The Complete Menu: Creating a Sustainable Food Future

The analysis of individual menu items in Courses 1–5 estimates how much each item could help the world close our three gaps to meet targets for increasing food production, minimizing expansion of agricultural land area, and reducing greenhouse gas (GHG) emissions. In this section, we use the GlobAgri-WRR model to examine several plausible (or at least possible) combinations of menu items for closing these gaps and achieving a sustainable food future.

TABLE OF CONTENTS

CHAPTER 32

COMBINING MENU ITEMS: THREE INCREASING LEVELS OF GLOBAL AMBITION

In this chapter, we describe and, where possible, quantify the level of effort required in each menu item to realize each of our three combined scenarios: the Coordinated Effort, Highly Ambitious, and Breakthrough Technologies scenarios.

Modeling efforts often categorize each component action (what we call "menu items" in this report), into three levels of ambition: "low, medium, and high" or "conservative, moderate, and aggressive." Each level is determined by expert judgment, degree of change relative to current or projected status, cost,[1] or other criteria. Modelers then aggregate the "low ambition" components into a combined "conservative" scenario, the "medium ambition" components into a combined "moderate" scenario, and the "high ambition" components into a combined "aggressive" scenario.

The "Coordinated Effort," "Highly Ambitious," and "Breakthrough Technologies" Scenarios

We also aggregate our menu items into three levels of ambition, but we follow a different approach in combining them. We do not automatically aggregate all the low-ambition menu item scenarios into one "low" scenario and so on. The lower, medium, and higher scenarios of each individual menu item require different kinds of changes in behavior, different scales of government effort, and different levels of technological innovation. The changes required, for example, to obtain different levels of land use or GHG savings by shifting diets differ from the changes required to achieve different levels of reduction in emissions from fertilizer. To establish three scenarios with changes in each menu item that are conceptually consistent, we therefore apply the following principles as scenarios advance in ambition:

- **Coordinated Effort scenario.** For each component menu item, this aggregate scenario involves levels of progress that we are confident the world could achieve with a strong, coordinated, global commitment to action. Changes would come at limited economic cost (or even economic gains) and without the need for any fundamental breakthroughs in technology. Success would depend primarily on political will. The level of commitment required in the Coordinated Effort scenario would mean that the world's governments would need to muster financial resources and, in many situations, overcome political and logistical obstacles. Coordination is necessary in part to share technological knowledge and scientific understanding—such as reasonable progress in manure management—and also to implement globally consistent policies to ensure that progress in one country does not simply shift unsustainable practices to another. For example, effective forest and savanna protection in one set of countries could result in land- clearing for agriculture in other countries if the latter do not impose similar forest and savanna protection. Reductions in demand for meat in one country could lower meat prices and increase meat consumption in another if the latter does not have similar initiatives to reduce demand for meat. We do assume continued progress in and support for some technologies that are already developing, such as commercialization of some promising drugs or feed additives that lower enteric methane emissions and further improvements in plant-based meat substitutes, but we do not assume any fundamental technological breakthroughs.

- **Highly Ambitious scenario.** This scenario includes the menu items from the Coordinated Effort scenario and extends them by choosing a level of achievement that is based on technical achievability but is less concerned with cost or practicability. In some situations, this level of achievement will require existing technology to advance beyond current performance, but it will not require true technological breakthroughs. Some of these measures might be costly in economic terms and would require government support or regulatory action, but they should be technically feasible.

- **Breakthrough Technologies scenario.** This scenario includes all menu items in the Coordinated Effort and Highly Ambitious scenarios plus additional levels of achievement that could be realized only with technological breakthroughs that improve both performance and cost effectiveness. We consider technological breakthroughs only in fields where science has shown significant progress.

To illustrate the thinking behind our categorization, consider the menu item regarding fertility rates.

Our Coordinated Effort scenario includes population growth in sub-Saharan Africa that follows the "low fertility" projection of the United Nations. That projection assumes reductions in total fertility rates that are 0.5 children per woman lower in each country in each year than in the baseline "medium fertility" scenario. Achieving this reduction in fertility rates would require major new political and social efforts to improve access to education for girls, improve children's health care, and provide access to family planning. Although ambitious politically, these measures involve social investments that would be valuable for many political, social, and moral reasons independent of food security and sustainability concerns. In that sense, such measures would pay for themselves regardless of their effects on food security and the environment. We conclude they would be achieved if the world directed appropriate attention and ambition to these efforts.

For our Highly Ambitious scenario, we choose a reduction in fertility rates to replacement levels by 2050 because we consider such efforts to be socially and technologically achievable with even higher investments in health and education and in light of the speed of change that has occurred in some other countries. However, our Breakthrough Technologies scenario includes no more ambitious target because we are aware of no breakthrough technologies that would further reduce fertility rates—and in any case, replacement level fertility would have already been achieved and no further reductions would be necessary.

As another illustration, consider reducing methane emissions from ruminants. Our Coordinated Effort scenario assumes that a feed additive becomes commercially available at low cost that can reduce enteric methane by 30 percent from cattle, and that this additive is provided to most cattle that are fed from a central location at least every day. That level of application equates to roughly half of all dairy cattle and roughly one-quarter of beef cattle.[2] This effort would require modest improvements to a feed additive that is already invented and an ambitious—but entirely feasible—strategy to induce farmers worldwide to give that additive to their animals where practicable. Our Highly Ambitious scenario extends this 30 percent emissions reduction to two-thirds of all beef cattle that are at times fed concentrated feed or cut-and-carry grass, and to all dairy cattle and one-sixth of all sheep and goats. Such an achievement would require either some additional technological innovation for long-lasting, slow-release additives—which we do not consider rises to the level of a major breakthrough technology—or some more active, and likely expensive, practice involving feeding grazing animals. In the Breakthrough Technologies scenario, we extend the 30 percent methane emissions reduction to all ruminants, including goats and sheep, which we consider impractical without greater technological innovation.

Our food loss and waste and fertilizer management menu items illustrate our judgment about breakthrough technologies. We regard a 50 percent reduction in global food loss and waste as appropriate only for our Breakthrough Technologies scenario because such a high level of reduction would probably require innovative, simple, and inexpensive technologies that enable foods to be stored for far longer without spoilage. Similarly, in our "reduce nitrogen emissions from fertilizer" menu item, the shift to producing ammonia fertilizer using solar energy sources occurs only in the Breakthrough Technologies scenario. We believe that technological breakthroughs are necessary before these levels of reductions become practical and economical, but we also believe that promising technological options exist that make this scenario feasible.

For most of the menu items in Courses 1–5, one could hypothesize innovations that achieve far greater closure of gaps than those we incorporate even in the Breakthrough Technologies scenario; for example, food additives for ruminants that eliminate nearly all methane emissions, crop yield gains that easily produce three times as much food on the same land, or plant-based steak that is indistinguishable from the best Argentinian filet. A few of these technologies might become realities, and we consider research to realize these innovations important, but for now we consider them too speculative to meet our criteria. Including them in our scenarios could lead to unrealistic expectations or misplaced "bets" on necessary actions over the coming 5–10 years to get the world on a path to a sustainable food future.

As these examples illustrate, the level of ambition selected for each menu item in each of the three combined scenarios ultimately reflects our educated guess as to how hard it will be to achieve. Other researchers may reasonably disagree with our choices. The purpose of this exercise is to illustrate the kinds of combinations of menu items that could close the three gaps.

Table 32-1 shows the level of ambition we adopted for each menu item in each of the three combined scenarios. More detailed discussion of the rationale behind each level of ambition is provided in each of the relevant menu item chapters of this report.

Summary of the Baseline and Combined Scenarios

Table 32-1 | Summary of the GlobAgri-WRR 2050 baseline projection and three combined scenarios

MENU ITEM	2050 BASELINE	COORDINATED EFFORT	HIGHLY AMBITIOUS	BREAKTHROUGH TECHNOLOGIES	COMMENT
DEMAND-SIDE SOLUTIONS					
Course 1. Reduce growth in food demand					
Reduce food loss and waste	Rate of food loss and waste (24% of calories globally) maintained in each country and food type	10% reduction in rate of food loss and waste	25% reduction in rate of food loss and waste	50% reduction in rate of food loss and waste	The Coordinated Effort seems plausible because the United Kingdom reduced its food loss and waste by 14% between 2007 and 2012. A 25% reduction seems possible as an outer limit, but a 50% reduction seems unlikely without breakthroughs in technology (e.g., improved storage systems or technology that prevents spoilage for longer).
Shift to healthier and more sustainable diets	88% increase in demand for ruminant meat between 2010 and 2050 as incomes grow across the developing world	Ruminant meat demand increases only 69% above 2010 levels, and calories shift to pulses and soy. This represents a 10% reduction in ruminant meat demand relative to baseline.	Ruminant meat demand increases only 32% above 2010 levels, and calories shift to pulses and soy. This represents a 30% reduction in ruminant meat demand relative to baseline.	Same as Highly Ambitious	We do not include reductions in total consumption of animal-based foods in the combination scenarios because our baseline scenario (based on FAO projections) is arguably conservative in projecting "business-as-usual" demand for these foods. But U.S. and European experience shows that large reductions in beef demand are possible. A global 30% reduction in ruminant meat demand (relative to 2050 baseline) would require reductions of more than 20% in Europe, 40% in North America and Russia, and 60% in Brazil relative to 2010 levels, which we consider highly ambitious.

