHIFT FROM BEEF TO LEGUMES SCENARIO.** Consumption levels were modified in the same regions as the above scenario. The scenario reduced per capita beef consumption by 33 percent in these regions and fully replaced the reduced beef consumption with pulses and soy. This scenario could represent reformulation of beef-based products (e.g., meatballs that are two-thirds beef and one-third plant-based proteins). Overall calorie consumption remained unchanged relative to the 2009 reference.

We first show the per person effects of applying the three scenarios to the average consumption pattern of one high-consuming country—the United States—in Figure 15. The “US (Reference)” bars show the average US daily diet in 2009, and the associated agricultural land use and greenhouse gas emissions. The other bars show how caloric consumption, land use, and greenhouse gas emissions changed under the beef reduction scenarios.

Our findings under these scenarios included:<sup>156</sup>

- Nearly half of the agricultural land use and greenhouse gas emissions associated with supplying the average American diet stemmed from beef alone (red portion of “US (Reference)” bar).
- The *Ambitious Beef Reduction scenario*—which cut US beef consumption by more than 70 percent—required one-third less agricultural land (mostly driven by a reduction in pastureland by nearly half), and resulted in a 35 percent drop in greenhouse gas emissions from agricultural production.
- The *Shift from Beef to Pork and Poultry* and *Shift from Beef to Legumes* scenarios both reduced agricultural land use and greenhouse gas emissions by about 15 percent. The results of the two scenarios were similar because the one-third reduction in beef consumption had a far greater effect on land use and greenhouse gas emissions than the corresponding changes associated with increased consumption of pork, poultry, or legumes.

The global effects of applying the three beef reduction scenarios to food consumption in 2009 are shown in Table 4 and summarized below.

- Under all three beef reduction scenarios, world pastureland declined by around 200 to 300 million hectares in 2009, representing 6 to 9 percent of all pastureland and 4 to 6 percent of total agricultural land. To put this change into perspective, the reduction in pastureland from reducing beef consumption is similar to the entire global expansion in pastureland between 1961 and 2009 (270 million hectares).<sup>157</sup>
- Cropland slightly decreased under the *Ambitious Beef Reduction* and *Shift from Beef to Legumes* scenarios, reflecting the relatively small amount of feed crops dedicated to global beef production in 2009. Although total agricultural land decreased, cropland slightly




Figure 15 | **Reducing Beef Consumption Reduces the Agricultural Land Use and Greenhouse Gas Emissions Associated with the Average US Diet by up to One-Third per capita values, 2009**



Source: GlobAgri model.

Note: "US" data are for United States and Canada. Land-use change emissions are amortized over a period of 20 years and then shown as annual impacts. Calculations assume global average efficiencies (calories produced per hectare or per ton of CO<sub>2</sub>e emitted) for all food types.

Table 4 | **Global Effects of Reducing Beef Consumption on Agricultural Land Use and Greenhouse Gas Emissions in 2009**

SCENARIO <sup>a</sup>	REDUCTION IN AGRICULTURAL LAND USE <sup>b</sup> (MILLION HA)	AVOIDED FUTURE GHG EMISSIONS FROM AGRICULTURAL LAND-USE CHANGE <sup>c</sup> (MILLION TONS CO <sub>2</sub> E)	REDUCTION IN GHG EMISSIONS FROM AGRICULTURAL PRODUCTION (MILLION TONS CO <sub>2</sub> E)
<b>AMBITIOUS BEEF REDUCTION</b> APPLIED TO 1,463 M PEOPLE 	291 Pastureland 15 Cropland TOTAL 307	98,298	418
<b>SHIFT FROM BEEF TO PORK AND POULTRY</b> APPLIED TO 1,952 M PEOPLE 	196 Pastureland -26 Cropland TOTAL 170	51,116	238
<b>SHIFT FROM BEEF TO LEGUMES</b> APPLIED TO 1,952 M PEOPLE 	211 Pastureland 7 Cropland TOTAL 218	66,396	299

Source: GlobAgri model.

Notes:

Figures may not total correctly due to rounding.

a. Reference scenario included a world population of 6.8 billion, agricultural land use of 5 billion hectares (3.4 billion hectares of pastureland and 1.6 billion hectares of cropland), and 6.9 billion tons of greenhouse gas emissions from agricultural production.

b. “Cropland” includes land for aquaculture farms.

c. These estimates assume that the diet changes are sustained over time. If other improvements to the food system (e.g., yield gains) allowed the world to avoid future land-use change, these scenarios would allow some existing agricultural lands to revert to native vegetation and sequester the equivalent amount of carbon.

increased under the *Shift from Beef to Pork and Poultry* scenario, due to the increase in crop-based feeds needed for pork and poultry production more than offsetting those no longer necessary for beef production.

Each scenario resulted in reductions in greenhouse gas emissions from agricultural production, from 4 to 6 percent relative to reference. In addition, the avoided future emissions from land-use change—assuming the diet changes were sustained over time—ranged from 51 to 98 billion tons CO<sub>2</sub>e. To put this reduction in perspective, global greenhouse gas emissions in 2009 were 44 billion tons CO<sub>2</sub>e.<sup>158</sup>

For some people, shifting from beef to other meats or to legumes is more likely than just reducing beef consumption. In the United States and Europe, per capita beef availability (suggesting consumption) has already declined by more than 25 percent from historical highs, while availability of pork and chicken has increased.<sup>159</sup> The GlobAgri results suggest that a reduction in global beef consumption on the order of 30 percent—even if the reduced beef consumption were replaced with other meats—could alleviate pressure to further expand global pastureland, and that a portion of “spared” pastureland could probably be used to accommodate cropland expansion, while relieving agricultural pressure on forests and savannas.

## EFFECTS OF THE DIET SHIFTS IN 2050

The GlobAgri results for the three diet shifts showed significant effects on agricultural land use and greenhouse gas emissions when applied to food consumption in 2009. We do not model the effects of the diet shifts in 2050 in this paper, but we draw several conclusions using the GlobAgri 2009 results and FAO's food production and consumption projections for 2050.<sup>160</sup>

The effects of the three diet shifts on land use and agricultural greenhouse gas emissions relative to “business as usual” are likely to be even greater in 2050 than in 2009

because the number of people affected by each diet shift will likely increase by mid-century. Table 5 shows the number of people likely to be affected by the diet scenarios in 2050, when applying the scenario “rules” to a larger and more affluent population.<sup>161</sup> The *Ambitious Animal Protein Reduction* scenario, for example, affected nearly 2 billion people in 2009, but absent changes in demand would affect more than 9 billion people in 2050 when nearly all regions are projected to consume in excess of 60 grams of protein per day. The resulting global land use and greenhouse gas effects in 2050 could therefore be greater than they were in 2009, depending on the level of improvements in agricultural production efficiency.

Table 5 | **Effects of Diet Shifts in 2009 Versus 2050**

SCENARIO	WHO AFFECTED	CHANGE IN CROP CALORIE PRODUCTION, 2009 (PERCENT RELATIVE TO REFERENCE)	# PEOPLE AFFECTED, 2009 (MILLIONS)	# PEOPLE AFFECTED, 2050 (MILLIONS)
<b>DIET SHIFT 1: Reduce overconsumption of calories</b>				
Eliminate Obesity and Halve Overweight	Total obese population and half of overweight population	-3.3	1,385	2,078
Halve Obesity and Overweight	Half of obese and overweight populations	-2.1	1,046	1,569
<b>DIET SHIFT 2: Reduce overconsumption of protein by reducing consumption of animal-based foods</b>				
<b>Ambitious Animal Protein Reduction</b>	<b>Regions consuming more than 60 g of protein and 2,500 kcal per person per day</b>	<b>-8.5</b>	<b>1,907</b>	<b>9,444</b>
Traditional Mediterranean Diet	Half of population of regions consuming more than 40 g of animal-based protein and 2,500 (total) kcal per person per day	-0.6	437	1,638
Vegetarian Diet	Half of population of regions consuming more than 40 g of animal-based protein and 2,500 (total) kcal per person per day	-4.5	437	1,638
<b>DIET SHIFT 3: Reduce consumption of beef specifically</b>				
Ambitious Beef Reduction	Regions consuming beef above 2009 world average (3.2 g beef-based protein per person per day) and 2,500 (total) kcal per person per day	-1.1	1,463	4,019
Shift from Beef to Pork and Poultry	Regions consuming beef above 2009 world average	+1.2	1,952	4,299
Shift from Beef to Legumes	Regions consuming beef above 2009 world average	-0.6	1,952	4,299

Source: GlobAgri model.



All three diet shifts would likely help close the expected food gap (measured in crop calories) in 2050 (Figure 1). The GlobAgri estimates of “crop calorie production” under the three diet shifts in 2009 (Table 5) suggest that they could help close the gap. Nearly all scenarios resulted in a drop in crop calorie needs in 2009 relative to the reference level—with the *Ambitious Animal Protein Reduction* scenario causing the largest drop at 8.5 percent—meaning that they could also be expected to reduce crop calorie demand (and therefore help close the crop calorie gap) in 2050. However, the extent to which the shifts could help close the gap will depend on improvements in the efficiency of agricultural production systems between now and 2050.<sup>162</sup>

The *Ambitious Animal Protein Reduction* scenario, in particular, goes the furthest in incorporating all three diet shifts, as it reduces consumption of calories, animal-based protein, and beef. Based on FAO’s assumption that 25 percent of all crops (measured by calories) will be dedicated to animal feed in 2050,<sup>163</sup> applying this scenario to projected consumption patterns in 2050 could reduce the food gap by 30 percent—significantly reducing the challenge of sustainably feeding nearly 10 billion people by mid-century.<sup>164</sup> Other scenarios could also reduce the food gap, but Table 5 suggests they would do so to a lesser extent.

## SHIFTING STRATEGIES FOR SHIFTING DIETS

Overall, our analysis and many others show that what and how much people eat has a major impact on food security, resource use, and the environmental impacts of agriculture. Of the three diet shifts examined in this paper, the two shifts that reduced consumption of animal-based foods resulted in the largest potential contributions to a sustainable food future. However, looking out to 2050, the current trend of rising consumption of animal-based foods will likely continue, absent significant actions to shift demand.

Changing people’s consumption behavior is no easy task. Food choices are influenced by a variety of interacting factors, including price and taste of the food; age, gender, health, income, geography, social identity, and culture of the consumer; and exposure to a variety of external factors, such as marketing, media, and ease of access to supermarkets and restaurants. What can be done to influence people’s food choices on a large enough scale to contribute to a sustainable food future?

## Move beyond information and education campaigns

Typical strategies to shift diets rely on nutrition labeling or public health campaigns about the benefits of different food types or diets. Public health campaigns range from advocating for abstinence (e.g., vegetarianism or Meat Free Mondays); recommending balanced diets (e.g., the UK “eatwell” plate, Chinese Pagoda, US ChooseMyPlate, Canadian Food Rainbow); promoting fruits and vegetables; and warning against excessive consumption of particular food types.

There is limited evidence, however, that consumers make regular use of information labels and education campaigns when buying food.<sup>165</sup> A recent review of the influence of nutritional labeling, for example, found information to have only a modest impact at best on purchasing behavior.<sup>166</sup> In addition, a review of the effectiveness of education campaigns to increase fruit and vegetable consumption in Europe has reported a small impact.<sup>167</sup>

Analysis published in the *British Medical Journal* in 2011 found a similar pattern within the restaurant environment. Calorie and nutritional information about food served at fast-food chains in New York City resulted in no change in average calories bought, and only one in six people said they actually used the information.<sup>168</sup> The limited role of information alone is underscored by the fact that 44 percent of male doctors and 55 percent of nurses surveyed in the United States are overweight, even though they have ready access to information and education on the links between diet and health.<sup>169</sup>

In light of how consumers shop, the limited effectiveness of information and education strategies is not surprising. Consumers are bombarded with messages every day from multiple sources and, as a result, the information is likely to be screened out or quickly forgotten.<sup>170</sup> Much of consumer purchasing behavior is highly routinized, especially in a shopping behavior context, and product evaluation is rare.<sup>171</sup> Few people notice information and even fewer remember and respond to it. Shoppers tend to make purchases quickly and automatically, as if on autopilot,<sup>172</sup> and repeat these habitual behaviors even if they report an intention to do otherwise.<sup>173</sup> What ends up in the shopping cart is usually based on habit and unconscious mental processing rather than on rational, informed decisions.

Interventions to change food consumption behavior, therefore, need to affect not only consumers’ rational, informed decisions but also their automatic or unconscious decisions. This insight suggests that interventions must go beyond information and education campaigns—designed to help rational consumers make better choices—by altering consumers’ choices and the contexts and ways in which those choices are presented.<sup>174</sup>

What kinds of behavior change interventions might be employed to shift consumers’ habits? Table 6 is adapted from a UK government study that examined successful interventions to reduce smoking, increase purchases of energy-efficient products, and achieve other social goals. It categorizes behavior change interventions along a continuum from a high degree of intervention (e.g., bans on certain products) to a low degree of intervention (e.g., altering the way choices are presented) in individuals’ lives, and provides examples relevant to the diet shifts discussed in this paper.<sup>175</sup> It suggests that a wide variety of possible interventions exist beyond information and education.

### Engage the food industry, especially major food retailers

Until now, efforts to shift diets have primarily been led by governments and nongovernmental organizations. However, consumers make the majority of their food choices in stores and restaurants; influencing these choices will require the engagement of the food industry, particularly the retail and food service sectors.

Global food consumption patterns are converging as the food industry consolidates and gives rise to large-scale food processors, wholesale food companies, supermarkets and other retail store chains, and restaurant chains. In developed countries like the United States and countries in Western Europe, these changes have been taking place for more than a century, but they have also occurred—at a comparatively rapid pace—in Latin America, Asia, Eastern Europe, and parts of Africa since the 1980s.<sup>176</sup>

Table 6 | **Types of Behavior Change Interventions with Examples of Shifting Diets**

	HIGH DEGREE of intervention (eliminate choice)				LOW DEGREE of intervention (guide or enable choice)				
TYPE OF INTERVENTION	Eliminate or restrict choice	Fiscal disincentives	Fiscal incentives	Non-fiscal incentives and disincentives	Persuasion	Provision of information	Changes to physical environment	Changes to the default policy	Use of social norms
SHIFTING DIETS EXAMPLE	Ban trans fats, remove meat from restaurant menu	Tax on fat, sugar, or meat	Formulate plant-based alternative to be cheaper than conventional animal-based food	“30-day diet challenge” where successful employee earns a day off	Marketing campaign	Nutritional labeling, dietary guidelines	Put healthy foods at eye level in buffets, or end of aisles or checkout lines in supermarkets	Provide salad as default side dish in restaurant	Provide information about peers’ dietary choices

Source: Adapted from House of Lords (2011).

Supermarkets are a case in point. Supermarkets accounted for 70 to 80 percent of food retail sales in the United States and France in 2000.<sup>177</sup> They are also playing an increasingly important role in developing countries. From 1980 to 2000, supermarkets grew their share of food retail sales from an estimated 5–20 percent to 50–60 percent in East Asia, Latin America, urban China, South Africa, and Central Europe.<sup>178</sup> This expansion continued through the first decade of the 2000s; supermarket sales grew at a 40 percent compound annual growth rate in China, India, and Vietnam between 2001 and 2009.<sup>179</sup> New supermarkets typically open in urban areas with concentrations of affluent consumers before diffusing to middle- and lower-income consumers and expanding from urban to rural areas.<sup>180</sup> Supermarkets increase consumers' access to foods more common in developed countries like meat, dairy products, temperate fruits and vegetables, and processed foods and drinks.<sup>181</sup>

People are also increasingly choosing to dine out—in restaurants, cafeterias, and other food service facilities. In the United States, expenditures on “food away from home” as a share of total food expenditures grew from 25 percent in 1954 to 50 percent in 2013.<sup>182</sup> In China, out-of-home food consumption grew by more than 100-fold between 1978 and 2008, as people increasingly eat food from street stalls, traditional restaurants, and fast-food outlets.<sup>183</sup> The drivers of this trend toward increased dining out include a larger share of women in the workplace, higher incomes, smaller households, more affordable and convenient fast-food outlets, and increases in advertising by large restaurants.<sup>184</sup> Given that these drivers are broadly relevant across the globe, restaurants and other food service facilities will likely capture an increasing amount of global food sales in coming decades.