Table 32-1 | Summary of the GlobAgri-WRR 2050 baseline projection and three combined scenarios (continued)

MENU ITEM	2050 BASELINE	COORDINATED EFFORT	HIGHLY AMBITIOUS	BREAKTHROUGH TECHNOLOGIES	COMMENT
Avoid competition from bioenergy for food crops and land	Crop-based biofuels maintained at 2010 share of global transportation fuel (2.5%)	Both food and energy crop-based biofuels phased out	Same as Coordinated Effort	Same as Coordinated Effort	Our analysis shows no environmental or food security benefits from these biofuels, so phasing them out is solely a political question rather than an economic or technical question.
Achieve replacement-level fertility rates	UN medium fertility estimate; global population 9.8 billion in 2050	UN low fertility estimate in sub-Saharan Africa; global population 9.5 billion in 2050	Sub-Saharan Africa fertility drops to replacement level by 2050; global population 9.3 billion in 2050	Same as Highly Ambitious	Although the UN "low fertility" estimate is plausible, each new UN population projection since 2012 has revised sub-Saharan Africa's population in 2050 upward since the region's fertility rates have not dropped as rapidly as previously projected. Evidence from other countries of rapid drops in fertility rates nevertheless suggests that the Highly Ambitious scenario is possible.
SUPPLY-SIDE SOLUTIONS					
Course 2. Increase food production on existing agricultural land					
Increase livestock and pasture productivity	62% growth in beef output per hectare of pastureland, 53% growth in dairy output per hectare, and 71% growth in sheep and goat meat output per hectare	Same as baseline	Productivity growth is 25% faster, resulting in 67% growth in beef output per hectare, 58% growth in dairy output per hectare, and 76% growth in sheep and goat meat output per hectare	Same as Highly Ambitious	Because the baseline projection already includes faster efficiency gains than in the past 50 years, we maintain the baseline in the Coordinated Effort scenario. However, because pure technical potential is probably higher, we increase this level in Highly Ambitious scenario. Although improved breeding is critical to all progress, we foresee no breakthrough technologies.
Plant existing cropland more frequently	5% increase in cropping intensity between 2010 and 2050 (to 89%)	10% increase in cropping intensity between 2010 and 2050 (to 93%)	Same as Coordinated Effort	Same as Coordinated Effort	Extremely limited information on potential to increase double-cropping or reduce fallow periods— particularly without irrigation expansion—bars any confident predictions. But modest FAO prediction in the baseline leads us to estimate some higher potential in Coordinated Effort scenario.

Table 32-1 | Summary of the GlobAgri-WRR 2050 baseline projection and three combined scenarios (continued)

MENU ITEM	2050 BASELINE	COORDINATED EFFORT	HIGHLY AMBITIOUS	BREAKTHROUGH TECHNOLOGIES	COMMENT
Improve crop breeding to boost yields **Improve soil and water management** **Adapt to climate change**	48% increase in crop yields above 2010 levels (similar to average linear rates of yield growth from 1962 to 2006)	Same as baseline	Crop yields rise to 56% above 2010 levels (20% improvement over baseline growth rate)	Crop yields rise to 69% above 2010 levels (50% improvement over baseline growth rate)	Because baseline yields assume faster growth rates than recent decades, we believe they already require a large-scale, global coordinated effort. But technical potential to boost yields could allow a faster growth rate in the Highly Ambitious scenario, and new molecular biology methods suggest capacity for breakthrough technologies with adequate research effort.
Course 3. Protect and restore natural ecosystems and limit agricultural land-shifting					
Link productivity gains with protection of natural ecosystems	Linkage prevents most shifting of locations of agricultural land encouraged by yield gains	Same as baseline	Same as baseline	Same as baseline	Viewed globally, helping farmers to boost yields (Course 2) while at the same time avoiding gross agricultural land expansion is a necessary and cost-effective strategy to stabilize the climate. Since yield gains are realized in Course 2, this linkage to ecosystem protection is a political rather than a technical or economic challenge and belongs in all scenarios.
Limit inevitable cropland expansion to lands with lower environmental opportunity costs	Inevitable land expansion is limited such that carbon effects are offset by the next menu item (reforestation)	Same as baseline	Same as baseline	Same as baseline	Avoided conversion of forests and other natural ecosystems is embedded in the actions to reduce demand (Course 1) and increase crop and livestock production on existing agricultural land (Course 2).
Reforest abandoned, unproductive, and liberated agricultural lands	Reforestation of lands with little agricultural potential offsets carbon effects of inevitable shifting of locations of agricultural land	Same as baseline	Same as baseline	80 Mha of liberated land fully reforested (to achieve 4 Gt CO_2e/year target) 585 Mha of liberated land fully reforested to offset all remaining agricultural production emissions	Because of the ambitious nature of our strategies to liberate agricultural lands, we are reluctant to place too much emphasis on potential for large-scale reforestation. We therefore show two scopes of potential carbon sequestration gains from reestablishment of natural vegetation on liberated land in our Breakthrough Technologies scenario, which are shown as annual emissions offsets over a 40-year period.

Table 32-1 | Summary of the GlobAgri-WRR 2050 baseline projection and three combined scenarios (continued)

MENU ITEM	2050 BASELINE	COORDINATED EFFORT	HIGHLY AMBITIOUS	BREAKTHROUGH TECHNOLOGIES	COMMENT
Conserve and restore peatlands	Annual peatland emissions stay constant at 1.1 Gt CO_2e between 2010 and 2050	50% reduction in annual peatland emissions	75% reduction in annual peatland emissions	Same as Highly Ambitious	Although politically challenging, high levels of peatland restoration are probably an economically rational mitigation option. Technical potential suggests the possibility of increased hectares in the Highly Ambitious scenario, but some drained peatlands are in such intensive agricultural use or disrupted by changes in water flows that restoration of these peatlands is unfeasible.
Course 4. Increase fish supply					
Improve wild fisheries management	10% decline in wild fish catch between 2010 and 2050	Wild fish catch stabilized at 2010 level by 2050	Same as Coordinated Effort	Same as Coordinated Effort	Strategies to curb overfishing are well documented, and literature suggests that optimal fisheries management could even lead to increases in annual wild fish catch above 2010 levels, but overfishing remains near historical highs. Coordinated effort would be necessary just to maintain 2010 catch levels, and since optimal management in all major fishing countries seems overly optimistic, we decline to include scenarios of increases.
Improve productivity and environmental performance of aquaculture	10% increase in aquaculture production efficiencies between 2010 and 2050 across the board	50% of extensive pond production switches to semi-intensive production, and 50% of semi-intensive switches to intensive	Same as Coordinated Effort, plus 20% increase in aquaculture production efficiencies between 2010 and 2050 across the board	Same as Highly Ambitious	Shifts to more intensive production are technically possible although costs and feasibility will vary by location. Aquaculture is a young industry and additional efficiency gains (relative to terrestrial animals) seem possible.