This global consolidation of the food industry means that large-scale actors in the food industry should be an important focus of initiatives to shift dietary habits. The next section focuses on strategies that can be deployed by supermarkets, food service companies, and food manufacturers.

## SHIFT WHEEL: A FRAMEWORK FOR SHIFTING CONSUMPTION

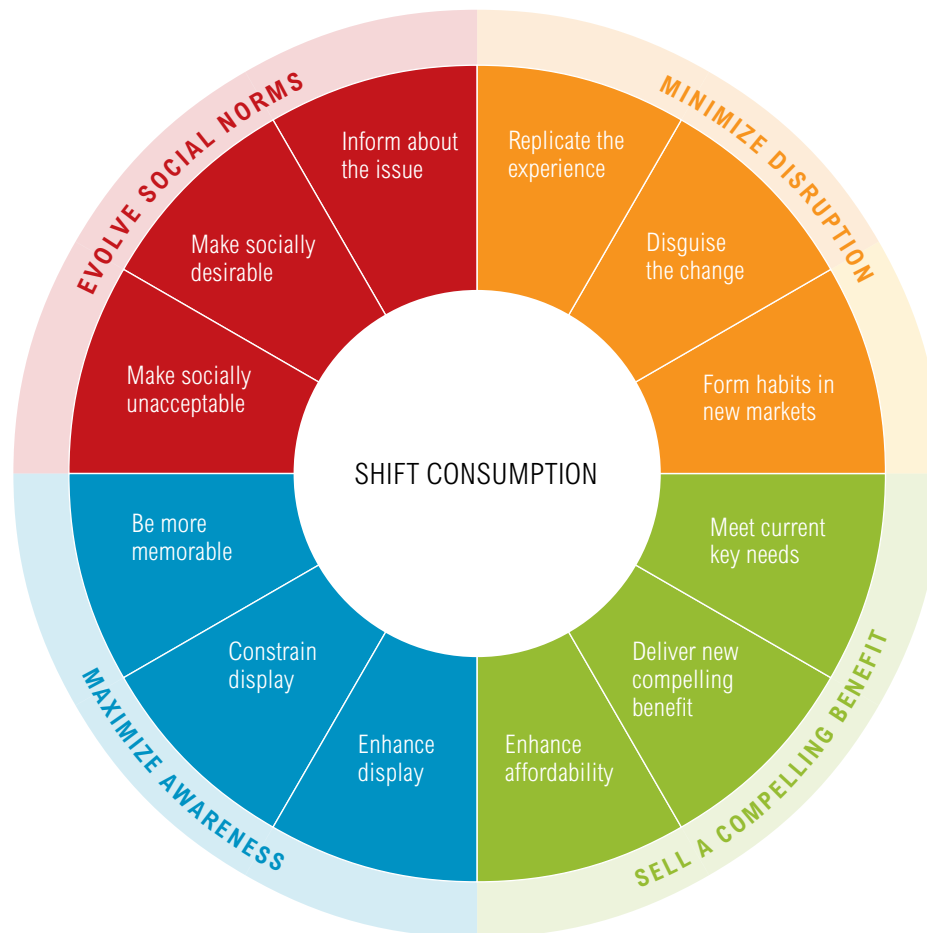
The world needs a new approach to shifting diets—one that uses strategies that work in step with how people purchase and target the places where they make their purchases. The food industry, governments, NGOs, research organizations, and others will all need to play a role in identifying and influencing the key factors that prompt people to choose animal-based food products over plant-based foods.

However, there is limited publicly available data on food consumption behavior at the point of purchase. As a result, there is a major knowledge gap on what really drives people's choices and what alternative strategies could be used to reduce high consumption of animal-based food products, especially beef.

To help address this knowledge gap and design more effective strategies, we looked across the field of fast-moving consumer goods<sup>185</sup>—not just food—at a number of specific consumption shifts that have been successfully orchestrated by industry, NGOs, and government. Notable examples include the shifts from incandescent to long-life light bulbs, from caged to free-range eggs in the United Kingdom, from big box to compact washing powder, from higher- to lower-alcohol beer in Europe, from butter to plant-based spreads, from trans fats to healthier fats, and a shift away from shark fin in China. While the shifts examined primarily drew on experience from developed countries, the resulting insights are likely to also be relevant to developing countries, given that food purchasing decisions around the globe are increasingly occurring in supermarkets and food service facilities such as restaurants and cafeterias.

We analyzed these shifts by reviewing published literature and market data reports, commissioning sales research, and consulting marketing strategy professionals and academic behavior specialists. The resulting insights—gleaned from recurring themes across the different examples of consumption shifts—informed the development of the “Shift Wheel” framework (Figure 16). The Shift Wheel comprises four complementary strategies to shift consumption: (1) minimize disruption; (2) sell a compelling benefit; (3) maximize awareness and display; and (4) evolve social norms. Each Shift Wheel strategy is described below, along with examples and case studies from the food and beverage sector of consumption shifts.

Figure 16 | The Shift Wheel Comprises Four Strategies to Shift Consumption



Source: Authors.

## Minimize Disruption

Changing food consumption behavior is challenging because it requires breaking current habits and investing time and effort in establishing new ones. A change in taste, look, texture, smell, packaging, and even in-store location can be a major barrier to changing a consumer's food buying decision. Therefore, an effective route to change is minimizing how perceivable any differences are, making them less disruptive to the consumer. Approaches that minimize disruption include:

- **REPLICATE THE EXPERIENCE.** This approach seeks to replicate the familiar taste, texture, look, and in-store position of the “conventional” animal product. Brands such as Quorn (a meat substitute made from mycoprotein) have, over the years, evolved their

chicken, minced/ground beef and tuna products to replicate the familiar texture of the meat alternative as closely as possible. New manufactured animal product alternatives are pursuing this approach in particular (Box 9).

Other products are replicating packaging formats and product placement. For example, several brands of soy milk have launched packaging that looks similar to that of fresh cow's milk and, rather than being stored at room temperature near long-life ultra-high temperature processed (UHT) milk, are being placed in retailers' chillers alongside fresh milk. Similarly, on restaurant menus, meat, egg, and dairy alternatives can be placed alongside their animal protein counterparts rather than in special vegetarian sections.

Companies and research organizations are developing and improving animal product substitutes to minimize the disruption from shifting from conventional meat, eggs, and dairy. Their approach to replicating animal products usually takes one of two forms, either the “meat” is constructed from manipulating plant or fungal material, or it is grown in the lab from animal stem cells.

These “meat” companies include Quorn, Beyond Meat, Impossible Foods, and Hampton Creek. The ingredients in Beyond Meat include soy protein, pea protein, and carrot fiber. Impossible Foods is a startup that is developing faux meat based on the heme of legumes and nitrogen fixing plants.<sup>a</sup> Heme, a molecule also found in the hemoglobin of animal blood, gives the faux meat an animal-based meat flavor. Hampton Creek uses Canadian yellow peas to create an eggless mayonnaise alternative called “Just Mayo,” and a similar approach to create egg- and dairy-free cookie dough and powdered scrambled faux eggs. The company is working on plant-based alternatives to ice cream, ranch dressing, and other animal-based foods. Its goal is to produce plant-based alternatives that not only have a lower environmental impact and reduce animal welfare concerns, but are more affordable and healthier than the conventional animal-based products, without compromising on taste or texture.<sup>b</sup>

Maastricht University leads a lab working on cultured meat.<sup>c</sup> The objective is to successfully create real meat without the environmental impacts generated by conventional sources,<sup>d</sup> by harvesting animal stem cells and growing them in a petri dish. In 2013, the first public tasting of this cultured meat showed success in replicating the texture and density of real meat, although the flavor seemed bland.<sup>e</sup>

*Notes:*

- a. Wall Street Journal (2014).
- b. Henry (2015).
- c. Jha (2013).
- d. Hanlon (2012).
- e. Maastricht University (2014).
- f. Oregon State University (2015).
- g. Bello (2013).
- h. Bello (2013).



And in 2015, Oregon State University researchers patented a new strain of red marine algae that is high in protein and tastes like bacon.<sup>f</sup>

Animal product replicates offer a promising contribution toward reducing livestock consumption. However, several challenges remain, including taste, affordability, safety, and trust. While Hampton Creek has been able to lower the price of its

eggless mayonnaise alternative below that of conventional mayonnaise, affordability is especially an issue for cultured meat since “cell culture is one of the most expensive and resource-intensive techniques in modern biology.”<sup>g</sup> The lab at Maastricht University predicts cultured meat will be able to compete with real meats in 10 to 20 years.<sup>h</sup> Finally, replicated animal products may face an issue of trust with consumers yet to be convinced about their merits (e.g., nutritional and health benefits).



- **DISGUISE THE CHANGE.** A number of products have blended in new ingredients within current formats to help disguise the shift toward plant-based ingredients. For example, the “Lurpack” brand of butter has released a number of variants, such as “Lurpack Lighter,” which has around 30 percent vegetable fat blended into the butter. These inclusions are listed in the ingredients label, but the marketing leads with messaging about its buttery taste and spread-ability (as a result of the vegetable fat inclusion). Within the meat category, a German company “Hackplus” launched a minced/ground product consisting of 70 percent meat and 30 percent plant protein. It is marketed as a product “for those who opt for a healthy diet but do not want to give up meat altogether” and it has 30 percent less fat and 30 percent less cholesterol than traditional ground meat.

Small, imperceptible steps are another approach to disguising change. Sometimes referred to as “stealth changes,” this approach has been used by food companies to steadily cut sodium and sugar levels in food. For example, salt levels in UK bread have fallen by an average of 20 percent over the past decade through actions by manufacturers. The change has been gradual over time and therefore largely unnoticeable to consumers. A 2013 study estimated that this change has resulted in approximately 2,400 strokes and heart attacks being prevented each year.<sup>186</sup>

- **FORM HABITS IN NEW MARKETS.** Getting consumers to purchase healthy and more sustainable products is less disruptive if they have yet to form buying habits. This approach is especially relevant to countries where consumption of animal-based protein and beef is rapidly rising or is projected to do so by 2050. Introducing programs that limit consumers shifting into buying more animal-based food products in geographies or social groups without a prior history or unformed buying norms can be an effective strategy.

## Sell a Compelling Benefit

Selling a compelling benefit involves marketing a product attribute that is known to stimulate consumers’ purchasing decisions. Not all food consumption shifts are disguisable; some will be apparent to consumers. In these situations, one approach is to explore whether the alternative product has attributes that are appealing enough to incentivize target consumers to change their purchasing behavior. Critical to selling a compelling benefit is defining and communicating attributes that are sufficiently motivating to stimulate behavior change with the majority of consumers—rather than factors that motivate only a small niche of consumers, such as the environment (Box 10). Approaches to selling a compelling benefit include:

- **MEET CURRENT KEY NEEDS.** This approach leverages a benefit already perceived by consumers. The UK egg industry, for example, has built upon and reinforced the consumer perception that eggs from free-range chickens taste better than those from cage-reared chickens. Brands such as “Happy Eggs,” with their tagline “happy hens lay tasty eggs,” demonstrate this approach. Although free-range eggs are 30–50 percent more expensive than conventional eggs, this quality association has helped capture around 45 percent of the UK market.<sup>187</sup> A similar example from the UK is the re-positioning of the fish “Pilchards” to “Cornish Sardines.” The fish was re-named with a view to enhancing its perceived taste benefits since sardines are a favored Mediterranean meal compared to that of the poorly perceived “Pilchard.” Since this repositioning in the late 1990s, catches of this fish in Cornwall have increased from 6 tons per year in the early 1990s to 2,000 tons in 2008 as fishers, processors, and retailers have worked together to rebuild demand.<sup>188</sup>
- **DELIVER A COMPELLING NEW BENEFIT.** This approach entails creating a new benefit for consumers that is not currently provided or advertised by existing options. For example, Birds Eye repositioned their pollock-based fish fingers (fish sticks), which are a more sustainable alternative to cod fish fingers, as healthier “Omega 3 Fish Fingers” and, in doing so, helped shift a large proportion of sales to more sustainable pollock.<sup>189</sup>
- **ENHANCE AFFORDABILITY.** This approach makes the desired alternative more affordable to the consumer. Price is an influential factor in food purchases and is frequently cited by consumers as a key determinant of



choice (Box 10). At a national level, it is estimated that income explains 65 to 70 percent of the variation in the average proportion of protein from animal-based food sources among countries.<sup>190</sup> It is likely that the falling price of chicken, relative to the price of beef, has played a role in the rise of per capita chicken consumption in the United States (and the decline in per capita beef consumption) since 1970.<sup>191</sup>

Taxing certain foods (e.g., those high in fat, salt, or sugar) in order to make other foods comparatively more affordable has been pioneered by a few nations. Although little is yet known about the real-world effectiveness of food taxes, there is reason to believe they can influence consumer decisions in the right circumstances (Box 11). Since around 2010, several countries—including Barbados, Chile, Denmark, Finland, France, Hungary, Mexico, and local governments in

the United States—have established taxes on foods deemed unhealthy.<sup>192</sup> However, the “fat tax” in Denmark was abolished after a year in 2013 in large part because consumers were able to cross the border into Germany and purchase the same products without a tax.<sup>193</sup> Political will to enact such taxes is often low, because of resistance from the food industry and because of fears that such taxes are regressive—that they could impact poor consumers more than the rich.<sup>194</sup>

Because plant-based proteins can be cheaper than animal-based ones,<sup>195</sup> companies can sell reformulated products with a greater share of plant-based ingredients at a lower price point and/or an increased profit. Indeed, part of Hampton Creek’s business model (Box 9) is to sell plant-based alternatives that are not only indistinguishable from, but also cheaper than, conventional animal-based products.

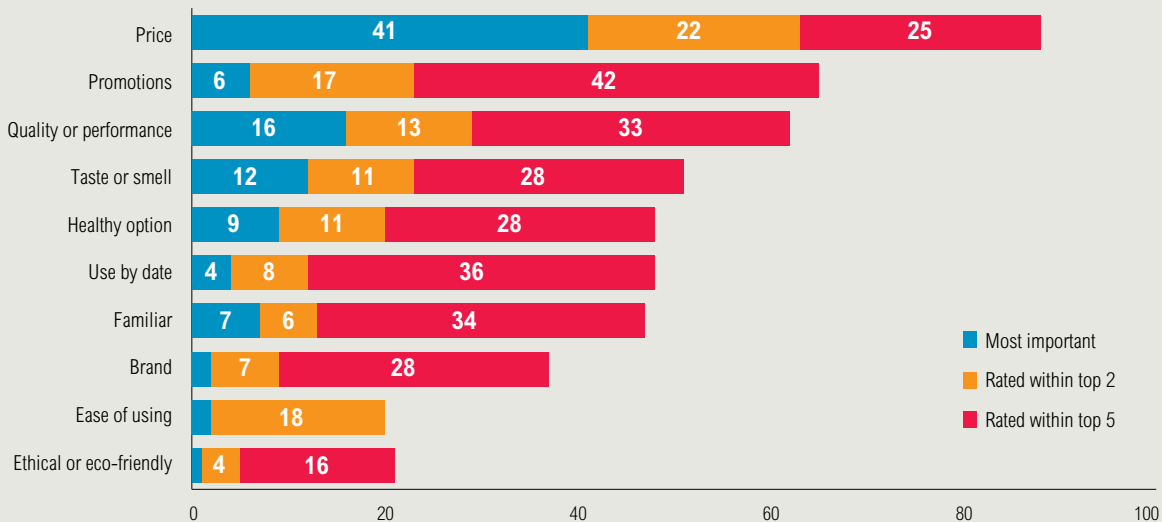
Box 10 | **The Myth of the Green Consumer**

Numerous consumer attitude surveys have reported that a large majority of consumers are interested in buying brands with an environmental benefit. However, this

research often disregards other factors. When product attributes such as price and quality are thrown into the mix, the relative importance of the environment to

purchasing decisions falls significantly for all but a small minority. Figure 17 demonstrates this for the United Kingdom.

**FIGURE 17 | PRICE AND QUALITY ARE MORE IMPORTANT TO UK CONSUMERS THAN ETHICAL OR ENVIRONMENTAL CONSIDERATIONS**  
FACTORS INFLUENCING CONSUMER PRODUCT CHOICE, PERCENTAGE OF SHOPPER RESPONSES



Source: DEFRA (2014b).

## Box 11 | Do Food Taxes Influence Consumption?

Modeling studies and limited real-world experience provide good reasons to believe that food taxes imposed at the retail level could change purchasing choices. Reviews of the limited efforts either to tax certain types of unhealthy foods or to subsidize healthier foods indicate a significant effect on consumption in some cases.<sup>a</sup> For example, Mexico's 10 percent tax on sugar-sweetened beverages, enacted in January 2014, led to a 12 percent decline in soft drink purchases (relative to expected purchases without the tax) by December of that year.<sup>b</sup>

Studies on food taxes highlight important caveats. First, taxes imposed by a country at the agricultural production level, such as a beef production tax, are unlikely to work because production can shift to another country.<sup>c</sup> Second, as the Denmark "fat tax" experience suggests, taxes imposed over broader regions are likely to be more effective than those imposed in a single country when consumers have the ability to shop abroad. Third, taxes will be more effective when the desired substitutes are untaxed, taxed less, or subsidized. For example, if beef is taxed but chicken is

not, it is likely that people will switch from beef to chicken (rather than consuming less food overall). Fourth, tax rates will likely have to be high to substantially reduce consumption; one survey found that demand elasticities for meats were often around 1, implying that roughly a 10 percent tax would be needed to achieve just a 10 percent reduction in consumption.<sup>d</sup> Such taxes could have unfair distributional consequences unless they are rebated through subsidies or reduced taxes on other necessities.

## Notes:

- a. Thow et al. (2014), Nordström and Thunström (2009), Hawkes (2012), Thow et al. (2010), Jensen and Smed (2013), Colchero et al. (2016).
- b. Colchero et al. (2016).
- c. Dumortier et al. (2012).
- d. Gallet (2010).

## Maximize Awareness and Display

The more chances consumers have to see and buy a product, the greater the chance they will consider purchasing it. For example, people tend to consume more of items they see first in a buffet.<sup>196</sup> Similarly, the more prominent a product is in a consumer's memory, the greater the likelihood they will purchase it. Approaches to maximize awareness and display include:

- **ENHANCE DISPLAY.** Improving the physical availability or visibility of a product—by putting it in a place that consumers easily access—can lead to higher sales of a desired food choice. A school cafeteria in the US state of Minnesota found that students waiting to pay faced an array of grain-based snacks, chips, granola bars, and desserts by the cash register that led to impulse purchases. Rather than remove these packaged food products, which would have reduced total sales, the cafeteria replaced them with fruits. As a result, fruit sales increased, snack food sales decreased, and total revenue did not significantly decrease.<sup>197</sup> In a retail environment, food manufacturers can encourage retailers to increase the amount and quality of space given

to displaying their products by providing greater margins to retailers or running promotional campaigns, such as offering discounts or engaging celebrity chefs to feature their products.

- **CONSTRAIN DISPLAY.** In some cases, undesired food choices have been curtailed by limiting product distribution and display. Public food procurement policies in schools, hospitals, prisons, and government offices have been used to influence consumption habits of large parts of the population. The complete removal or "choice editing" from stores is possible, but it is sensitive; 46 percent of British shoppers are in favor of more choice editing for ethical reasons but 26 percent object. With regard to choice editing for health reasons, 73 percent of British shoppers were found to be against it.<sup>198</sup> Some countries also are experimenting with limiting marketing of undesirable foods. Chile passed a law in 2012 that limits children's exposure (through marketing and sales) to foods that are high in calories, salt, sugar, and fat—although these provisions have yet to be implemented.<sup>199</sup>

■ **BE MORE MEMORABLE.** Consumers have been shown to shop quickly, allowing little time to evaluate the brands they purchase. The majority screen out information about new products and instead seek out products and brands that are in their current repertoire of choices. Products can disrupt these predetermined choices by being more noticeable in a purchasing situation (the two previous approaches), or by being more thought of in a purchasing situation. Creating memorable advertising campaigns and building consumers' memory associations with the desired food can, over time, increase the probability that it will be remembered and purchased.<sup>200</sup> Coca-Cola, for example, is associated in many consumers' minds with the color red, its distinctive bottle shape, its logo script, and its ability to refresh on a hot day.<sup>201</sup> In the United States, agricultural commodity marketing programs have been responsible for several memorable advertising campaigns, such as "Got Milk?" and "Beef: It's What's for Dinner." Developing memorable marketing programs for plant-based foods could play an important role in shifting purchasing behavior.

### Evolve social and cultural norms

Research has shown that the cultural environment and social norms of the group a person belongs to can influence what and how much that person eats. A study in the *Journal of the Academy of Nutrition and Dietetics*, for example, reported that people eat more when others around them are eating more, and choose food types based on what they perceive will help them fit in with a given group and gain social approval.<sup>202</sup> Adapting the underlying social and cultural norms is difficult, but offers another potential strategy for change. Approaches to evolve social and cultural norms include:

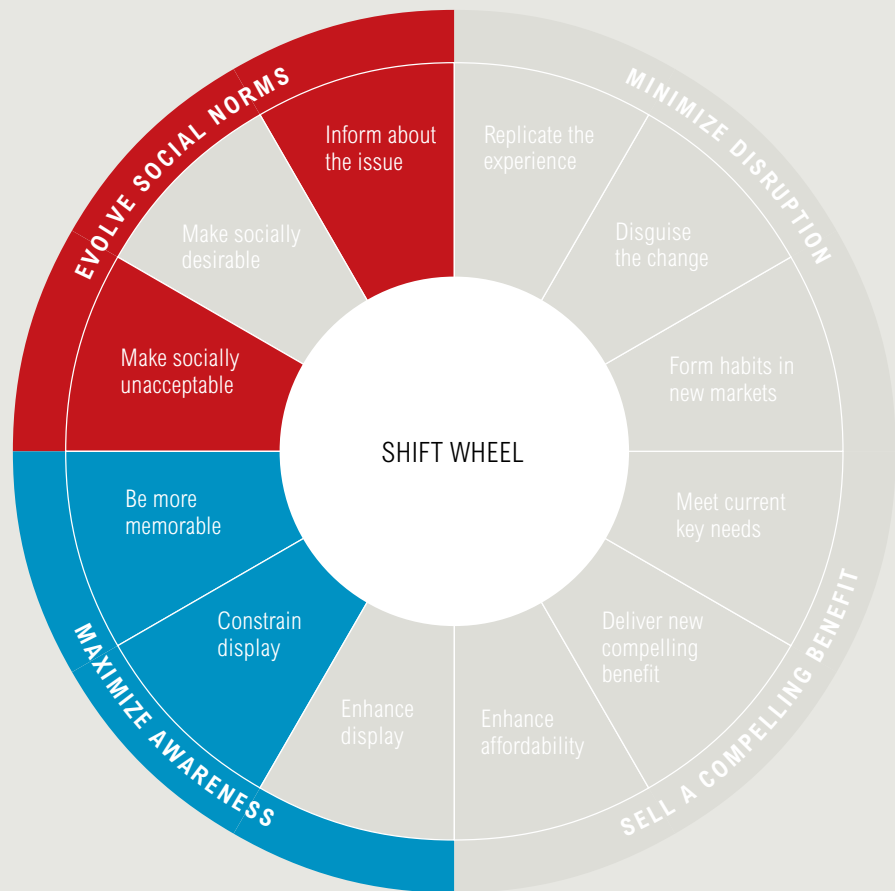
- **MAKE SOCIALLY UNACCEPTABLE.** A number of campaigns have helped make a specific food socially unacceptable to consumers. For example, in 2008 the celebrity chefs Hugh Fearnley-Whittingstall and Jamie Oliver both launched high-profile TV programs and campaigns to highlight the issues associated with buying non-free-range chicken. During the campaign, sales of free-range poultry reportedly increased by 35 percent relative to the previous year, while sales of caged birds fell by 7 percent.<sup>203</sup> In another example, WildAid launched a campaign to draw attention to the devastating impacts of shark fishing, helping to reduce consumption of shark fins in China (Box 12). It is important to note, however, that the long-term impact of these campaigns is unknown.
- **MAKE SOCIALLY DESIRABLE.** In contrast, another approach is to make the preferred food type socially desirable. For example, in 2012 celebrity chef Delia Smith helped increase UK sales of gammon (ham) nearly three-fold relative to the previous year after featuring a recipe for gammon on the television. The chef's influence over food sales has been called the "Delia effect," a term coined when sales of cranberries quadrupled the day after she used them on television.<sup>204</sup>
- **INFORM ABOUT THE ISSUE.** As noted earlier, information and education campaigns, such as nutrition labeling or public health campaigns, have been the leading policy strategy to shift consumption in recent decades, but a variety of evidence shows that information and education alone is insufficient to lead to action.<sup>205</sup> Still, information and education can be a valuable ingredient in a broader effort to shift consumption, as evidenced by its role in reducing consumption of shark fin in China (Box 12) and trans fats across several countries (Box 13). In many cases, information can lead to indirect or multiplier effects, by raising the profile of an issue, prompting product reformulation (in the case of labeling), or forming the basis of food and nutrition policy and programs (e.g., national dietary guidelines).<sup>206</sup>

Box 12 | Reducing the Unsustainable Consumption of Shark Fin in China

Shark fin soup originated as a tradition in the Sung Dynasty (AD 960–1279) and became an essential royal banquet dish in the Ming Dynasty (circa 1368–1644). It became a popular status symbol among China’s emerging middle class in recent years, and was regularly eaten at formal occasions such as business receptions and weddings. The demand for shark fin has led to as many as an estimated 73 million sharks killed annually from 1996–2000<sup>a</sup> and the near extinction of the 14 most-caught shark species in the shark fin trade.<sup>b</sup> China and Hong Kong account for 94 percent of the demand for shark fins.<sup>c</sup>

In 2006, the conservation organization WildAid began a series of public service announcements on the devastating effects of shark fishing. The campaign featured high-profile celebrities like former professional basketball player Yao Ming, various Olympic athletes, CEOs, and famous actors and screenwriters, all publicly declaring their opposition to shark fin soup and challenging its social acceptability.

Building on the campaign, several well-established businessmen petitioned the National People’s Congress with the support of 30 members of Congress, to ban shark fin at government banquets. In July 2012, China’s State Council, the national administrative body, issued a ban on serving shark fin at official government receptions. Originally given one to three years to come into effect, the ban was enforced within half a year because it coincided with a crackdown on extravagant spending by government officials.<sup>d</sup>



After the ban, studies found that shark fins contain “dangerously high levels of mercury and other heavy metals,”<sup>e</sup> decreasing their traditional health appeal. In addition, a series of TV reports in 2013 revealed multiple restaurants and markets selling fake shark fins, furthering consumer doubts about consuming shark fin soup.

It is still early, but the Chinese Ministry of Commerce reported a 70 percent decline in shark fin sales during the Spring Festival period of 2012–13.<sup>f</sup> In addition, prices of fins fell by 20–30 percent in major fishing markets in Asia after the first six months of the ban.<sup>g</sup>

Notes:

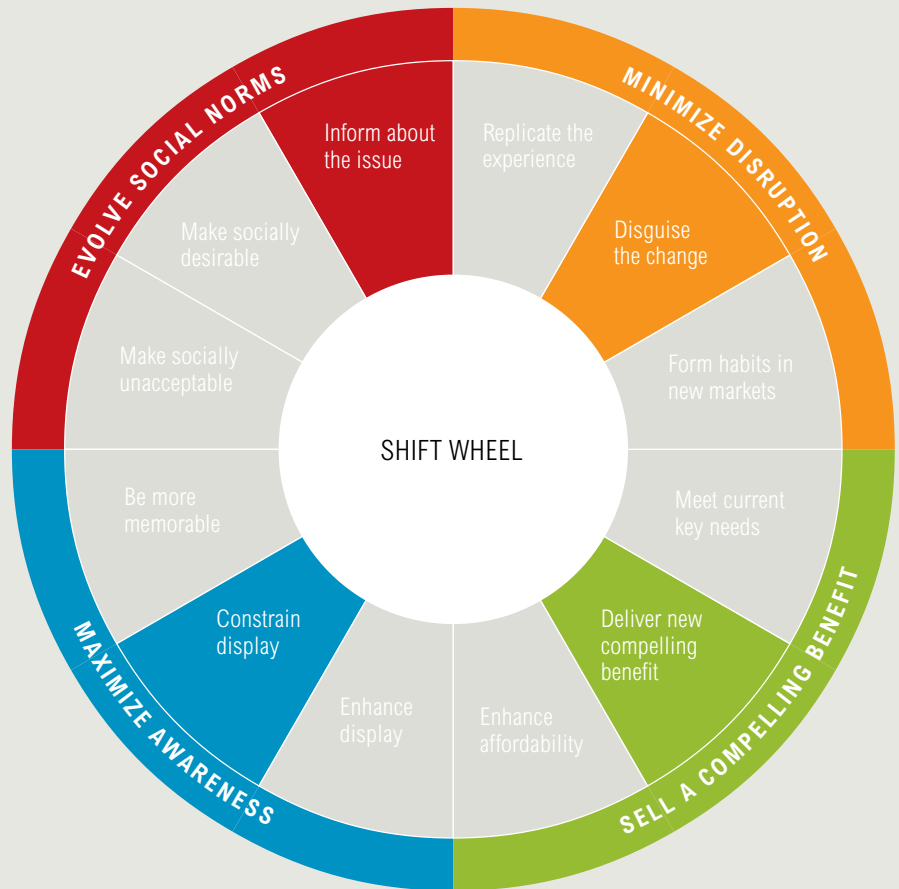
- a. Bakalar (2006).
- b. Shark Savers (2015).
- c. Save Our Seas Foundation (2015).
- d. Flannery (2014) and China Daily (2012).
- e. Evans (2014).
- f. Ministry of Commerce People’s Republic of China (2013).
- g. Videll (2014).

Trans fatty acids (TFAs) are unsaturated fats found in industrially produced partially hydrogenated vegetable oils, and also naturally (at low levels) in meat and dairy. Consumption of industrially produced TFAs has been associated with an increased risk of heart disease, infertility, Alzheimer's disease, diabetes, and some cancers. By the 1990s, studies had made the TFA-health link clear, leading to public health campaigns to remove TFAs from diets. In 2009, the World Health Organization called for the elimination of industrially produced TFAs from the global food supply. However, while some food companies have made large efforts to reformulate their products to remove TFAs, others in the food industry have been resistant to removing TFAs because they are cheap; semisolid at room temperature, making them easy to use in baked products; and have a long shelf life.