Table 32-1 | Summary of the GlobAgri-WRR 2050 baseline projection and three combined scenarios (continued)

MENU ITEM	2050 BASELINE	COORDINATED EFFORT	HIGHLY AMBITIOUS	BREAKTHROUGH TECHNOLOGIES	COMMENT
Course 5. Reduce GHG emissions from agricultural production					
Reduce enteric fermentation through new technologies	Enteric methane emissions of 3.4 Gt CO_2e in 2050 (51% above 2010 level)	30% emissions reduction from half of dairy cows, and one-quarter of beef cattle—leading to a 9% reduction in methane emissions from ruminants (38% growth above 2010 level)	30% emissions reduction from all dairy cows, half of beef cattle, and one-sixth of sheep—leading to an 18% methane emissions reduction from ruminants (24% growth above 2010 level)	30% methane emissions reduction from all ruminants, including those permanently grazed (6% growth above 2010 level)	Recent progress in feed additives suggests the potential for 30% reductions but only in cattle that can be easily fed additives daily, and possibly, many times. However, the technical potential exists to extend to all cattle through daily feeding. No credible science, however, suggests higher potential with additives free of other major environmental or health limitations.
Reduce emissions through improved manure management	Manure management emissions of 770 Mt CO_2e in 2050 (31% above 2010 level)	40% reduction of methane emissions from wet manure (14% growth above 2010 level)	80% reduction of methane emissions from wet manure plus 20% reduction of all other manure management emissions (17% reduction below 2010 level)	Same as Highly Ambitious	Digesters can greatly reduce emissions from wet manure compared to baseline if carefully implemented, and solid separation can probably reduce nitrous oxide emissions generally, although efforts must reach vast numbers of farms. Although other technologies may emerge, they are too speculative to include here.
Reduce emissions from manure left on pasture	Emissions from manure left on pasture of 653 Mt CO_2e in 2050 (46% above 2010 level)	Same as baseline	20% reduction of nitrogen left on pastures for nonarid systems (31% growth above 2010 level)	40% reduction of nitrogen left on pastures for nonarid systems (15% growth above 2010 level)	Most promising technologies involve nitrification inhibitors either spread on intensively grazed farms or consumed by animals. Because the technology is not so advanced, we include them only in the two more aggressive scenarios yet at modest levels of progress.
Reduce emissions from fertilizers by increasing nitrogen use efficiency	Nitrogen use efficiency grows from 46% in 2010 to 48% in 2050	57% nitrogen use efficiency due to a range of management measures	61% nitrogen use efficiency due to a range of management measures	67% nitrogen use efficiency due to a range of management measures plus new technologies	Coordinated Effort assumes better general management while Highly Ambitious and Breakthrough Technologies assume different levels of progress on changing nitrogen compounds (including inhibitors), and possibly in crop breeding to enhance efficiency.

Table 32-1 | Summary of the GlobAgri-WRR 2050 baseline projection and three combined scenarios (continued)

MENU ITEM	2050 BASELINE	COORDINATED EFFORT	HIGHLY AMBITIOUS	BREAKTHROUGH TECHNOLOGIES	COMMENT
Adopt emissions-reducing rice management and breeds	Rice methane of 1.3 Gt CO_2e in 2050 (13% above 2010 level)	10% reduction in rice methane (17% below 2010 level) thanks to new water management practices and new rice breeds	Same as Coordinated Effort	Same as Highly Ambitious, plus 20% faster rate of rice yield gain (31% reduction of rice methane below 2010 level)	Alternate wetting and drying (AWD) and straw management are proven technologies but require major efforts for implementation, probably including improvements in many irrigation systems. Science shows some rice varieties have lower methane emissions and new breeds have potentially lower emissions. High crop yields in some locations also suggest potential for higher yields if full breeding potential is utilized.
Increase agricultural energy efficiency and shift to non-fossil energy sources	25% decrease in energy emissions per unit of agricultural output between 2010 and 2050	Same as baseline	50% decrease in energy emissions per unit of agricultural output between 2010 and 2050	75% decrease in energy emissions per unit of agricultural output between 2010 and 2050	Because baseline incorporates increases in energy efficiency, we consider that it already requires coordinated effort. Highly Ambitious effort could further reduce emissions through incorporation of renewable energy. The Breakthrough Technologies scenario requires new technologies for nitrogen synthesis in fertilizer manufacturing.
Focus on realistic options to sequester carbon in agricultural soils	Soil carbon gains sufficient to assure no net loss of soil carbon globally and contribute to yield gains	Same as baseline	Same as baseline	Same as baseline	The most promising opportunity for soil carbon gains are those that would result from increased productivity, and thus are already built into our baseline and Course 2. Because of the scientific uncertainty, we do not rely on additional soil carbon gains for offsetting ongoing agricultural production emissions.

CHAPTER 33

A TALE OF THREE GAPS, REVISITED

In this chapter, we quantify the contribution of each of the combined scenarios to reducing the food gap, the land gap, and the GHG mitigation gap.

Table 32-1 summarizes the components of each combined scenario. The "waterfall charts" in this chapter show the role played by the various menu items (and courses) in each combined scenario. Because the quantitative effects of menu items to some extent depend on or affect others, simply adding the effects of each individual menu item would not correctly calculate the effect of any combination of menu items. We therefore employ a form of mathematical averaging to estimate the distinct role of each item in a combined menu.[3]

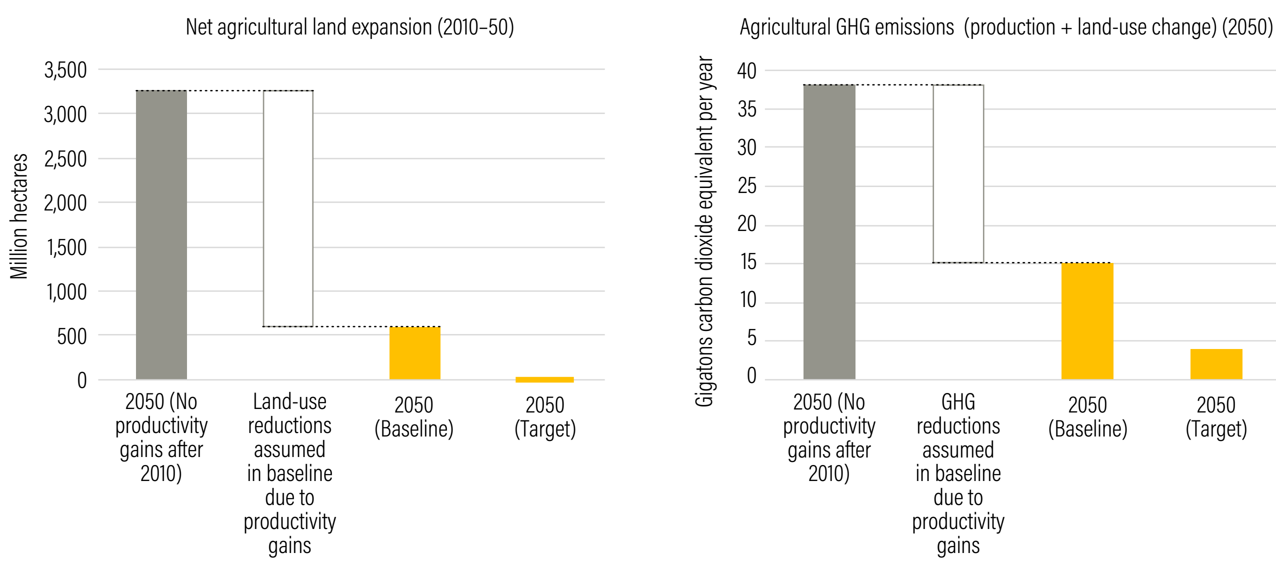
As discussed in Chapter 2, we define the food gap as the entire gap between crop calories produced in 2010 and those required to feed everyone in 2050 under the baseline scenario. This definition of the gap allows us to focus on demand-side measures that can reduce the size of the gap and thereby assist in closing the land and GHG mitigation gaps. Narrowing the food gap also provides greater assurance that the world will produce enough food to feed everyone nutritiously and at a price they can afford.

In the case of land use and GHG mitigation, the gaps represent the difference between our expected area of agricultural land and level of agriculture-related emissions in 2050 under a "business-as-usual" scenario (our 2050 baseline) and the targets for a sustainable food future; that is, net zero agricultural land expansion and agricultural emissions at or below 4 gigatons carbon dioxide equivalent (Gt CO_2e) per year. See Chapter 2 in "Scope of the Challenge and Menu of Possible Solutions" for a full explanation of the food, land, and GHG mitigation gaps.

Understanding Our Baseline Scenario

It is important to repeat that our business-as-usual baseline scenario already assumes significant progress in agricultural productivity, based on projections by the Food and Agriculture Organization of the United Nations (FAO) and our own effort to project gains in livestock and pasture productivity. Agricultural productivity gains built in to the 2050 baseline close more than 80 percent of the land gap and roughly two-thirds of the GHG mitigation gap that would occur if no productivity gains occurred after 2010 (Figure 33-1). All the combined scenarios therefore focus on *additional* productivity gains beyond our baseline, as well as other menu items that reduce demand for agricultural products or that further reduce GHG emissions.

Figure 33-1 | Improvements in crop and livestock productivity already built in to the 2050 baseline close most of the land and GHG mitigation gaps that would otherwise exist without any productivity gains after 2010



Source: GlobAgri-WRR model.