Several types of public and private policies have aimed to reduce the amount of TFAs in the food supply, ranging from voluntary TFA limits agreed to by companies to mandatory labeling and/or bans enforced by national and subnational governments. As of 2012, these types of policies were in place in more than 10 countries across North and South America, Western Europe, and Asia. All types of policies have been effective in decreasing the amount of TFAs in food products. In general, as the food industry has reduced the amount of TFAs, it has increased levels of the healthier mono- and polyunsaturated fatty acids and total fat levels have remained relatively constant.

Not surprisingly, bans have been the most effective type of policy in reducing the amount of TFAs in the food supply. For example, Denmark introduced a ban on industrially produced TFAs in 2003, and by 2006 they had been virtually eliminated from the country's food supply.

It also appears that mandatory labeling laws have helped to drive product reformulation and consumer choice, as consumers increasingly demand low-TFA foods. For instance, a study conducted in the United



States found a 58 percent reduction in TFA in blood plasma following mandatory labeling. (Still, labeling policy was only one influence in the United States, because 20 percent of the country's population also lives in areas covered by a TFA ban.) However, labeling has its limitations as an instrument of change. Higher-income, higher-educated segments of the population are most likely to shift consumption in response to labeling. If cheaper, high-TFA products are still available, price-conscious consumers might not be swayed by labeling. In addition, in low- and middle-income countries, the main source of TFAs comes from street vendors, not processed food sold by retailers, limiting the potential reach of labeling.

The use of industrially produced, partially hydrogenated vegetable oils became common following earlier public health campaigns in the 1960s aimed at decreasing the use of animal fats in foods. And just as those earlier campaigns led to a rise in consumption of an unhealthy alternative, there are concerns that the anti-TFA movement could lead to a rise in consumption of palm oil—which is cheap and abundant, but high in saturated fatty acids, and associated with tropical deforestation. The rise in TFA consumption serves as a cautionary tale for those seeking to catalyze consumption shifts: it will be necessary to not only identify the “undesirable” foods but also to encourage shifts toward the “desirable” alternative(s).

Source: Summarized from Downs et al. (2013).

Box 14 | **Shifting to Lower-Alcohol Beer in the United Kingdom**

In 2011, the UK government challenged the beverage industry to remove 1 billion units of alcohol from the nation’s diet by the end of 2015. Keen to do this in a way that maintained their sales volume, manufacturers sought to shift consumers to lower-alcohol drinks.

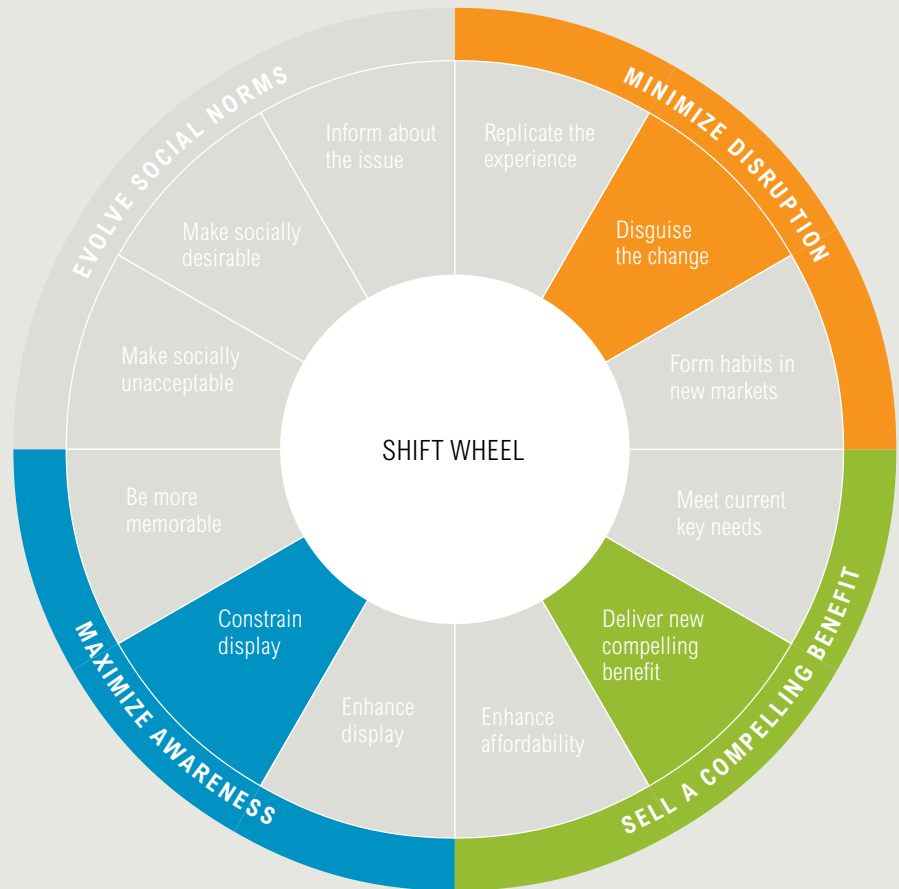
Low-alcohol beer had already been available in the United Kingdom for many years but was an unpopular choice. Key barriers to its consumption included:

- It did not sell a compelling benefit—consumers were not interested in a low-alcohol benefit.
- It was disruptive to consumers—alcohol is a key contributor to taste and removing it changed the taste of beer.
- Awareness and display were limited—low-alcohol beers were displayed in the low-traffic areas of stores and rarely featured on highly visible display-ends.

In 2012, Molson Coors launched a range of beers called Carling Zest that only contained 2.8 percent alcohol (versus the usual 4.8 percent). To disguise the lack of alcohol taste, the beer was launched with lemon, lime, and ginger flavors and was promoted as “light refreshment.” Around the same time, the UK government announced a 50 percent duty (tax) reduction on beers of 2.8 percent alcohol by volume or less and a 25 percent increase for those over 7.5 percent.<sup>a</sup> The company kept the price of Carling Zest the same as its standard (higher-alcohol) Carling lager and invested in advertising the new brand and securing promotional displays in stores. A number of retailers also featured Carling Zest in the main beer aisle.

Notes:

- a. Leicester (2011).
- b. Leicester (2011).
- c. Brown (2014).
- d. Donnelly (2015).
- e. Health Improvement Analytical Team (2014).



Following the launch of Carling Zest, other brands, such as Foster’s Radler, have followed suit in launching similar offerings. Low-alcohol beers have experienced significant growth over the previous years, rising from 0.2 percent of the UK retail and wholesale beer and cider market in 2010<sup>b</sup> to a predicted 5 percent of the market by 2024.<sup>c</sup>

Taking a complementary approach, manufacturers have also slightly reduced the alcohol content of their best-selling

products—a largely imperceptible shift to consumers. For example, Stella Artois, Budweiser, and Beck’s all reduced the alcohol content of their popular lagers from 5 percent to 4.8 percent.<sup>d</sup>

Between 2011 and 2013, the number of units of alcohol consumed in the United Kingdom was reduced by 1.9 billion, already exceeding the goal set for 2015. Of this reduction, an estimated 1.3 billion units were due to reductions in the alcohol content of beverages, especially beer, which contributed 1.2 billion units to the reduction.<sup>e</sup>



During World War II, American citizens faced a potential meat shortage, as meat was rationed to soldiers and allies for the war effort. Needing to find a substitute protein source, the government sought to incorporate organ meats into citizens' diets. The Department of Defense established the Committee on Food Habits in 1940, led by anthropologist Margaret Mead and consisting of psychologists, sociologists, anthropologists, food scientists, dieticians, and home economists. The committee's role was to field-test and identify optimal ways to shift dietary habits toward a novel food source. Since organ meats were not a preferred option of consumers, the barriers to consumption were high. Simply educating consumers about organ meats' nutritional benefits would not have been effective. Thus, the committee advised that the barriers to consumption must first be addressed and removed. Major barriers, and the strategies to overcome them, included:

**Perception of appropriateness:** People do not perceive the new food as appropriate for them to consume. Studies found the following strategies to be effective in changing that perception: (1) using relatable role models within audience's social group to set examples; (2) exposing people at a young age, as this leads to easier adoption later in life; and (3) aligning the new food with a compelling cause, such as national security or patriotism during the war effort.

**Unusual taste:** Studies found the following strategies to be effective in increasing taste tolerance to a new food: (1) preparing the new food in a familiar manner, adapting popular recipes to incorporate the new food; (2) presenting the food with a familiar appearance; and (3) introducing the new food as a side dish to highly palatable existing foods, thereby increasing favorability.



**Unfamiliarity:** In order to increase familiarity, studies suggested (1) increasing the availability of the new food (e.g., in butcher shops), as this increases the perception of acceptability; and (2) offering a variety of the type of food being introduced, as studies found that focusing on just one type of organ meat led to low adoption, while variety helped increase acceptance and adoption.

The committee found that an accepted food is a food that is SAFE: that is, it is selected (i.e., needs to taste good), available (i.e., easily

accessible in markets), familiar, and exactly as expected (i.e., in look, taste, and feel). Marketers of these novel foods would need to communicate these traits to consumers.

World War II ended before the meat shortages became critical, and the government did not have to implement many of the committee's recommendations. However, the lessons learned from the committee's findings can be applied to current efforts to encourage people to shift their dietary habits.

Source: Summarized from Wansink (2002).

In nearly all the case studies reviewed, a shift in consumption behavior was achieved by using multiple strategies from the Shift Wheel, including minimizing disruptions to consumers, marketing product attributes important to consumers, maximizing awareness and availability of preferred products, and evolving social norms around food consumption. Shifts also typically involved groups across a range of sectors, including manufacturers, retailers, nongovernmental organizations, and government agencies working in concert to bring about change. Furthermore, in many of the cases, the shifts created a financial benefit for the companies involved. Box 14, which outlines the shift toward lower-alcohol beer in the United Kingdom, shows how collaboration and coordinated action among different groups using multiple strategies were critical in driving the change. Box 15, which highlights the findings of the Committee on Food Habits established in the United States during World War II, shows how the government intended to use multiple strategies to encourage citizens to incorporate protein-rich organ meats into their diets while domestic meat was rationed for the war effort.<sup>207</sup> It is striking how many of the insights on dietary change gleaned in the 1940s are still relevant today.

Given the significant benefits of shifting diets, how might the Shift Wheel be applied to achieve this end? The first step would be to analyze the landscape of animal- and plant-based food consumption in a given geography or market. Who are the consumers? What are they eating? Where, when, why, and how is this consumption occurring? This analysis would help identify the most promising intervention points. These could be a specific occasion (e.g., family evening meals); a particular product format (e.g., meatballs); a social perception (e.g., that plant-based protein is inferior to meat); certain demographic groups (e.g., millennials); or specific outlets (e.g., school or workplace cafeterias). The next step would be to design approaches to achieve the chosen shift, drawing on relevant strategies from the Shift Wheel. The final steps would be testing the selected approaches and scaling up successes.

## RECOMMENDATIONS

We conclude by outlining four recommendations to help shift diets. These recommendations focus on increasing the share of plant-based protein in diets, while reducing consumption of animal-based protein and beef specifically. Our analysis demonstrates that these two diet shifts in particular, if implemented at a wide scale, could make the most significant contribution to a sustainable food future in terms of closing the food gap and reducing agriculture's resource use and environmental impacts.

### 1. Set targets, apply the Shift Wheel, learn from the results, and scale up successes

**WHO:** Governments, food retailers, food service companies, companies with office cafeterias, food manufacturers, NGOs, research organizations, and other private sector organizations.

**WHAT AND WHY:** Governments and companies in the food value chain, and companies that provide food services, should set quantifiable targets to reduce the consumption of animal-based protein and beef specifically. They should experiment with using the Shift Wheel to drive progress toward these targets. The growing market dominance of large food manufacturers, retailers, and service companies makes them especially well placed to influence consumer choices. Increasing the share of plant-based protein in food sales (relative to animal-based protein) can reduce costs, as animal-based proteins can be more expensive than plant-based proteins.<sup>208</sup> Shifting to more sustainable food consumption choices can also help businesses deliver on their sustainability commitments, including those regarding water, climate change, and deforestation. Governments should also use the Shift Wheel to drive sustainable food choices in government-managed facilities such as schools, prisons, and hospitals.

**HOW:** Targets to shift diets can take a number of forms, including reductions in the use of beef and animal-based protein as well as increases in plant-based food sources. Additionally, food service companies should make vegetarian options—or options low in animal-based ingredients—more prominent on menus and store shelves, and devote increased advertising resources to them. NGOs and research organizations should help build communities of practice with the private sector and others to pilot test the Shift Wheel. The results should be measured and evaluated, and the lessons widely disseminated in order to accelerate transfer and scaling up of successes within

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and across countries. Potential allies for such initiatives include healthcare providers, the environment community, and animal welfare groups. For example, Kaiser Permanente, a US healthcare provider, has created a 30-day challenge for its customers to eat a plant-based diet and see if it has a positive impact on their health.<sup>209</sup>

## 2. Ensure government policies are aligned with promoting sustainable food choices

**WHO:** Government agencies at all levels from city to national scale.

**WHAT AND WHY:** A broad range of government policies already influence diet choices. Diet choices, in turn, affect multiple policy goals, including public health, agricultural production, rural development, climate change mitigation, biodiversity protection, and food and water security. Environmental sustainability has been discussed in the context of nutrition recommendations and policies in several countries in the past decade, including Australia, Brazil, Germany, the Netherlands, Sweden, and the United States.<sup>210</sup> However, government policies are not always aligned and can work at cross-purposes. One example is that of government support for meat and dairy producers. Bailey et al. (2014) noted that livestock subsidies in OECD countries amounted to \$53 billion in 2013, and pork subsidies in China exceeded \$22 billion in 2012.

**HOW:** Governments should ensure coherence among health, agriculture, water, and environmental policies in relation to promoting sustainable diets. As a first step, governments should establish a multidisciplinary cross-agency task force to identify policies and regulations that influence diet choices; assess whether they are aligned with promoting healthy, sustainable diets; and recommend changes to ensure alignment. Key agencies to involve include agriculture, health, environment, education, forests, water, and the lead agency for implementing the United Nations Sustainable Development Goals. Agriculture production subsidies should be an important focus given their size and influence on what types of food farmers produce, although subsidy reform is politically difficult. As discussed above, several countries have also recently established taxes on “unhealthy” foods high in fat, salt, and/or sugar. Others are experimenting with regulations to clearly label unhealthy foods and/or limit the marketing of those foods. Governments should evaluate the effectiveness of these taxes and regulations and scale up approaches that prove effective.

## 3. Increase funding for efforts targeted at shifting diets

**WHO:** Philanthropic community, government, research grant organizations, consumer data agencies, and retailers.

**WHAT AND WHY:** The funding community should increase support for research and actions to shift diets, especially those that go beyond information and education campaigns. As this paper has shown, diet shifts can deliver significant environmental, health, resource use, and food security benefits, serving multiple objectives. Yet the amount of funding currently focused on shifting diets is tiny relative to the amounts focused on increasing the efficiency of food production. There is no dedicated funding mechanism for investing in new ideas for shifting diets, even though it holds significant promise for closing the food gap, reducing climate change, and contributing to the Sustainable Development Goals.

**HOW:** Governments and foundations should create funding mechanisms to support the development, testing, and rollout of evidence-based strategies to shift diets. This could include funds for NGOs and research organizations. Market research agencies, food retailers, and service companies should also provide resources in kind, such as access to data on food consumption behavior, and partnering to test and evaluate the application of the Shift Wheel in retail stores and restaurants.

## 4. Create a new initiative focused on testing and scaling up strategies to shift diets

**WHO:** Philanthropic community, business, and NGOs.

**WHAT AND WHY:** To our knowledge, there is no initiative dedicated exclusively to convening across disciplines, developing research, piloting actions to shift diets at the point of purchase, and scaling up the results. To date, much of the discussion on shifting diets has happened in proverbial silos and is not underpinned by data on current food consumption patterns or on the efficacy and cost-effectiveness of different interventions to effect dietary changes. Nor is it focused on delivering scalable results. Moreover, potentially influential actors have been missing from the conversation—including research agencies, marketing strategists, advertising agencies, and important actors within food supply chains, such as manufacturers, retailers, restaurant chains, and celebrity chefs.