Table 33-1 summarizes the results of the three combined scenarios in terms of their contribution to closing the food, land, and GHG mitigation gaps and their effects on absolute changes in agricultural land area and GHG emissions by 2050. For reference, the table also summarizes the results of our baseline scenario (business-as-usual with built-in productivity gains) and the "no productivity gains after 2010" scenario, in which we assume no change in crop yields or pasture and livestock productivity beyond 2010 levels.

A caveat on the contribution of individual menu items

Within the combined scenarios, the contribution to closing gaps made by individual menu items does not illustrate the potential gains *relative to effort* (e.g., cost of menu item implementation) because the size of the contribution of each menu item inherently reflects the scale at which that menu item is defined. For example, we define our menu item "reduce food loss and waste" as a single global-scale percentage reduction in all sources of loss or waste of all plant- and animal-based foods. That definition results in enormous land savings globally but requires changes by millions of farms, food processors, and retailers, as well as by billions of consumers all over the world. The contribution would appear much smaller if we had instead defined 100 or 1,000 separate menu items for reducing food loss and waste differentiated by region, food type, and stage in the food supply chain. Such an analysis was not possible due to lack of reliable information about potential reductions at these more granular scales.

By contrast, our menu item "achieve replacement-level fertility rates" is defined at the regional level. We focus on the benefit of reducing fertility rates in sub-Saharan Africa alone, since all other regions are projected to have fertility rates at or below replacement level by 2050. The population of sub-Saharan Africa will account for less than one-quarter of the world's projected 2050 population, but we present

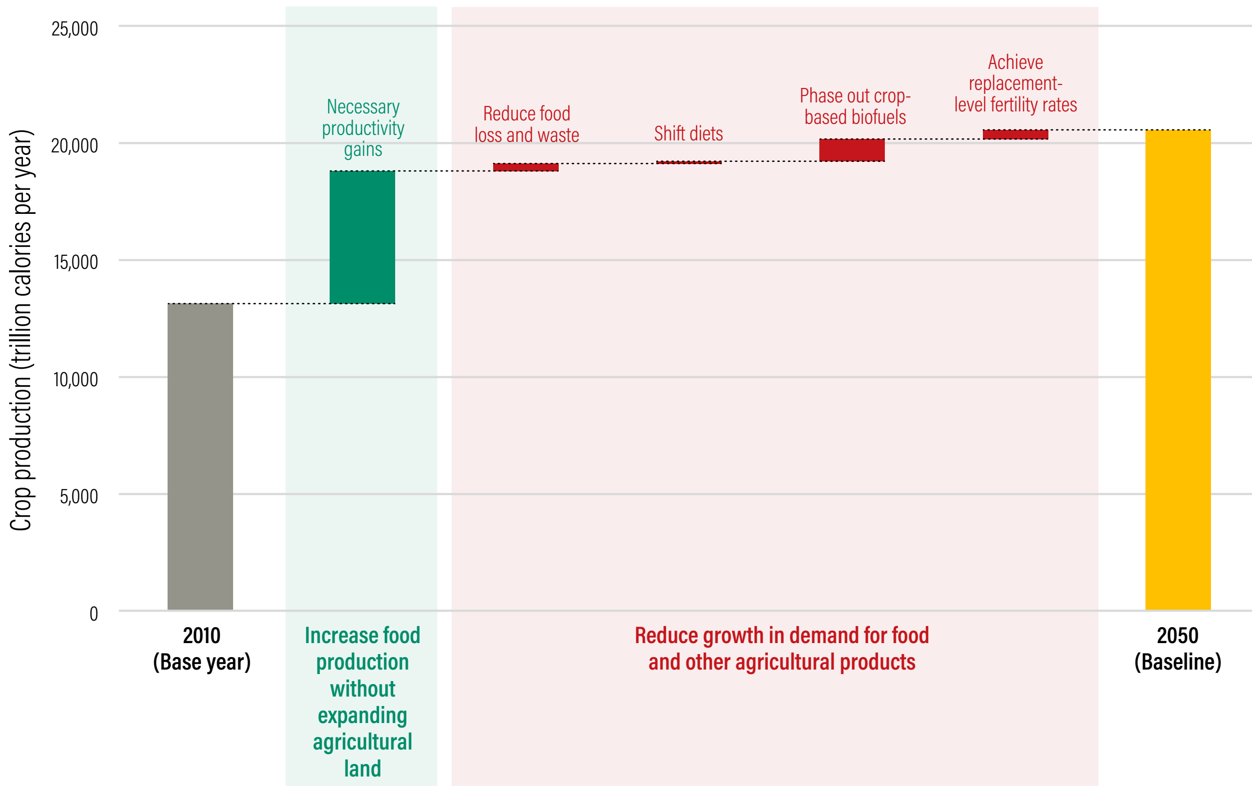
Table 33-1 | Global effects of combined 2050 scenarios on the three gaps

SCENARIO	FOOD GAP, 2010–50 (%)	CHANGE IN AGRICULTURAL AREA, 2010–50 (MHA)			ANNUAL GHG EMISSIONS, 2050 (GT CO_2E)				GHG MITIGATION GAP (GT CO_2E)
		Pasture-land	Cropland	Total	Agricultural production	Land-use change[a]	Peatlands	Total	
No productivity gains after 2010	62	2,199	1,066	3,265	11.3	25.8	1.1	38.2	34.2
2050 Baseline	**56**	**401**	**192**	**593**	**9.0**	**4.9**	**1.1**	**15.1**	**11.1**
Coordinated Effort	43	128	4	132	7.4	1.1	0.6	9.1	5.1
Highly Ambitious	35	-390	-180	-570	5.5	0.0[b]	0.3	5.8	1.8
Breakthrough Technologies	29	-446	-355	-801	4.4	0.0[b]	0.3	4.6	0.6

Notes: Numbers may not sum correctly due to rounding.
a. Does not include peatland emissions.
b. Under the Highly Ambitious and Breakthrough Technologies combined scenarios, total agricultural area declines between 2010 and 2050. In order to keep estimates of associated emissions reductions conservative, here we do not credit any negative land-use change emissions as offsets against agricultural production emissions. We discuss the need to reforest "liberated" agricultural lands to offset agricultural production emissions in Chapter 20.

Source: GlobAgri-WRR model.

Figure 33-2a | The combined scenarios reduce the size of the food gap by reducing growth in demand (Coordinated Effort scenario)



Note: Includes all crops intended for direct human consumption, animal feed, industrial uses, seeds, and biofuels.
Source: GlobAgri-WRR model.

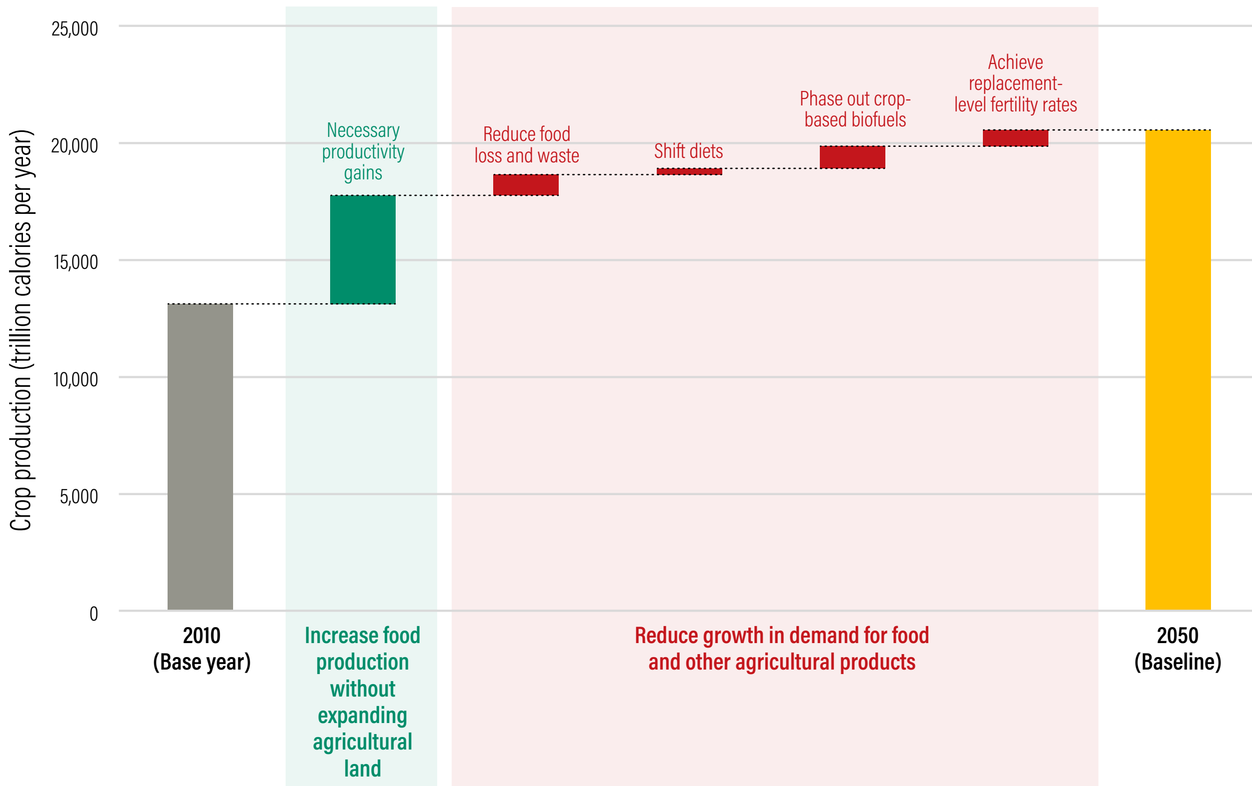
in these tables the contribution of changes in sub-Saharan Africa's fertility rates to reducing the three gaps at the global level. The effects therefore appear comparatively small. Similarly, improvements in aquaculture appear to make modest contributions to closing the global gaps, but this is because farmed fish are likely to occupy "only" 40 million hectares (Mha) of ponds and make up roughly 1 percent of all calories consumed in 2050. Because we do not believe that sufficient reliable information exists to make quantitative economic estimates of future menu item costs, there is no obvious data-backed way to evaluate savings relative to scope of effort.

Effects of the Combined Scenarios on the Food Gap

All of our three combined scenarios make a meaningful contribution to closing the food gap because each one has significant effects on demand for agricultural products (Figures 33-2a–c).

The demand-side menu items reduce the challenge of producing more food (as measured by crop calories) from the 56 percent increase needed between 2010 and 2050 in our baseline scenario to increases of 43 percent, 35 percent, and 29 percent,

Figure 33-2b | The combined scenarios reduce the size of the food gap by reducing growth in demand (Highly Ambitious scenario)



Note: Includes all crops intended for direct human consumption, animal feed, industrial uses, seeds, and biofuels.
Source: GlobAgri-WRR model.

respectively. Viewed another way, the Breakthrough Technologies scenario reduces the size of the food gap by nearly half.

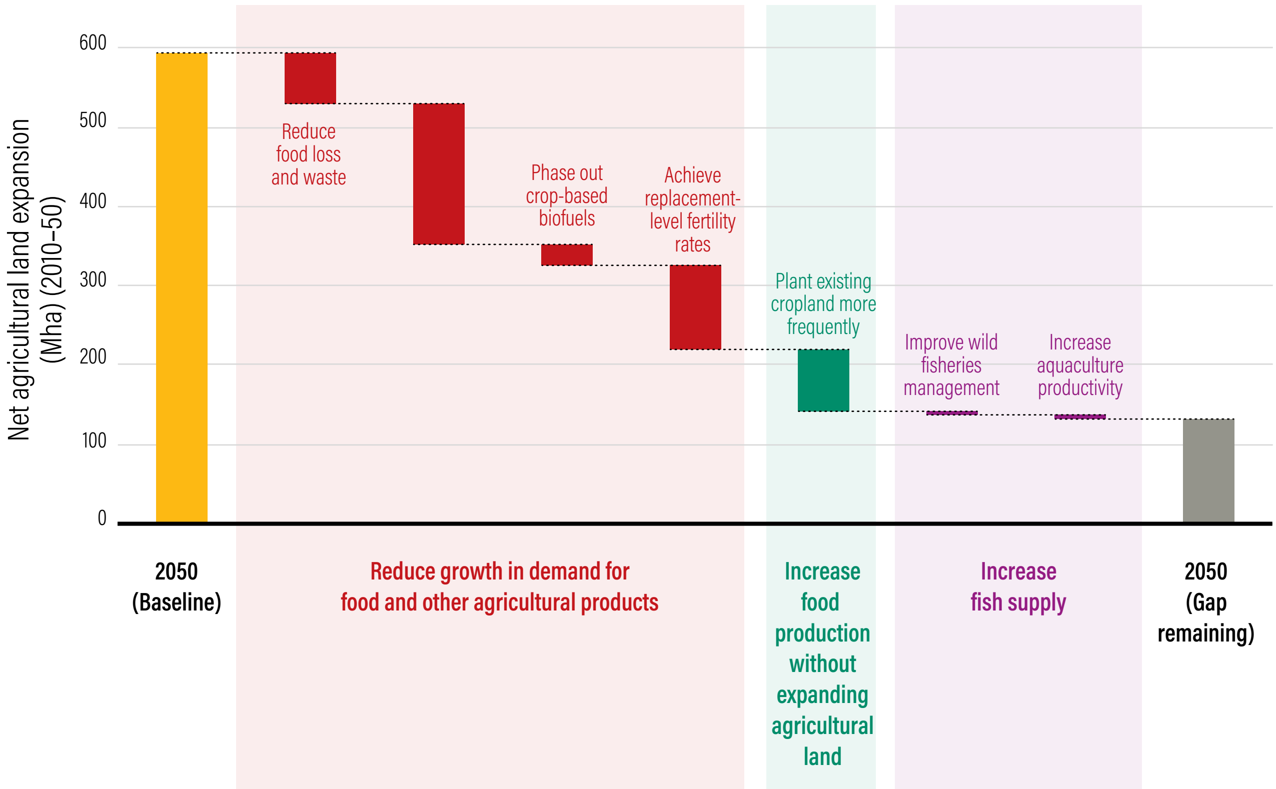
The biggest potential reductions in the food gap result from reductions in food loss and waste. Reductions in ruminant meat consumption do not significantly reduce the food gap (technically, a crop calorie gap) in this analysis because ruminants consume relatively few crops; however, this menu item is of far greater importance in closing the land and GHG mitigation gaps.

In the Coordinated Effort scenario, the phasing out of crop-based biofuels makes a significant contribution to closing the food gap. However, this estimate is contingent on the assumption in our baseline scenario that there will be no further growth in the share of crop-based biofuels in the transportation fuel mix, despite current public policy goals that seek to greatly expand this share. The assumption is likely optimistic. Changing public policies to phase out crop-based bioenergy production and avoid future expansion of land-based bioenergy production should be recognized as critical to closing the food gap.

Figure 33-2c | The combined scenarios reduce the size of the food gap by reducing growth in demand (Breakthrough Technologies scenario)

Note: Includes all crops intended for direct human consumption, animal feed, industrial uses, seeds, and biofuels.
Source: GlobAgri-WRR model.

Figure 33-3a | Two of the three combined scenarios could more than close the land gap and liberate land for reforestation (Coordinated Effort scenario)



Source: GlobAgri-WRR model.