**HOW:** A new initiative should be established to convene marketing and consumer behavior change experts and others involved in food value chains, catalyze new approaches to shifting diets, conduct pilot tests, build an evidence base, and share and scale up successes. Its goal should not be to turn everyone into a vegan or vegetarian, but rather to promote diets that encourage greater consumption of plant-based foods, while reducing consumption of animal-based protein and beef specifically. The organization should prioritize countries that are already consuming high amounts of animal-based protein and beef, or are on their way to becoming high consumers. Results should be measured and evaluated to examine the extent of behavior change; existence of unintended consequences (and ways to mitigate them); and the impact of the behavior change on key economic, social (e.g., health), and environmental indicators. Over time, this initiative should apply its knowledge on shifting diets to other consumption-based challenges, such as transportation, housing, and energy use.

## CALL TO ACTION

In a world that is on a course to demand more than 70 percent more food, nearly 80 percent more animal-based foods, and 95 percent more beef between 2006 and 2050, much of the action on how to sustainably feed the world by mid-century has focused on boosting agricultural production and productivity. However, it will be extremely difficult, if not impossible, to meet the challenge through productivity gains alone, given that global yields would need to rise one-third more quickly than they did during the Green Revolution. Therefore, it will also be critical to shift food consumption patterns in the coming decades.

The three diet shifts recommended in this paper, which aim to reduce overconsumption of food—especially resource-intensive foods—can (a) close the food gap by nearly one-third; (b) significantly reduce agriculture’s pressure on ecosystems, freshwater, and the climate; and (c) contribute to several Sustainable Development Goals. “Shifting diets” is therefore an essential item on the menu for a sustainable food future.

## APPENDIX A. GLOBAGRI REGIONS

Table A1 shows how the world's countries and territories are grouped into 11 regions in GlobAgri: Asia (except China and India), Brazil, China, European Union, Former Soviet Union, India, Latin America (except Brazil), Middle

East and North Africa, OECD (other countries), sub-Saharan Africa, and the United States and Canada. Brazil, China, and India are countries that are counted as their own regions.

Table A1 | Countries, Territories, and Regions in the GlobAgri Model

COUNTRY OR TERRITORY	GLOBAGRI REGION	COUNTRY OR TERRITORY	GLOBAGRI REGION
Afghanistan	Asia (ex. China and India)	Brunei Darussalam	Middle East and North Africa
Albania	OECD, other countries	Bulgaria	EU 27
Algeria	Middle East and North Africa	Burkina Faso	Sub-Saharan Africa
American Samoa	Asia (ex. China and India)	Burundi	Sub-Saharan Africa
Andorra	OECD, other countries	Cambodia	Asia (ex. China and India)
Angola	Sub-Saharan Africa	Cameroon	Sub-Saharan Africa
Anguilla	Latin America (ex. Brazil)	Canada	US & Canada
Antarctica	Not classified	Cape Verde	Sub-Saharan Africa
Antigua and Barbuda	Latin America (ex. Brazil)	Cayman Islands	Latin America (ex. Brazil)
Argentina	Latin America (ex. Brazil)	Central African Republic	Sub-Saharan Africa
Armenia	Former Soviet Union	Chad	Sub-Saharan Africa
Aruba	Latin America (ex. Brazil)	Channel Islands	EU 27
Australia	OECD, other countries	Chile	Latin America (ex. Brazil)
Austria	EU 27	China	China
Azerbaijan	Former Soviet Union	Christmas Island	Not classified
Bahamas	Latin America (ex. Brazil)	Cocos (Keeling) Islands	Not classified
Bahrain	Middle East and North Africa	Colombia	Latin America (ex. Brazil)
Bangladesh	Asia (ex. China and India)	Comoros	Sub-Saharan Africa
Barbados	Latin America (ex. Brazil)	Congo	Sub-Saharan Africa
Belarus	Former Soviet Union	Cook Islands	Asia (ex. China and India)
Belgium	EU 27	Costa Rica	Latin America (ex. Brazil)
Belgium-Luxembourg	EU 27	Côte d'Ivoire	Sub-Saharan Africa
Belize	Latin America (ex. Brazil)	Croatia	OECD, other countries
Benin	Sub-Saharan Africa	Cuba	Latin America (ex. Brazil)
Bermuda	OECD, other countries	Cyprus	EU 27
Bhutan	Asia (ex. China and India)	Czech Republic	EU 27
Bolivia (Plurinational State of)	Latin America (ex. Brazil)	Czechoslovakia	EU 27
Bosnia and Herzegovina	OECD, other countries	Democratic People's Republic of Korea	Asia (ex. China and India)
Botswana	Sub-Saharan Africa	Democratic Republic of the Congo	Sub-Saharan Africa
Brazil	Brazil	Denmark	EU 27
British Indian Ocean Territory	Not classified	Djibouti	Sub-Saharan Africa
British Virgin Islands	Latin America (ex. Brazil)	Dominica	Latin America (ex. Brazil)

Table A1 | Countries, Territories, and Regions in the GlobAgri Model (continued)

COUNTRY OR TERRITORY	GLOBAGRI REGION	COUNTRY OR TERRITORY	GLOBAGRI REGION
Dominican Republic	Latin America (ex. Brazil)	Iraq	Middle East and North Africa
Ecuador	Latin America (ex. Brazil)	Ireland	EU 27
Egypt	Middle East and North Africa	Isle of Man	EU 27
El Salvador	Latin America (ex. Brazil)	Israel	Middle East and North Africa
Equatorial Guinea	Sub-Saharan Africa	Italy	EU 27
Eritrea	Sub-Saharan Africa	Jamaica	Latin America (ex. Brazil)
Estonia	EU 27	Japan	OECD, other countries
Ethiopia	Sub-Saharan Africa	Jordan	Middle East and North Africa
Ethiopia PDR	Sub-Saharan Africa	Kazakhstan	Former Soviet Union
Falkland Islands (Malvinas)	Latin America (ex. Brazil)	Kenya	Sub-Saharan Africa
Faroe Islands	OECD, other countries	Kiribati	Asia (ex. China and India)
Fiji	Asia (ex. China and India)	Kuwait	Middle East and North Africa
Finland	EU 27	Kyrgyzstan	Former Soviet Union
France	EU 27	Lao People's Democratic Republic	Asia (ex. China and India)
French Guiana	Latin America (ex. Brazil)	Latvia	EU 27
French Polynesia	Asia (ex. China and India)	Lebanon	Middle East and North Africa
French Southern and Antarctic Territories	Not classified	Lesotho	Sub-Saharan Africa
Gabon	Sub-Saharan Africa	Liberia	Sub-Saharan Africa
Gambia	Sub-Saharan Africa	Libya	Middle East and North Africa
Georgia	Former Soviet Union	Liechtenstein	OECD, other countries
Germany	EU 27	Lithuania	EU 27
Ghana	Sub-Saharan Africa	Luxembourg	EU 27
Gibraltar	OECD, other countries	Madagascar	Sub-Saharan Africa
Greece	EU 27	Malawi	Sub-Saharan Africa
Greenland	OECD, other countries	Malaysia	Asia (ex. China and India)
Grenada	Latin America (ex. Brazil)	Maldives	Asia (ex. China and India)
Guadeloupe	Latin America (ex. Brazil)	Mali	Sub-Saharan Africa
Guam	Asia (ex. China and India)	Malta	EU 27
Guatemala	Latin America (ex. Brazil)	Marshall Islands	Asia (ex. China and India)
Guinea	Sub-Saharan Africa	Martinique	Latin America (ex. Brazil)
Guinea-Bissau	Sub-Saharan Africa	Mauritania	Sub-Saharan Africa
Guyana	Latin America (ex. Brazil)	Mauritius	Sub-Saharan Africa
Haiti	Latin America (ex. Brazil)	Mayotte	Sub-Saharan Africa
Holy See	OECD, other countries	Mexico	Latin America (ex. Brazil)
Honduras	Latin America (ex. Brazil)	Micronesia (Federated States of)	Asia (ex. China and India)
Hungary	EU 27	Monaco	OECD, other countries
Iceland	OECD, other countries	Mongolia	Asia (ex. China and India)
India	India	Montenegro	OECD, other countries
Indonesia	Asia (ex. China and India)	Montserrat	Latin America (ex. Brazil)
Iran (Islamic Republic of)	Middle East and North Africa	Morocco	Middle East and North Africa



Table A1 | Countries, Territories, and Regions in the GlobAgri Model (continued)

COUNTRY OR TERRITORY	GLOBAGRI REGION	COUNTRY OR TERRITORY	GLOBAGRI REGION
Mozambique	Sub-Saharan Africa	Saint Pierre and Miquelon	OECD, other countries
Myanmar	Asia (ex. China and India)	Saint Vincent and the Grenadines	Latin America (ex. Brazil)
Namibia	Sub-Saharan Africa	Samoa	Asia (ex. China and India)
Nauru	Asia (ex. China and India)	San Marino	OECD, other countries
Nepal	Asia (ex. China and India)	São Tomé and Príncipe	Sub-Saharan Africa
Netherlands	EU 27	Saudi Arabia	Middle East and North Africa
Netherlands Antilles	Latin America (ex. Brazil)	Senegal	Sub-Saharan Africa
New Caledonia	Asia (ex. China and India)	Serbia	OECD, other countries
New Zealand	OECD, other countries	Serbia and Montenegro	OECD, other countries
Nicaragua	Latin America (ex. Brazil)	Seychelles	Sub-Saharan Africa
Niger	Sub-Saharan Africa	Sierra Leone	Sub-Saharan Africa
Nigeria	Sub-Saharan Africa	Singapore	Asia (ex. China and India)
Niue	Asia (ex. China and India)	Slovakia	EU 27
Norfolk Island	Asia (ex. China and India)	Slovenia	EU 27
Northern Mariana Islands	Asia (ex. China and India)	Solomon Islands	Asia (ex. China and India)
Norway	OECD, other countries	Somalia	Sub-Saharan Africa
Occupied Palestinian Territory	Middle East and North Africa	South Africa	Sub-Saharan Africa
Oman	Middle East and North Africa	Spain	EU 27
Pacific Islands Trust Territory	Not classified	Sri Lanka	Asia (ex. China and India)
Pakistan	Asia (ex. China and India)	Sudan	Sub-Saharan Africa
Palau	Asia (ex. China and India)	Suriname	Latin America (ex. Brazil)
Panama	Latin America (ex. Brazil)	Svalbard and Jan Mayen Islands	OECD, other countries
Papua New Guinea	Asia (ex. China and India)	Swaziland	Sub-Saharan Africa
Paraguay	Latin America (ex. Brazil)	Sweden	EU 27
Peru	Latin America (ex. Brazil)	Switzerland	OECD, other countries
Philippines	Asia (ex. China and India)	Syrian Arab Republic	Middle East and North Africa
Pitcairn Islands	Not classified	Tajikistan	Former Soviet Union
Poland	EU 27	Thailand	Asia (ex. China and India)
Portugal	EU 27	The former Yugoslav Republic of Macedonia	OECD, other countries
Puerto Rico	Latin America (ex. Brazil)	Timor-Leste	Asia (ex. China and India)
Qatar	Middle East and North Africa	Togo	Sub-Saharan Africa
Republic of Korea	Asia (ex. China and India)	Tokelau	Asia (ex. China and India)
Republic of Moldova	Former Soviet Union	Tonga	Asia (ex. China and India)
Réunion	Sub-Saharan Africa	Trinidad and Tobago	Latin America (ex. Brazil)
Romania	EU 27	Tunisia	Middle East and North Africa
Russian Federation	Former Soviet Union	Turkey	Middle East and North Africa
Rwanda	Sub-Saharan Africa	Turkmenistan	Former Soviet Union
Saint Helena	Sub-Saharan Africa	Turks and Caicos Islands	Latin America (ex. Brazil)
Saint Kitts and Nevis	Latin America (ex. Brazil)		
Saint Lucia	Latin America (ex. Brazil)		

Table A1 | **Countries, Territories, and Regions in the GlobAgri Model (continued)**

COUNTRY OR TERRITORY	GLOBAGRI REGION
Tuvalu	Asia (ex. China and India)
Uganda	Sub-Saharan Africa
Ukraine	Former Soviet Union
United Arab Emirates	Middle East and North Africa
United Kingdom	EU 27
United Republic of Tanzania	Sub-Saharan Africa
United States of America	US & Canada
United States Virgin Islands	Latin America (ex. Brazil)
Unspecified	Not classified
Uruguay	Latin America (ex. Brazil)
USSR	Former Soviet Union
Uzbekistan	Former Soviet Union
Vanuatu	Asia (ex. China and India)
Venezuela (Bolivarian Republic of)	Latin America (ex. Brazil)
Viet Nam	Asia (ex. China and India)
Wake Island	Not classified
Wallis and Futuna Islands	Asia (ex. China and India)
Western Sahara	Middle East and North Africa
Yemen	Middle East and North Africa
Yemen Dem	Sub-Saharan Africa
Yugoslav SFR	OECD, other countries
Zambia	Sub-Saharan Africa
Zimbabwe	Sub-Saharan Africa

## APPENDIX B. DIET SHIFT SCENARIOS

This appendix contains further detail on the data sources, calculation methods, and assumptions behind each of the diet shift scenarios in this paper. Table B1 also contains further detail on the caloric composition of the reference diets and scenarios presented in Figures ES-3, 3, 6, 10, and 15.

### DIET SHIFT 1: REDUCE OVERCONSUMPTION OF CALORIES

Scenario: Eliminate Obesity and Halve Overweight

- Use country-level obesity and overweight prevalence data (mean percentage values) from Ng et al. (2014a) and data on percentage of population ages 0–14 from World Bank (2015).
- Assume even distribution of women vs. men and girls vs. boys in each country.
- Apply region-level or nearby country data for countries with no data in Ng et al. (2014a) and World Bank (2015).
- Scale 2013 obesity/overweight prevalence values in Ng et al. (2014a) to 2009 population data in GlobAgri model to estimate the number of obese and overweight adults and children in 2009. (Although “adult” in Ng et al. 2014a is defined as age 20 or older, and in World Bank 2015 is defined as age 15 or older, for convenience, these calculations assume that the definitions of “adult” are equivalent.)
- Assume that it takes an extra 500 kcal/day (sustained over time) for a person to become obese and extra 250 kcal/day (sustained over time) to become overweight, as informed by FAO (2004) and Hall et al. (2011a).
- Assume a 100 percent reduction in obesity and a 50 percent reduction in overweight relative to 2009 reference.
- Calculate the number of “avoided excess calories” consumed each year in each country (multiplying the reduction in the obese population \* 500 kcal/day \* 365 days/year, and multiplying the reduction in the overweight population \* 250 kcal/day \* 365 days/year).
- Divide the “avoided excess calories” by the number of calories actually consumed in each country in 2009 to determine a “calorie adjustment factor” for each country.
- Lower the number of calories actually consumed in 2009 by each country’s calorie adjustment factor, applying the factor equally across all food categories in each country.

- For 2050, assume the number of obese and overweight people will increase by 50 percent relative to 2009 (from approximately 2.1 billion to approximately 3.1 billion). The implied compounded annual rate of growth in obesity and overweight of about 1 percent per year is slower than historical growth rates and takes into account the fact that countries with high obesity levels have started to see growth rates taper off.<sup>211</sup>

### Scenario: Halve Obesity and Halve Overweight

- Same as the *Eliminate Obesity and Halve Overweight* scenario, but assume a 50 percent reduction in obesity and a 50 percent reduction in overweight relative to 2009 reference.

## DIET SHIFT 2: REDUCE OVERCONSUMPTION OF PROTEIN BY REDUCING CONSUMPTION OF ANIMAL-BASED FOODS

### Scenario: Ambitious Animal Protein Reduction

- Use 2009 region-level consumption data from GlobAgri.
- Only modify diets in regions where daily per capita consumption (of all foods) is above 2,500 kcal (a consumption level above FAO's average daily energy requirement of 2,353 kcal/capita/day) and 60 g of protein (a level well above the average estimated daily requirement of 50 g protein/capita/day). This requirement eliminates Asia (ex. China and India), the former Soviet Union, China, India, other OECD, and sub-Saharan Africa. (2,500 kcal and 60 g protein per capita daily thresholds were also used in Bajzelj et al. 2014).
- In all other regions (Brazil, US & Canada, Latin America [ex. Brazil], Middle East and North Africa, European Union), calculate the 2009 “excess protein consumption” above 60 g/day.
- Subtract “excess protein consumption” from actual 2009 animal protein consumption to determine “adjusted animal protein consumption.”
- Divide “adjusted animal protein consumption” by actual 2009 animal protein consumption to determine “animal product adjustment factor.”
- Apply the “animal product adjustment factor” to 2009 animal product calorie consumption to determine the downward adjustment in calories of animal products.
- Subtract the “adjustment in calories of animal products” from actual 2009 total calorie consumption to determine “adjusted calorie consumption.”

- If “adjusted calorie consumption” is below 2,500 kcal/capita/day, raise the “animal product adjustment factor” until per capita calorie consumption is back to 2,500.
- Finally, in Brazil, US & Canada, Latin America [ex. Brazil], Middle East and North Africa, and the European Union, multiply 2009 consumption of each animal food group (aquatic animal products, beef, dairy, eggs, pork meat, poultry meat, small ruminant meat) by each region's “animal product adjustment factor” (ranges from 0.11 to 0.93) to determine adjusted consumption of each product in 2009.
- For 2050, these criteria would lead to all world regions being affected by this scenario, except the former Soviet Union.

### Scenario: Traditional Mediterranean Diet

- Use a weighted average of the Spanish and Greek national diets from 1980 as the “Mediterranean 1980” diet (as given in the “food supply” column of FAO 2015), mapped to GlobAgri food categories. (The Mediterranean 1980 diet has a per capita food supply (availability) of just more than 3,000 kcal/capita/day, suggesting low levels of both hunger and obesity in those countries in 1980.)
- Only modify diets in regions where average daily per capita consumption was above 2,500 calories and 40 grams of animal-based protein (in 2009, this includes EU and US & Canada).
- Scale consumed calories to 2009 reference levels in the regions where consumption levels were modified.
- For the global analysis, assume that 50 percent of people in those regions shift their consumption to the “Mediterranean 1980” diet.
- For 2050, these criteria would lead to the following regions being affected by this scenario: Brazil, US & Canada, China, Latin America (ex. Brazil), other OECD, and European Union.

### Scenario: Vegetarian Diet

- Use the UK 1993–99 vegetarian diet as reported in Scarborough et al. (2014), mapped to GlobAgri food categories. (This vegetarian diet includes small amounts of meat, as “vegetarians” in the study were self-reported.)

- Only modify diets in regions where average daily per capita consumption was above 2,500 calories and 40 grams of animal-based protein (same regions as in the *Traditional Mediterranean Diet* scenario).
- Scale consumed calories to 2009 reference levels in the regions where consumption levels were modified.
- For the global analysis, assume that 50 percent of people in those regions shift their consumption to the “UK vegetarian” diet.
- For 2050, the regions affected by this scenario would be the same as those affected by the *Traditional Mediterranean Diet* scenario.

### DIET SHIFT 3: SHIFT FROM BEEF SPECIFICALLY

#### Scenario: Ambitious Beef Reduction

- Use 2009 region-level consumption data from GlobAgri.
- Only modify diets in regions where daily beef consumption is above 2009 world average (3.2 g protein/capita/day) and where kcal consumption is above 2,500 kcal/capita/day. This eliminates Asia (ex. China and India), China, Former Soviet Union, India, Middle East and North Africa, sub-Saharan Africa, and other OECD.
- In all other regions (Brazil, US & Canada, Latin America [ex. Brazil], European Union), reduce beef consumption to world average (3.2 g protein/capita day). World average divided by actual beef consumption gives the “beef adjustment factor” for each region.
- Multiply the “beef adjustment factor” (which ranges from 0.25 to 0.60) by 2009 beef consumption in each region. Due to regional differences in the ratio of beef-based calories to beef-based protein, adjusted beef consumption varied between 25 and 35 kcal/capita/day in regions where the scenario was applied.
- Verify that applying the “beef adjustment factor” does not reduce overall calorie consumption below 2,500 kcal/capita/day, or protein consumption below 60 g protein/capita/day, in any of the regions where applied.
- For 2050, these criteria would lead to the following regions being affected by this scenario: Brazil, US and Canada, China, Latin America (ex. Brazil), Middle East and North Africa, other OECD, and European Union.

#### Scenario: Shift from Beef to Pork and Poultry

- Use 2009 region-level consumption data from GlobAgri.
- Only modify diets in regions where daily beef consumption is above world average. This includes all regions modified in the *Ambitious Beef Reduction* scenario, plus the former Soviet Union and other OECD. Because this scenario does not alter calorie consumption, it is fine to alter the diets of the regions that consumed below 2,500 kcal/capita/day (former Soviet Union and other OECD).
- In these regions, reduce per capita beef consumption by 33 percent. (Justification: FAO 2015 data shows that per capita beef consumption has dropped from peak levels by 27 percent in Japan, 32 percent in the EU, and 40 percent in the US.)
- Replace that reduced beef consumption with increases in consumption of pork and poultry (proportionately to what people in each region consumed in 2009).
- Overall calorie consumption remains unchanged, as people just shift from one type of meat calories to two other types.
- For 2050, these criteria would lead to the following regions being affected by this scenario: Brazil, US and Canada, China, former Soviet Union, Latin America (ex. Brazil), Middle East and North Africa, other OECD, and European Union.

#### Scenario: Shift from Beef to Legumes

- Use 2009 region-level consumption data from GlobAgri.
- As in the *Shift from Beef to Pork and Poultry* scenario, only modify diets in regions where daily beef consumption is above world average. In these regions, reduce beef consumption by 33 percent.
- Replace that reduced beef consumption with (equal) increases in consumption of pulses and soybeans (simulating, for instance, ground beef being replaced with a mixture that is two-thirds beef, one-third plant proteins).
- Overall calorie consumption remains unchanged, as people just shift from one type of calories to two others.
- For 2050, the regions affected by this scenario would be the same as those affected by the *Shift from Beef to Pork and Poultry* scenario.

**Table B1 | Detailed Composition of Reference Diets and Scenarios**  
per capita daily food consumption (kcal), 2009

			REDUCE OVERCONSUMPTION OF CALORIES		REDUCE OVERCONSUMPTION OF PROTEIN BY REDUCING CONSUMPTION OF ANIMAL-BASED FOODS			REDUCE CONSUMPTION OF BEEF SPECIFICALLY			
Food type	US (Reference)	World (Reference)	US (Eliminate Obesity & Halve Overweight)	US (Halve Obesity & Overweight)	US (Ambitious Animal Protein Reduction)	US (Traditional Mediterranean)	US (Vegetarian)	US (Ambitious Beef Reduction)	US (Beef to Pork and Poultry)	US (Beef to Legumes)	
ANIMAL-BASED FOODS	Beef	94	36	88	90	46	80	3	25	63	63
	Dairy	306	119	287	294	149	306	432	306	306	306
	Eggs	45	31	43	44	22	60	78	45	45	45
	Fish	21	26	20	21	10	35	2	21	21	21
	Pork	113	100	106	109	55	129	4	113	125	113
	Poultry	165	46	155	159	80	67	0	165	183	165
	Sheep and goat	3	10	3	3	2	3	2	3	3	3
PLANT-BASED FOODS	Fibers	14	11	13	13	14	15	0	14	14	14
	Fruits and vegetables	138	149	130	133	138	275	596	138	138	138
	Maize	140	146	131	134	140	10	36	140	140	140
	Oil (other oilcrops)	29	38	27	28	29	271	64	29	29	29
	Other cereals	97	105	91	93	97	63	156	97	97	97
	Other oilcrops	54	37	51	52	54	27	0	54	54	54
	Other plant products	54	28	51	52	54	59	89	54	54	54
	Other products	66	37	62	63	66	48	4	66	66	66
	Palm oil	1	50	1	1	1	4	0	1	1	1
	Pulses	40	58	38	39	40	64	164	40	40	56
	Rapeseed and mustard seed	45	20	42	43	45	0	0	45	45	45
	Rapeseed and mustard seed oil	56	29	52	54	56	0	0	56	56	56
	Rice	268	493	251	258	268	74	111	268	268	268
	Roots and tubers	63	118	59	61	63	155	230	63	63	63
	Soybean oil	395	71	371	380	395	69	0	395	395	395
	Soybeans	1	13	1	1	1	0	94	1	1	17
	Sugar plants and products	253	194	237	243	253	281	191	253	253	253
	Sunflower seed	5	0	5	5	5	0	0	5	5	5
	Sunflower seed oil	6	27	6	6	6	117	7	6	6	6
	Wheat	432	442	406	416	432	690	639	432	432	432
TOTALS	Animal-based foods	747	367	702	719	363	681	522	678	747	716
	Plant-based foods	2,156	2,065	2,025	2,077	2,156	2,223	2,382	2,156	2,156	2,188
	<b>GRAND TOTAL</b>	<b>2,904</b>	<b>2,433</b>	<b>2,726</b>	<b>2,796</b>	<b>2,520</b>	<b>2,904</b>	<b>2,904</b>	<b>2,834</b>	<b>2,904</b>	<b>2,904</b>

Source: GlobAgri model with source data from FAO (2015) and FAO (2011a).

Note: All "US" data are for United States and Canada. The vegetarian diet scenario, which uses data from Scarborough et al. (2014), includes small amounts of meat, as "vegetarians" were self-reported.



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## ENDNOTES

1. Authors' calculations from Searchinger et al. (2013), adjusted upward to reflect the latest United Nations estimate of 9.7 billion people as given in UNDESA (2015). This crop calorie gap, which we estimate at 71 percent, is sometimes referred to as the "food gap" in this paper. This paper, and others in the *Creating a Sustainable Food Future* series, rely on data from the FAO Food Balance Sheets (FAO 2015) and an FAO projection of food demand and production by 2050 by long-time experts Jelle Bruinsma and Nikos Alexandratos (Alexandratos and Bruinsma 2012). Searchinger et al. (2013) and this paper's authors adjusted the FAO 2050 projection of food demand upward in two ways: (1) to ensure 3,000 calories per person per day are available in all the world's regions by 2050, and (2) to reflect the latest United Nations mid-range population estimate for 2050.

Two possible ways to quantify human calorie requirements are calories from crop production or calories from all food available directly for human consumption. Measuring food directly available to people omits calories in animal feed, but counts calories in animal products. Each approach has its merits. The estimated food gap between 2006 and 2050 by either measure is similar, ranging from 71 percent for the needed increase in crop production to 68 percent for the needed increase in food calories available for direct human consumption (Searchinger et al. 2013, adjusted by the authors of this paper).

Using the food balance sheets in FAO (2015) to estimate diets requires several assumptions. For example, in nearly all countries, food balance sheets suggest more food available per person than people actually eat in part because "available food" includes food that people waste in their homes or dining out, and ultimately do not consume. To estimate consumption, the GlobAgri model subtracted waste estimated from these food balance sheets by region based on FAO (2011a). The GlobAgri consumption estimates compare quite favorably with our own estimates using data from Lipinski et al. (2013) and FAO (2011a), as well as the European Union consumption estimates using a different food waste dataset reported in Westhoek et al. (2015). As widely acknowledged, these waste estimates are rough. In addition, our analysis determined that some of the wastes estimated in FAO (2011a) are already reflected in processing wastes that the food balance sheets use to compute available food from raw products. Our analysis adjusted for these processing wastes.

Strengths of these FAO data sources include the inclusion of nearly all of the world's countries, relatively comparable methods across countries, and open access to data. Furthermore, food availability estimates are ultimately derived from production and trade data. Use of FAO estimates of food availability to estimate actual diets (consumption) is therefore necessary to link food consumption estimates in a consistent way to food production estimates (how many crops and animal products are actually produced, and where in the world that production occurs), which in turn is necessary to estimate the land use and greenhouse gas emissions generated to supply the food produced for human consumption. In short, there is currently no alternative to using FAO data to make these estimates.

However, FAO food balance sheets result in estimates of actual dietary intake in many countries that are inconsistent with separate estimates of actual calorie consumption in those countries, typically undertaken through national diet surveys. For example, Del Gobbo et al. (2015) note that mean total energy intake (consumption) in the United States

in the 2009–10 National Health and Nutrition Examination survey was estimated at 2,081 kcal/capita/day, far lower than the 3,652 kcal/capita/day (food availability) given in FAO (2015) for the United States in 2009. Even when the FAO food availability figure is adjusted downward for food waste, the corresponding estimate of food consumption derived from FAO data in GlobAgri is still around 2,900 kcal/capita/day. Several factors could explain the discrepancy between FAO and natural survey estimates. In some contexts, people may underestimate their actual calorie consumption in national surveys. Another possible explanation is that there is even more food waste than estimated by FAO (2011a). If waste figures are higher than estimated by FAO (2011a), our calculation of the land use and greenhouse gas consequences of diets in each country would still be accurate (so long as FAO food availability estimates are accurate). This error would just mean that more of the environmental burden of supplying food results from waste of that food along the supply chain.

Ongoing global efforts to produce better estimates of food consumption, and of food losses and waste, should in the future permit refinement of the dietary estimates in this paper.

2. UNDESA (2015). 9.7 billion people in 2050 reflects the medium-growth scenario.
3. "Middle class" is defined by OECD as having per capita income of \$3,650 to \$36,500 per year or \$10 to \$100 per day in purchasing power parity terms. "Middle class" data from Kharas (2010).
4. UNDESA (2014).
5. Foresight (2011).
6. Searchinger et al. (2013).
7. Authors' calculations, adjusted upward from FAO projections in Alexandratos and Bruinsma (2012). See endnote 1 for more on adjustments.
8. Searchinger et al. (2013).
9. UNFCCC (2015).
10. Searchinger et al. (2013).
11. Garnett (2014a), Swinburn et al. (2011), FAO (2013), Tulchinsky (2010).
12. Steinfeld et al. (2006).
13. When diet shifts reduce agricultural land use, the resulting negative emissions from land-use change represent one-time gains in land-based carbon sequestration (or, alternatively, avoided future emissions from land-use change).
14. Pulses are annual leguminous crops harvested for dry grain, including beans, peas, and lentils.
15. Keats and Wiggins (2014), Khoury et al. (2014), Tilman and Clark (2014), Popkin et al. (2012).
16. Delgado et al. (1999), Popkin (2003), Popkin and Gordon-Larsen (2004), Kearney (2010). Indeed, Popkin (2003) notes that preferences for dietary fats and sugars may be an innate human trait.
17. Khoury et al. (2014), Pingali (2007).