Effects of the Combined Scenarios on the Land Gap

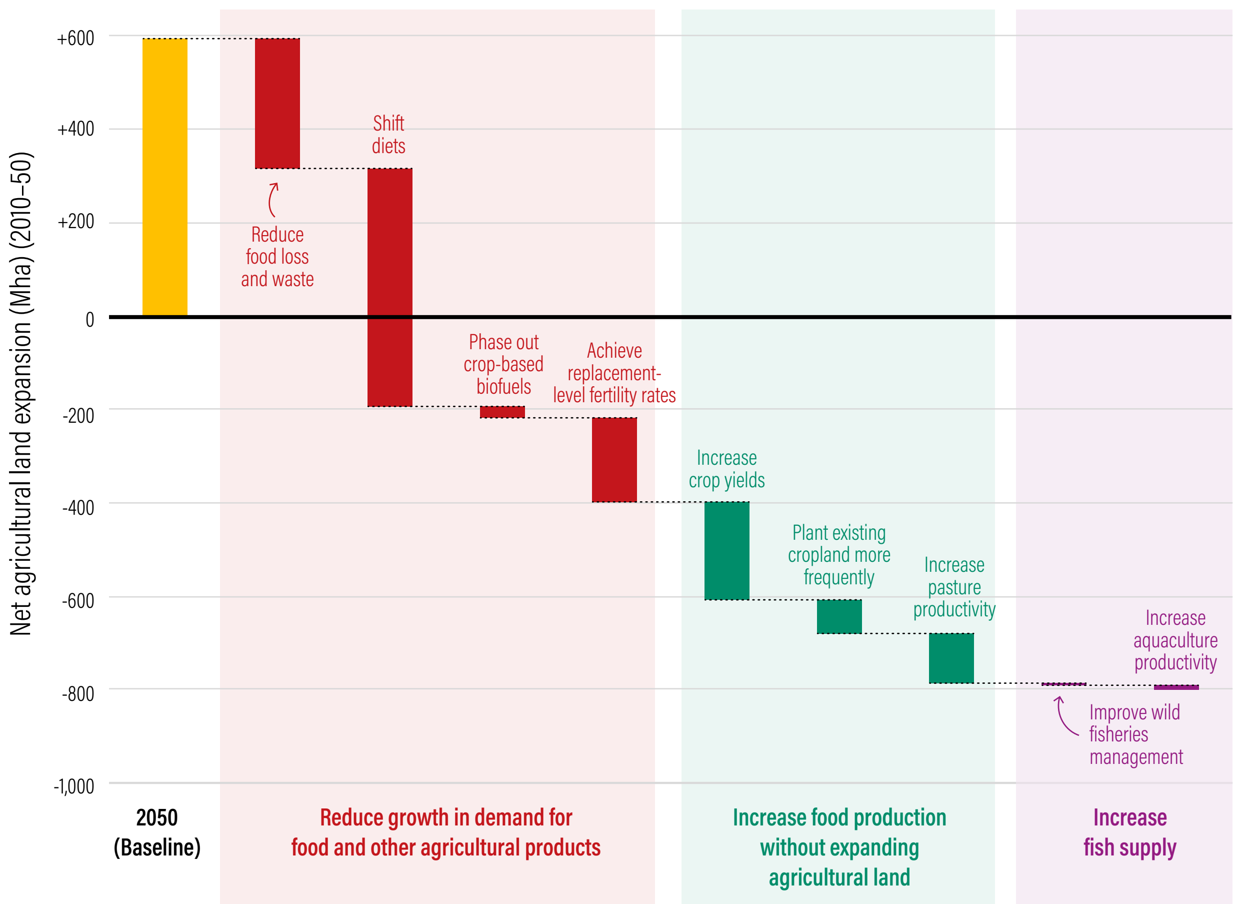
All three scenarios have large consequences for closing the land gap (Figures 33-3a–c). In the Coordinated Effort scenario, cropland area remains relatively constant between 2010 and 2050, but pasture area still expands by 128 Mha. The Highly Ambitious and Breakthrough Technologies scenarios completely close the 593 Mha land gap and potentially make hundreds of millions of hectares available for other uses or for reforestation, which we discuss further below.

As discussed in Course 3 (Protect and Restore Natural Ecosystems and Limit Agricultural Land-Shifting), slower demand growth and increased productivity do not guarantee the full potential benefits of avoided agricultural land expansion for protecting biodiversity and storing carbon. These changes, by themselves, do not prevent shifts in locations of agricultural land between and within regions and countries. Yield growth can even trigger further agricultural land expansion as farming becomes more profitable in some regions. To achieve reductions in agricultural land area and the associated environmental benefits, additional policies are necessary to reduce shifts in locations of agricultural land, avoid conversion of the most valuable and carbon-rich lands, and actively restore lands that will be abandoned as a result of some inevitable shifts in location of agriculture.

Figure 33-3b | Two of the three combined scenarios could more than close the land gap and liberate land for reforestation (Highly Ambitious scenario)

Source: GlobAgri-WRR model.

Figure 33-3c | Two of the three combined scenarios could more than close the land gap and liberate land for reforestation (Breakthrough Technologies scenario)



Source: GlobAgri-WRR model.

Effects of the Combined Scenarios on the Greenhouse Gas Mitigation Gap

Under all three combined scenarios, the most difficult gap to close completely is the gap in GHG mitigation (Figures 33-4a–c), because it is difficult to reduce annual agricultural production emissions to the 4 Gt CO_2e target while providing enough food for everyone in 2050. Measures taken in the Coordinated Effort scenario would still leave total emissions from agriculture and land-use change at 9.1 Gt of CO_2e per year by 2050, more than 5 Gt above our 4 Gt target. The Highly Ambitious scenario reduces emissions to 5.8 Gt per year. Only the Breakthrough Technologies scenario, resulting in annual emissions of 4.6 Gt, gets close to the target. The implication is that it is easier to hypothesize scenarios that eliminate net land-use change than scenarios that eliminate production emissions. Reaching the 4 Gt goal would require major technological advances as well as full reforestation on at least 80 Mha of liberated agricultural land.

The Potential of Reforestation and Savanna Restoration to Further Reduce Greenhouse Gas Emissions

Two of our three combined scenarios result in a net reduction in agricultural land area between 2010 and 2050—a total of 570 Mha in the Highly Ambitious scenario and roughly 800 Mha in the Breakthrough Technologies scenario. These reductions could be used to sequester carbon by reforesting land and restoring savannas by midcentury. The resulting carbon sequestration could count as negative emissions.

Although GlobAgri-WRR can estimate the potential GHG emissions reductions from reforestation and savanna restoration, we are concerned about fully crediting these potential gains for two reasons. First, we believe that some shifting in the location of agricultural land (between and within regions and countries) is inevitable, and that such shifts will result in net positive amounts of GHG emissions, so some active reforestation of net abandoned land will be necessary just to offset the emissions from this agricultural land-shifting. Second, some amount of the "liberated" agricultural land under these three scenarios will likely be needed to accommodate projected expansion of urban areas and forest plantations.

Because of these caveats, in Figure 33-4c (Breakthrough Technologies scenario), we show first the potential for ecosystem restoration to achieve our 4 Gt CO_2e target, which would require restoring at least 80 Mha to natural vegetation and would generate an annual average of 0.6 Gt of negative emissions for 40 years.[4]

A variety of analyses have also suggested that to meet the more ambitious 1.5 degree warming target enshrined in the Paris Agreement, the world will need to use the land sector to achieve negative emissions.[5] Typically, these scenarios do not require the elimination of nitrous oxide and methane emissions from agriculture, but they do require uses of land either for reforestation or some other mechanism for negative emissions—either to offset remaining emissions from other sectors (e.g., energy) or to reduce carbon dioxide levels after "overshooting" temperature targets. To reach a target of net-zero emissions in the land sector, restoration of natural vegetation on at least 585 Mha would be necessary, which would be 73 percent of the 801 Mha potentially liberated by our Breakthrough Technologies scenario.[6] Thus we also show the potential to achieve net-zero emissions in Figure 33-4c (Breakthrough Technologies scenario) through restoring at least 585 Mha.

Figure 33-4a | Only the Breakthrough Technologies scenario comes close to closing the greenhouse gas mitigation gap; reforestation and peatland restoration would be necessary to meet the target of 4 gigatons per year (Coordinated Effort scenario)