18. Anand et al. (2015), Reardon et al. (2014).
19. Popkin and Gordon-Larsen (2004).
20. USDA and HHS (2010), WHO (2012).
21. In this paper, we use the term “per capita [calorie or protein] availability” to mean the quantity of food *reaching the consumer*, as defined in the FAO Food Balance Sheets (FAO 2015). We use the term “per capita consumption” to mean the quantity of food *actually consumed*, when accounting for food waste at the consumption stage of the value chain. “Consumption” quantities (which exclude all food loss and waste) are therefore lower than “availability” quantities. Data on “per capita consumption” are from the GlobAgri model, using source data from FAO (2015) on “per capita availability” and FAO (2011a) on food loss and waste. Because historical rates of food loss and waste are unknown, graphs showing trends from 1961 display “availability” instead of “consumption.”
22. FAO (2015).
23. Alexandratos and Bruinsma (2012).
24. While the FAO data paint a broad picture of food availability and consumption at the national level, food consumption surveys, such as the China Health and Nutrition Survey, reveal differences in diets consumed by different population groups within countries (FAO 2015). In particular, diets vary between rural and urban areas and between high- and low-income groups. In China, for example, adults in urban areas consumed an average of 400 calories from animal-based foods per day in 2011, while those in rural areas only consumed 220 calories, and urban consumers ate 40 percent more processed food per capita than rural consumers (Zhai et al. 2014). Given this variation in diets, interventions to shift diets will need to be carefully targeted in terms of countries and segments of the population within countries.
25. Land use and greenhouse gas emissions are estimated by GlobAgri. Water use estimates are from authors’ calculations using data from Mekonnen and Hoekstra (2011, 2012). The following additional information about the water use estimates are summarized from Hoekstra et al. (2011) and Water Footprint Network (2016):

The water use estimates are divided into “blue” and “green” water footprints. “Blue water footprint” represents the volume of surface and groundwater consumed as a result of the production of a crop or animal-based food (i.e., irrigation). “Water consumption” refers to the volume of freshwater used and then evaporated or incorporated into a product. It also includes water abstracted from surface or groundwater in a watershed and returned to another watershed or the sea (but not to the watershed from which it was withdrawn). “Green water footprint” represents the volume of rainwater consumed during the production of a crop or animal-based food, and is equal to the total rainwater evapotranspiration (from fields and plantations) plus the water incorporated into the harvested crop. In the case of grazing land, Mekonnen and Hoekstra (2012) only calculate the evapotranspiration for the portion of grass consumed by animals (versus all of the water evapotranspired from the entire surface area). This narrower scope helps to explain why green water use in Figure 2 does not more closely track total land use as calculated by GlobAgri (especially for cattle, which rely heavily on grasses for feed).

Freshwater availability on earth is determined by annual precipitation above land. One part of the precipitation evaporates and the other part runs off to the ocean through aquifers and rivers. Both the evaporative flow and the runoff flow can be made productive for human purposes. The evaporative flow can be used for crop growth or left for maintaining natural ecosystems; the green water footprint measures which part of the total evaporative flow is actually appropriated for human purposes. The runoff flow—the water flowing in aquifers and rivers—can be used for all sorts of purposes, including irrigation, washing, processing, and cooling. The blue water footprint measures the volume of groundwater and surface water consumed.

Since freshwater availability on earth is limited, it is important to know how it is allocated over various purposes, to inform discussions around use of water for maintaining natural ecosystems versus production of food or energy, or around the use of water for basic needs versus production of luxury goods. Water footprint estimates, when overlaid with maps of water stress, can also identify “hotspots” where water footprint reduction is most urgent.

26. Data are from the most recent years possible. Most data are from 2009. Data on aquaculture production are from 2008 (as reported in Hall et al. 2011b and Waite et al. 2014), and data on water use efficiency are from 1996–2005 (as reported in Mekonnen and Hoekstra 2011, 2012).
27. The analysis in this section—and similar sections analyzing the per capita effects of diet shifts later in the paper—uses actual average per capita food consumption for the “United States and Canada” region in 2009. Because the United States’ population was 90 percent of the total population of this region in 2009, and because consumption patterns across the US and Canada are quite similar, we present these findings as for “the United States” for simplicity’s sake.
28. GlobAgri model. More precisely, the per person land use and greenhouse gas effects of each diet, as modeled in GlobAgri and shown in Figures 3, 6, 10, and 15, are the marginal effects of adding one additional person to the world population in 2009. This is why the per person land-use change emissions are higher than the agricultural production emissions; because yields and trade patterns are held constant, GlobAgri estimates the annual emissions that would result from converting the additional land (roughly 0.5 hectares for the average world diet and roughly 1 hectare for the average US diet) from natural ecosystems to agricultural production.
29. GlobAgri model.
30. GlobAgri model. Note that land-use change emissions in Figure 3 are amortized over a period of 20 years and then shown as annual impacts. The annual per person land-related agriculture emissions from consuming the average world diet (around 8 tons CO<sub>2</sub>e in 2009 as shown in Figure 3), when multiplied by the world population of 6.8 billion, do not equate to the annual estimates of global land-use change emissions (around 5 billion tons CO<sub>2</sub>e globally per year as given in Smith et al. 2014). (Multiplying 8 tons CO<sub>2</sub>e per person by the world population would lead to an estimate of more than 50 billion tons CO<sub>2</sub>e globally, about 10 times higher than actual land-use change emissions.) This is because GlobAgri estimates land-use change at the margin, and only 81 million people (not 6.8 billion people) were added to the world population in 2009. Given steady growth in crop and livestock yields, there would be no land-use change emissions if increases in food demand were fully met by agricultural productivity increases and people’s diets



did not change. Land-use change emissions occur when food demand growth cannot be fully met by yield gains—as is currently the case. Each individual's consumption affects this quantity of expansion and emissions, and the GlobAgri model attempts to estimate by how much. For more on calculations of land-use change emissions, see Box 4.

31. Authors' calculations. Total US energy-related emissions of 5,386 million tons CO<sub>2</sub> (EIA 2015), when divided by a US population of 306.8 million, equal per capita emissions of 17.6 tons CO<sub>2</sub>e in 2009. Land-use-change emissions of 300 tons CO<sub>2</sub>e are therefore equal to roughly 17 times average US per capita energy-related CO<sub>2</sub> emissions in 2009. Energy-related CO<sub>2</sub> emissions are those stemming from the burning of fossil fuels. These estimates differ in that the dietary land-use-change emissions include the global consequences of diets, while the energy-related emissions calculate only those emissions from energy use within the US. Factoring in a portion of energy emissions associated with imported products increases those US energy emissions somewhat. For example, Davis and Caldeira (2010) estimate that US consumption-based CO<sub>2</sub> emissions (defined as the amount of emissions associated with the consumption of goods and services in a country, after accounting for imports and exports) were 22 tons per capita per year in 2004.
32. The three diet shifts are interconnected because they are not mutually exclusive. Figures 6, 10, and 15, which show the effects of the three diet shifts on caloric consumption in the United States, make this point clear. The two scenarios that reduce overconsumption of calories (Figure 6) also reduce animal-based food consumption, including beef. The *Ambitious Animal Protein Reduction* (Figure 10) and *Ambitious Beef Reduction* (Figure 15) scenarios also reduce calories in all affected regions. In addition, although overall calorie consumption was held constant in the *Traditional Mediterranean Diet* and *Vegetarian Diet* scenarios (relative to the reference levels) to isolate the effects of the shifts away from resource-intensive foods (Figure 10), in practice a shift to a Mediterranean or vegetarian diet could also reduce calorie consumption (further reducing the associated agricultural land use and greenhouse gas emissions).
33. The World Health Organization defines “overweight” as having a body mass index (BMI) greater than or equal to 25 and “obese” as having a BMI greater than or equal to 30. BMI is an index of weight-for-height that is commonly used to classify overweight and obesity in adults. It is defined as a person's weight in kilograms divided by the square of his height in meters (kg/m<sup>2</sup>) (WHO 2012).
34. Ng et al. (2014a).
35. Ng et al. (2014a).
36. FAO (2014).
37. FAO, WHO, and UNU (1985).
38. GlobAgri model with source data from FAO (2015) and FAO (2011a). Although median levels of consumption would give the most accurate picture of an “average” person's consumption in a given country or region, data presented in Figures 4, 7, and 11 are means, because means are the only globally available averages. Of course, countries exceeding the 2,353 calorie threshold on an average basis will likely have a percentage of their populations below the threshold. For instance, although China, Nigeria, and Indonesia all lie above the threshold in Figure 4, in 2010–12, 12 percent of China's population was undernourished, as were 6 percent in Nigeria, and 11 percent in Indonesia, according to FAO, IFAD, and WFP (2015). This underscores the importance of properly targeting diet shifts at “overconsuming” segments of the population within a country or region
39. WHO (2012).
40. Gortmaker et al. (2011), Spencer et al. (2002), Campbell et al. (1992).
41. USDA and HHS (2010), WHO (2012).
42. USDA and HHS (2010).
43. OECD (2010).
44. American Diabetes Association (2008).
45. Finkelstein et al. (2009).
46. *Economist* (2014).
47. Bloom et al. (2011), Hojjat (2015).
48. Fry and Finley (2005).
49. Finkelstein et al. (2010).
50. Behan and Cox (2010).
51. Bloom et al. (2011).
52. Dobbs et al. (2014).
53. We chose the countries and regions in Figure 5 because they have high populations, are home to more than half of the world's people, and cover a wide range of geographies and stages of economic development. The nine countries and regions shown in Figures 5, 9, and 14 include seven of the ten most populous countries projected for 2050 (medium fertility scenario), plus Japan, which was the 11th most populous country in 2015. The population of the European Union—the only region included in these figures—was 505 million in 2015. All countries and regions shown will have a population of at least 100 million in 2050 under UNDESA's medium fertility scenario. All told, these countries and regions were home to 60 percent of the world's population in 2015 and are projected to contain 53 percent of the world's population in 2050 (Authors' calculations from UNDESA 2015).
54. All statistics in this paragraph are from Ng et al. (2014a).
55. Ng et al. (2014a). Countries are listed in order of number of obese individuals.
56. Alexandratos and Bruinsma (2012).
57. Popkin et al. (2012).
58. Popkin (2002).
59. *Economist* (2014).
60. Cecchini et al. (2010).
61. Monteiro et al. (2007).

62. FAO, WFP, and IFAD (2012).
63. Gortmaker et al. (2011).
64. Jones-Smith et al. (2011).
65. Within a population, the degree to which calorie availability has peaked varies based on a number of factors, such as socioeconomic status and race/ethnicity. See Ng et al. (2014b) for a discussion relevant to the United States.
66. Grecu and Rotthoff (2015).
67. FAO, IFAD, and WFP (2015).
68. FAO, IFAD, and WFP (2015).
69. FAO, IFAD, and WFP (2015).
70. See notes 1 and 21 for more on adjusting availability for consumption loss and waste.
71. GlobAgri model with source data from FAO (2015) and FAO (2011a).
72. The first analysis of the per person effects of the diet scenarios involves quantifying the additional (marginal) agricultural land use and greenhouse gas emissions required to add one average US resident to the world population in 2009 and then assessing how these would change under the diet scenarios. The second analysis of the global effects of the diet scenarios involves quantifying actual global agricultural land use and greenhouse gas emissions in 2009, and then assessing how these would change under alternative diet scenarios applied across all overconsuming populations.
73. For full descriptions of the data sources, calculations, and assumptions underlying each scenario, and further detail on the caloric composition of the reference diets and scenarios, see Appendix B. Under all scenarios, agricultural yields (of crops and livestock) and food consumption (by non-affected populations) were held constant.
74. FAO has estimated that consumption of 2,700 to 3,000 kcal/person/day will lead to obesity by people with sedentary lifestyles (FAO 2004). Using the mid-point of 2,850 kcal, and assuming that an acceptable diet would consist of 2,350 kcal/person/day, this estimate implies that the elimination of obesity would reduce consumption by 500 kcal/person/day. This estimate is also generally consistent with the estimate of the excess calorie consumption for extremely obese US adults—those with a BMI over 35—of roughly 500 kcal/person/day (Hall et al. 2011a). The latter estimate represents the increased calorie consumption to *maintain* obese conditions for US adults, and is actually more than double the increased calorie consumption necessary to *become* obese. As Hall et al. (2011a) explain, the estimate represents a revised view upward compared to the traditional view of only 200 kcal/person/day, which did not account for the greater calorie intake required to maintain the larger body size of the overweight or obese. The 500 kcal/day assumes that all obese children have a similar overconsumption. We assume half this amount for leading to and sustaining being overweight. With this assumption, we do not intend to imply that reducing calorie consumption is all that is needed to reduce obesity in the global population; the focus of this paper is on the potential for “shifting diets” to contribute to closing the food gap and thus here we focus on overconsumption of calories (instead of complementary approaches such as increasing physical activity).
75. There is no perfect way to calculate greenhouse gas emissions from land use attributable to agricultural demand. Our emissions estimates here are based on the GlobAgri model. For each individual crop or animal-based food, the model estimates the additional amount of land that would be used to produce an additional quantity of that product as shown either in a region, a set of regions, or the world. It also estimates the amount of carbon this agricultural land would otherwise store. When forests and savannas are converted to annual cropland, the amount of carbon stored in vegetation is nearly eliminated, and while the soil carbon numbers vary, a general estimate of a loss of 25 percent of the carbon in the top meter of soil is a reasonable estimate based on meta-analyses (Searchinger et al. 2015; Guo and Gifford 2002). When lands are converted from natural vegetation to agriculture, the bulk of carbon loss and therefore emissions occur quickly (although soils may continue to lose carbon for many years), and are one-time emissions. But based on the approach taken by the European Union for estimating emissions from land-use change for biofuels, we show one-twentieth of these emissions as the annual emissions. This approach assigns one-twentieth of these emissions to each year of crop production for twenty years. Although losses will not occur indefinitely, this approach recognizes the time value of reducing greenhouse gas emissions earlier rather than later, and it also provides a way of combining emissions from land-use change with those from food production into one level of total emissions. For most of the diet scenarios analyzed in this paper, there is a reduction in crop and pasture demands and therefore a reduction in total land-use demands. The GlobAgri model estimates the amount of carbon that these lands would sequester over time by regrowing native vegetation and, in the case of abandoned cropland, rebuilding soil carbon. Because this carbon regrowth occurs over longer periods of time, and because it is hard to imagine a sudden diet shift by millions of people in a single year, we decided it was not plausible to allocate these emissions over only a 20-year period. Furthermore, because global agricultural land is expanding—as food demand growth continues to outpace yield growth—the real-world consequences of reducing food demand under the scenarios modeled in this paper would be to avoid future land-use change. Therefore, in Tables 2, 3, and 4, we display these emissions as avoided future emissions from land-use change. For more on the calculations of greenhouse gas emissions from land-use change, see Box 4.
76. CAIT Climate Data Explorer (2015).
77. “Fish” is defined in this paper as all aquatic animals, including finfish, crustaceans, and mollusks. Other (less-commonly-consumed) animal-based protein sources include animal fats and offal (FAO 2015).
78. As noted above, the global-level data shown in Figure 2 mask variations among locations, production systems, and farm management practices (Box 5).
79. Similarly to other developed countries, the US government (CDC 2015) lists the estimated daily requirement for protein as 56 grams per day for an adult man and 46 grams per day for an adult woman, or an average of 51 grams of protein per day. Paul (1989) estimates the average protein requirement at 0.8 g per kg of body weight per day. Since the average adult in the world weighed 62 kg in 2005 (Walpole et al. 2012), applying the rule of 0.8 g/kg/day would yield an estimated global average protein requirement of 49.6 grams per day. Other international estimates are lower still; for instance, FAO, WHO, and UNU (1985) estimate an average requirement of 0.75 g/kg/day. Furthermore, these estimates are conservative to ensure that they cover individual variations within a population group; for example, the estimated protein requirement of 0.8 g per kg of