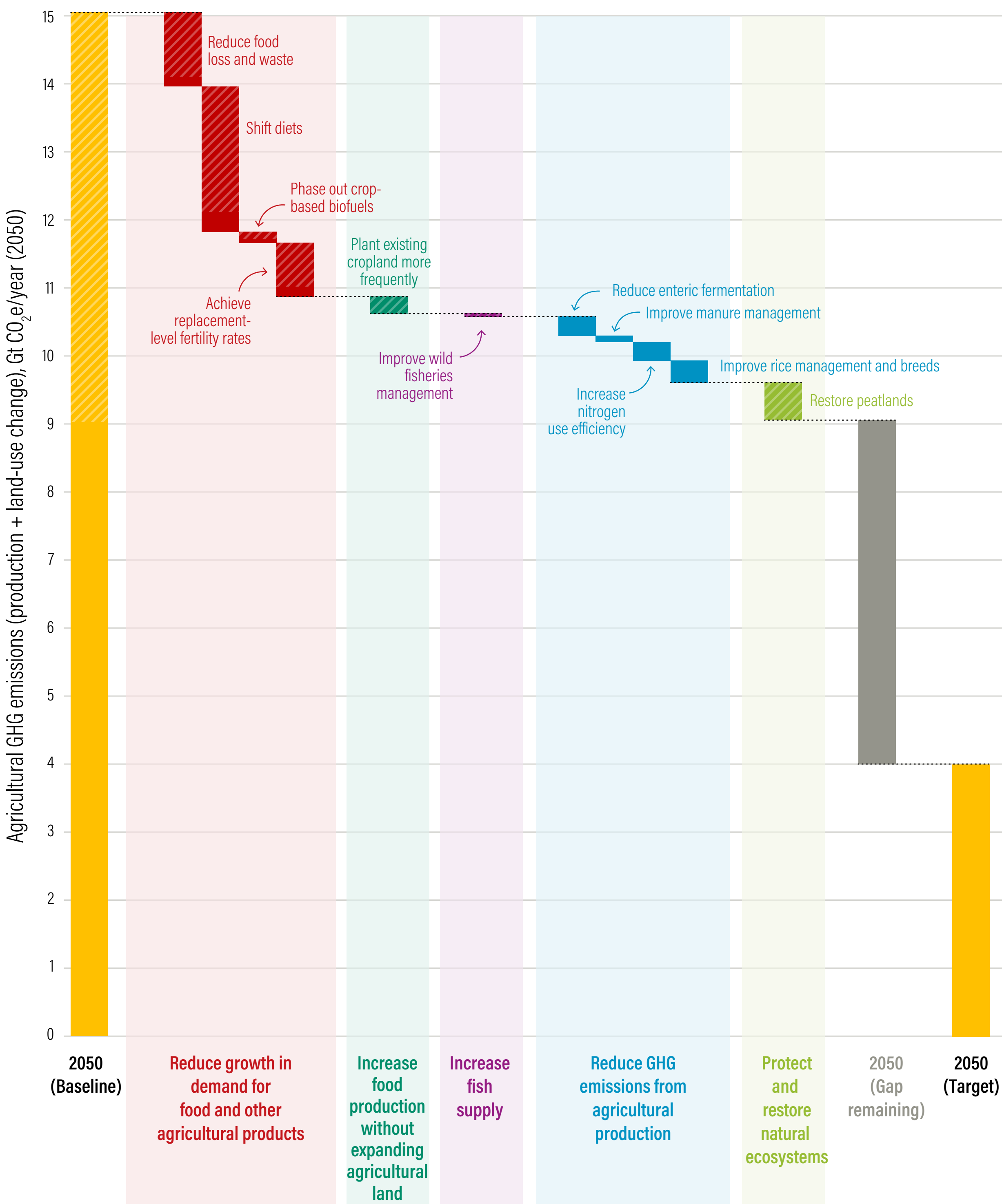


Figure 33-4b | Only the Breakthrough Technologies scenario comes close to closing the greenhouse gas mitigation gap; reforestation and peatland restoration would be necessary to meet the target of 4 gigatons per year (Highly Ambitious scenario)

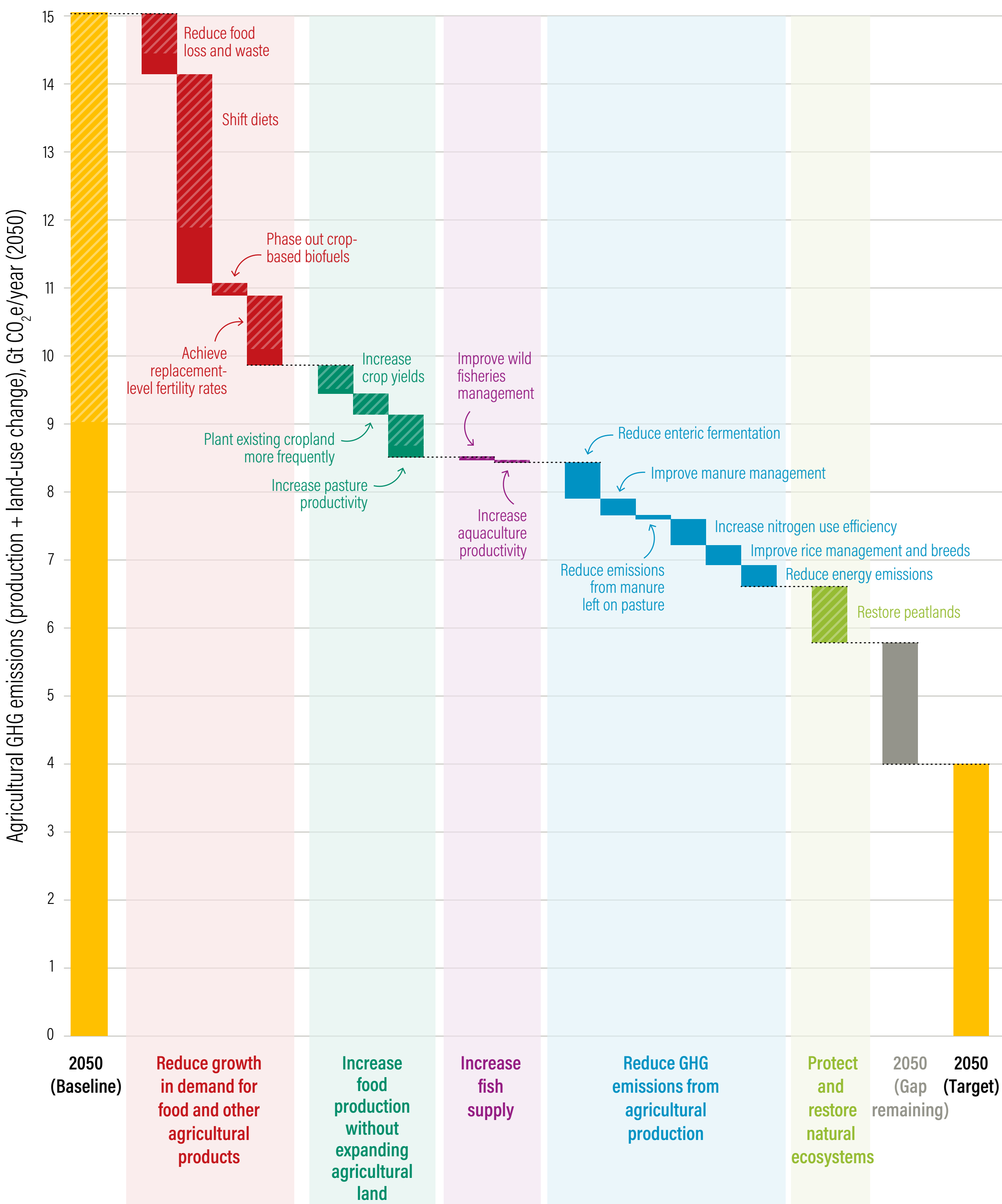
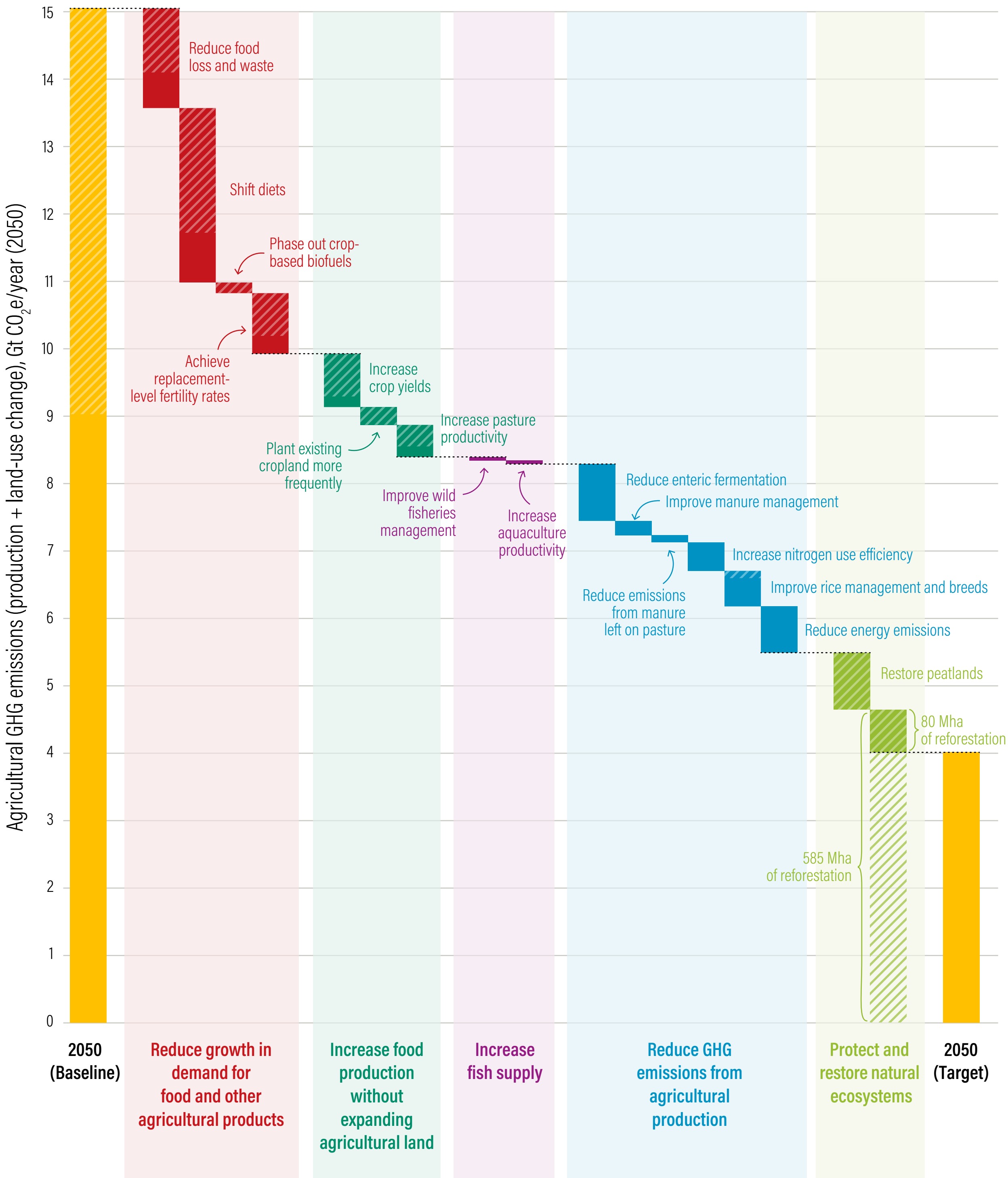