- body weight per day given in Paul (1989) includes 0.35 g/kg/day as a safety margin.
80. FAO, WHO, and UNU (1985). Factors include age, sex, height, weight, level of physical activity, and pregnancy and lactation.
  81. GlobAgri model with source data from FAO (2015) and FAO (2011a).
  82. GlobAgri model with source data from FAO (2015) and FAO (2011a). Of course, countries exceeding the threshold of consumption of 50 grams of protein per capita per day will likely have a percentage of their populations below the threshold. For example, Semba et al. (2016) found that in rural villages in southern Malawi, chronically malnourished young children were low in all essential amino acids, and more than 60 percent of these children were stunted. See the discussion around Figure 4.
  83. Keats and Wiggins (2014), FAO (2015), Tilman and Clark (2014), Weeks (2012).
  84. Popkin et al. (2012), Delgado et al. (1999).
  85. Godfray et al. (2010).
  86. Neumann et al. (2010).
  87. Godfray et al. (2010), Steinfeld et al. (2006).
  88. Pica-Ciamarra et al. (2011).
  89. However, it is true that the possible effects of the diet shifts in this paper would not necessarily be limited to livestock farmers. For example, given that livestock in overconsuming countries are fed largely on grains, reducing consumption in those countries would lead to surplus grains and lower prices for grains globally. This could help poor consumers in developing countries, but could hurt poor farmers. The GlobAgri model did not estimate economic effects of the various diet scenarios in this paper, but such effects would need to be carefully monitored and managed to avoid the diet shifts harming poor farmers.
  90. GlobAgri model. "Agricultural land for animal-based food production" includes pastureland plus cropland used for growing feeds.
  91. See Garnett et al. (2015) for an in-depth discussion on the various definitions of "environmental efficiency" in animal-based food production, tradeoffs, and implications for sustainability.
  92. Mekonnen and Hoekstra (2012).
  93. Precise impacts depend on how animal welfare is defined (Fraser 2008), but generally increasing the number of animals confined in intensive, cramped, industrial-style farm production systems, often with high levels of ammonia, raises welfare concerns. Of course, production systems can be improved, but improving the conditions in which animals are kept can also create tradeoffs for resource use and environmental impacts, by increasing feed requirements, greenhouse gas emissions, and land use relative to more intensive systems (Westhoek et al. 2011).
  94. Landers et al. (2012). Although data are limited, the quantity of antibiotics used in animal food production in the United States likely exceeds the quantity used to treat humans (HHS and CDC 2013).
  95. Dwyer and Hetzel (1980), Armstrong and Doll (1975), Sinha et al. (2009), Larsson and Orsini (2013).
  96. Larsson and Orsini (2013), Rohrmann et al. (2013), Pan et al. (2012).
  97. Larsson and Orsini (2013).
  98. Di Maso et al. (2013), Pan et al (2012).
  99. Binnie et al. (2014).
  100. Bouvard et al. (2015). "Processed meat" refers to meat that has been transformed through salting, curing, fermentation, smoking, or other processes to enhance flavor or improve preservation. Most processed meats contain pork or beef, but might also contain other red meats, poultry, offal (e.g., liver), or meat byproducts such as blood.
  101. FAO (2015).
  102. Authors' calculations, adjusted upward from FAO projections in Alexandratos and Bruinsma (2012). See endnote 1 for more on adjustments.
  103. GlobAgri model with source data from FAO (2015) and FAO (2011a).
  104. Weeks (2012), Fox and Ward (2007).
  105. Foresight (2011).
  106. Delgado et al. (1999), Khoury et al. (2014).
  107. Zhai et al. (2014). Zhai et al. (2014) note that animal-based food consumption is now rising in rural China as well; between 1991 and 2011, per capita animal-based food consumption in urban China remained relatively unchanged, while it grew by about 30 percent in rural areas.
  108. FAO (2012b).
  109. Authors' calculations based on Alexandratos and Bruinsma (2012) with WRI adjustments. See endnote 1 for more on adjustments.
  110. See Searchinger et al. (2013) and Waite et al. (2014).
  111. Tilman et al. (2011).
  112. For full descriptions of the data sources, calculations, and assumptions underlying each scenario, and further detail on the caloric composition of the reference diets and scenarios, see Appendix B. Under all scenarios, agricultural yields (of crops and livestock) and food consumption (by nonaffected populations) were held constant. The analysis for the United States also included Canada.
  113. These minimum consumption levels give a buffer between world average daily energy requirements (2,353 kcal/capita/day) and average daily protein requirements (50 grams/capita/day), and are also equal to the minimum consumption levels used in Bajzelj et al. (2014).
  114. Overconsuming countries and regions in 2009 included Brazil, the United States and Canada, Latin America (ex. Brazil), the Middle East and North Africa, and the European Union.
  115. One way to picture this scenario is to remove the parts of the red bars above the "60 grams of protein line" in Figure 4. We also ensured that this reduction in protein consumption did not cause total calorie intake to drop below 2,500 calories per day. In regions where calorie intake did drop below 2,500, we adjusted animal-based protein consumption back upward until calorie intake was exactly 2,500.

116. Authors' calculations. The *Ambitious Animal Protein Reduction* scenario led global animal protein consumption to fall from 61.8 million tons in 2009 to 51.0 million tons, a reduction of approximately 17 percent. This 17 percent figure is for the entire world, so it includes regions whose diets were not altered.
117. This global caloric reduction of 2.4 percent was greater than the caloric reduction under the *Halve Obesity and Overweight* scenario (2.1 percent) but less than the reduction under the *Eliminate Obesity and Halve Overweight* scenario (3.1 percent).
118. Anand et al. (2015), Buckland et al. (2011), Estruch et al. (2013), Fung et al. (2009), Martinez-Gonzalez et al. (2011), Nunez-Cordoba et al. (2009), Romaguera et al. (2009), Scarmeas et al. (2006). The intention here is not to advocate that the whole world shift to a Mediterranean diet as eaten in the Mediterranean region, but to explore the effects of a commonly studied "healthy diet" on agriculture's resource use and environmental impacts. A "Mediterranean-style diet" could be adapted to all regional diets (see, for example, examples for adaptation in East Asia, South Asia, Middle East, Africa, North and South America, and Europe in Anand et al. 2015, Supplementary Table 1).
119. FAO (2015).
120. The effect of switching half of these regions' populations to a Mediterranean (or vegetarian) diet would also be equivalent to that of switching the regions' entire populations halfway toward the alternative diet. Regardless of the interpretation, we felt that a 50 percent switch was more plausible than a 100 percent switch when modifying the diets of entire regions.
121. Scarborough et al. (2014). These data were the best and most recent representation of an actual (not stylized) vegetarian diet. We converted the raw consumption data from Scarborough et al. (2014) to GlobAgri food categories to be able to compare the environmental effects of this diet to the others analyzed in this paper.
122. All results are from GlobAgri.
123. The vegetarian respondents in Scarborough et al. (2014) were self-identified, and a small percentage (less than 1 percent) reported eating some level of meat—which explains the small amount of beef consumption reported in the "Vegetarian" bars of Figure 10. Most of the "other animal products" category shown in the "Vegetarian" bars of Figure 10 is composed of eggs.
124. This insight also suggests that any concerns about micronutrient deficiency in the scenarios analyzed (e.g., in the *Ambitious Animal Protein Reduction* scenario, which reduces US animal product consumption by about half and overall calorie consumption by almost 400 kcal/person/day relative to 2009 reference) could be readily addressed by adding in appropriate plant-based products to maintain a balanced diet, without greatly affecting overall land use and greenhouse gas emissions. For example, Bajzelj et al. (2014) set minimums of three portions of vegetables per day (136 kcal/capita/day) and two portions of fruit per day (119 kcal/capita/day) in their "healthy diets" scenarios—adjusting fruit and vegetable consumption upward to meet these minimums would add a relatively small amount of land use and greenhouse gas emissions to the scenario results.
125. FAO (2015).
126. CAIT Climate Data Explorer (2015).
127. Land-use change emissions were slightly positive under this scenario, even though there was a small net reduction in agricultural land use. This result is most likely due to the fact that the soil carbon in the additional land that went into production under this scenario (e.g., for more pulses and fish) was slightly more than the carbon in the land taken out of production (e.g., for beef), as estimated by GlobAgri.
128. FAO (2015).
129. Global greenhouse gas emissions in 2009 were 44 billion tons (CAIT Climate Data Explorer).
130. GlobAgri model with source data from FAO (2015) and FAO (2011a).
131. Authors' calculations, adjusted upward from FAO projections in Alexandratos and Bruinsma (2012). See endnote 1 for more on adjustments.
132. Rosegrant and Thornton (2008).
133. Increasing pastureland productivity is another item on the menu for a sustainable food future (Figure 1) and is addressed in Searchinger et al. (2013).
134. See Waite et al. (2014) for a discussion of the conversion efficiency and environmental performance of aquaculture, including farmed finfish, crustaceans, and mollusks. Farmed mollusks (e.g., clams, mussels, scallops, and oysters) and filter-feeding carps are even more efficient than the other animal products shown in Figure 8 because they obtain all their food from plankton and dead and decaying organic matter suspended in the surrounding water—meaning there is no "food-out/terrestrial feed-in" ratio.
135. Authors' calculations from FAO (2015).
136. Wirseniens et al. (2010).
137. Eshel et al. (2014).
138. FAO (2011b).
139. Authors' calculations from Mekonnen and Hoekstra (2012) and average protein content of animal-based foods in FAO (2015).
140. Mekonnen and Hoekstra (2012).
141. Authors' analysis based on UNEP (2012), FAO (2012a), EIA (2012), IEA (2012), and Houghton (2008) with adjustments.
142. Authors' calculations ( $0.47 * 0.13 = 0.06$ ).
143. Alexandratos and Bruinsma (2012).
144. Pan et al. (2012).
145. Mintert et al. (2009).
146. Authors' calculations from FAO (2015) and Alexandratos and Bruinsma (2012).
147. FAO (2015).
148. Jarvis (1986).

149. USDA/FAS (2014).
150. For full descriptions of the data sources, calculations, and assumptions underlying each scenario, and further detail on the caloric composition of the reference diets and scenarios, see Appendix B. Under all scenarios, agricultural yields (of crops and livestock) and food consumption (by nonaffected populations) were held constant.
151. Regions affected by this scenario included Brazil, the European Union, Latin America (ex. Brazil), and the US and Canada.
152. One way to picture this scenario is that the parts of the bars above the “world average” line in Figure 11 were removed. The scenario was designed to ensure that reductions in beef consumption did not cause per capita daily calorie consumption to drop below 2,500 calories or total protein consumption to drop below 60 grams. In regions where consumption did drop below 2,500 calories, beef consumption was adjusted back upward so calorie consumption was exactly 2,500.
153. Authors’ calculations. The *Ambitious Beef Reduction* scenario led global beef-based protein consumption to fall from 7.9 million tons to 5.5 million tons, a reduction of approximately 30 percent. This 30 percent figure is for the entire world, so it includes regions whose diets were not altered.
154. Regions affected by this scenario included Brazil, the European Union, the former Soviet Union, Latin America (ex. Brazil), US and Canada, and other OECD. They included all regions affected by the *Ambitious Beef Reduction* scenario but also others that consumed less than 2,500 calories per capita per day in 2009, so affected nearly 2 billion people in all.
155. The 33 percent level was chosen following the observation that FAO (2015) data show that in the US, EU, and Japan, per capita consumption has already declined by 27–40 percent from peak levels. We assumed that similar reductions could be achieved in other high-consuming regions, and that further reductions in Northern America and Europe were plausible.
156. All results are from GlobAgri model.
157. FAO (2015).
158. CAIT Climate Data Explorer (2015).
159. FAO (2015).
160. The final World Resources Report will use GlobAgri to quantify the environmental effects of the diet shifts on 2050 baseline food consumption.
161. Authors’ calculations. See Appendix B for more on assumptions related to the diet scenarios in 2050. The 2050 population projections are from UNDESA (2015).
162. As an example, the one scenario that required more crop calories relative to reference in 2009—the *Shift from Beef to Pork and Poultry* scenario, which involved a switch from a predominantly grass-fed meat to two predominantly crop-fed meats—could switch to a “gap narrowing” scenario in 2050 if beef production becomes more crop-fed and pork and poultry production become more efficient in the use of crop-based feeds.
163. Alexandratos and Bruinsma (2012).
164. Authors’ calculations. The 71 percent crop calorie gap shown in Figure 1 is equal to approximately 6,800 trillion calories. Alexandratos and Bruinsma (2012) assume that 25 percent of all crops (measured by calories) will be dedicated to animal feed in 2050, or  $16,300 * (0.25) = 4,075$  trillion calories of feed crops. In a hypothetical extreme scenario where animal product consumption was completely eliminated by 2050, demand for animal feed would disappear and crop calorie needs in 2050 would drop by 4,075 trillion calories. The *Ambitious Animal Protein Reduction* scenario, when applied to projected 2050 consumption patterns, would result in roughly half of animal-based protein being removed from the human diet relative to FAO’s baseline projection (authors’ calculations). Therefore, under that scenario, crop calorie needs in 2050 would drop by half of 4,075 trillion calories, or 2,038 trillion calories—equal to 30 percent of the 6,800 trillion calorie food gap.
165. Beattie et al. (2010), Tootelian and Ross (2000).
166. Larson and Story (2009). However, studies have shown that labeling can provide an incentive to food companies to reformulate products to make them healthier (Vyth et al. 2010, Variyam 2005).
167. Capacci et al. (2012).
168. Dumanovsky (2011).
169. Ajani et al. (2004), Han et al. (2011).
170. Hammer et al. (2009).
171. Winter and Rossiter (1988), McDonald et al. (2002).
172. Wood and Neal (2009).
173. Ji and Wood (2007).
174. Thaler and Sunstein (2008), Garnett (2014b), Bailey and Harper (2015), Wellesley et al. (2015).
175. House of Lords (2011).
176. Reardon and Timmer (2012).
177. Reardon et al. (2003).
178. Reardon et al. (2003), Reardon and Timmer (2012).
179. Reardon and Timmer (2012).
180. Reardon et al. (2007).
181. Pingali (2007).
182. USDA/ERS (2014a).
183. Hawkes (2008) in Garnett and Wilkes (2014).
184. USDA/ERS (2014b).

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185. Fast-moving consumer goods are products that are sold quickly and at relatively low cost (including foods and beverages).
  186. Brinsden et al. (2013).
  187. DEFRA (2014a).
  188. Stummer (2003), Cornish Sardine Management Association (2015).
  189. Birds Eye (2015).
  190. Keats and Wiggins (2014).
  191. Haley (2001).
  192. Ecorys (2014), Thow et al. (2014), Nordström and L. Thunström (2009), Hawkes (2012), Thow et al. (2010), Jensen and Smed (2013), Colchero et al. (2016).
  193. Economist (2012).
  194. Caraher and Cowburn (2005).
  195. For example, based on average US retail prices in 2013, the price per gram of protein ranged from 0.9 cents for dried lentils, 1.1 cents for wheat flour, 1.2 cents for dried black beans, and 2.3 cents for dried white rice, to 2.7 cents for eggs, 2.9 cents for milk, 3.1 cents for fresh whole chicken, and 4.4 cents for ground beef. Authors' calculations based on USDA/ERS (2015a), USDA/ERS (2015b), BLS (2015), and USDA (2015).
  196. Wansink and Hanks (2013).
  197. Just and Wansink (2009).
  198. Arnold and Pickard (2013).
  199. Corvalán et al. (2013).
  200. Sharp (2010), Chapter 12.
  201. Sharp (2010), Chapter 12.
  202. Robinson et al. (2014).
  203. Hickman (2011).
  204. Smith (2008).
  205. House of Lords (2011), Reisch et al. (2013). Beattie et al. (2010), Tootelian and Ross (2000), Capacci et al. (2012), Dumanovsky (2011).
  206. USDA/HHS (2015).
  207. Wansink (2002).
  208. See note 200.
  209. Kaiser Permanente (2013).
  210. USDA/HHS (2015).
  211. OECD (2014), Ng et al. (2014a).

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