Figure 33-4c | Only the Breakthrough Technologies scenario comes close to closing the greenhouse gas mitigation gap; reforestation and peatland restoration would be necessary to meet the target of 4 gigatons per year (Breakthrough Technologies scenario)



Note: Solid areas represent agricultural production emissions. Hatched areas represent emissions from land-use change.
Source: GlobAgri-WRR model.


TRADING

CHAPTER 34

INSIGHTS FROM THE MENU COMBINATIONS

We believe that plausible paths exist toward closing the food, land, and GHG mitigation gaps and reaching our targets for world food production, agricultural land use, and emissions. This chapter presents several insights that flow from our analysis of the three scenarios. Realizing the potential of these scenarios will require strong political and social commitments.

Truly closing the GHG mitigation and land gaps would require taking all reasonable actions globally that we know of today, which will entail changes on billions of hectares of land, implemented by tens of millions of farmers. Fortunately, even though we do not know enough to generate true economic estimates, all of the actions contemplated can plausibly be expected to impose only modest costs or even lead to economic benefits, as discussed throughout Courses 1–5.

Achieving Even Our Coordinated Effort Scenario Requires Reversing a Wide Range of Current Trends

On the demand side, we rely on large reductions in ruminant meat consumption, relative to the 2050 baseline. However, as discussed in Chapter 6, many modelers project even larger global increases in consumption of animal-based foods than we do in our baseline. To take another example, our 2050 baseline assumes no increase in the share of biofuels in transportation—even though global policy is encouraging a fourfold increase. Current bioenergy strategies, if fully realized, could require harvesting levels of biomass equal to all the world's presently harvested crops, crop residues, wood, and forages consumed by livestock. And although we rely on large reductions in food loss and waste to close the three gaps, most food loss and waste reduction efforts are still in their infancy.

On the production side, the Coordinated Effort scenario requires faster rates of crop yield growth than historical rates (going back to the 1960s), but we have shown that recent yield trend lines (starting from the 1980s) are slower than those in our baseline, and far from the additional yield gains required. Ruminant meat and milk yield gains for the Coordinated Effort scenario require massive increases in output per hectare of grazing land—far greater than the output gains projected by extending a linear trend line from the 1960s.

Four Categories of Menu Items Are Particularly Important at the Global Level

All menu items are needed to have any hope of achieving the 4 Gt per year emissions target. In focusing on the relative role of different actions, however, we emphasize four particularly important types of menu items:

- **Boost agricultural productivity.** Without the productivity gains already built into our baseline, agricultural land would expand by more than 3 billion hectares and emissions would rise to 38 Gt CO_2e/year, including emissions from land-use change. Productivity gains already in our baseline are responsible for closing two-thirds of the GHG mitigation gap and more than 80 percent of the land gap that would exist if there were no productivity gains at all between 2010 and 2050. Additional productivity gains play a relatively smaller role than built-in productivity gains in reducing the gaps defined by our baseline. But, when we add in the additional productivity gains required to meet our 4 Gt target, the role of productivity gains grows to 72 percent.[7]

- **Shift diets away from ruminant meat.** Reducing ruminant meat consumption by 30 percent globally, relative to the 2050 baseline, reduces emissions by more than 5 Gt and reduces agricultural land demand by more than 500 Mha. Assuming the yield gains in our baseline, this change alone nearly eliminates net land-use change on a global basis. We believe this menu item is particularly promising because relatively few people eat large quantities of ruminant meat, there are highly attractive alternatives to ruminant meat, and people in the United States and Europe have already reduced per capita beef consumption by one-third from peak levels in the 1970s.

- **Reduce food loss and waste.** Globally reducing the rate of food loss and waste by 10, 25, or 50 percent would contribute significantly to closing all three gaps. However, we caution that while there are abundant options, there is little precedent for achieving such large-scale reductions. In particular, as countries' economies develop, waste near the consumption side of the food supply chain tends to grow even as food loss near the production side decreases. The overall share of food produced that is lost or wasted tends to stay at similar levels although the sources of the loss and waste shift downstream.

- **Restore peatlands and reforest liberated agricultural lands.** These menu items are essential to reach GHG mitigation targets. Because peatland emissions of more than 1 Gt CO_2e per year result from only 26 Mha, half of which has limited agricultural use, peatland restoration provides a highly promising mitigation opportunity. In addition, to achieve the 4 Gt target for 40 years, reforestation of at least 80 Mha of liberated agricultural land will be necessary, and additional reforestation will likely be necessary to compensate for emissions that result from shifting of locations of agricultural land between and within regions and countries.

Achieving Technological Innovations

Even our Coordinated Effort scenario requires measures such as further refinement of additives to reduce enteric methane emissions from livestock, new forms of manure management, and accelerated energy conservation steps. However, none of our scenarios require innovations for which scientists have not already shown a promising path.

Agricultural production emissions are the hardest to reduce, but technological innovations could make significant reductions possible. One reason why production emissions may appear harder to reduce than emissions from land-use change is that there is less of a track record of production emissions reductions. The measures in our more ambitious scenarios can actually reduce agricultural land area, and we have some confidence in these results because the world has a long track record of increasing crop and pasture yields. Past yield gains reflect vast and expensive commitments by farmers, governments, and agriculture-related industries. By contrast, conscious efforts to reduce production emissions—except as a by-product of yield gains—have been miniscule. There is no track record of mitigation of production emissions that we can build into our baseline or our mitigation scenarios. Yet the reality is that we do not know what the world could achieve. For example, even in our Breakthrough Techologies scenario, we assume no more than a 30 percent reduction in enteric methane emissions through use of feed additives, and only a 10 percent reduction in methane emissions achieved by new rice varieties. With strong research efforts, larger reductions might become possible.

ENDNOTES

1. Some analyses regarding agriculture, land use, and climate change attempt to rank greenhouse gas mitigation potential into categories of low, medium, and high based on US$ per ton of emissions reduction and then develop combined scenarios based on cost. Economic estimates of agricultural mitigation potential tend to be low, in part because they focus on a small set of mitigation targets and in part because the ability to provide cost estimates for mitigation is highly limited. The data on costs of agricultural production today are rough, the distribution of these costs across different farms in different regions is even rougher, the knowledge of mitigation costs is limited, and for most practices that are not common today or that depend on new technology, quantitative cost estimates can become quite speculative. Therefore, we do not use cost to distinguish our low, medium, and high scenarios.

2. In 2050, we estimate that 77 percent of beef cattle (including buffalo) will be raised in mixed or urban production systems. Unlike dairy cow herds, which require milking every day, many farm animals in mixed systems lack direct human management every day. We estimate that roughly one-third of these bovines will have daily human feeding and could therefore be given a daily feed supplement. For milk production, we estimate that 86 percent of production will be in mixed or urban systems, and we perhaps conservatively estimate that 50 percent of all dairy cattle will be fed such an additive.

3. Simply summing each individual menu item in combined scenarios does not correctly estimate the effect of implementing all menu items together because the interactions among menu items reduce the effect of each menu item modeled separately. To scale the effect of each menu item, we used the following four-step process: (1) add up individual menu items' contributions as analyzed in Courses 1–5 to generate a "sum of the individual modeled results"; (2) use GlobAgri-WRR to estimate the reductions for each scenario; (3) estimate a ratio by dividing the result in step 2 by the result in step 3, which always produces a fraction less than 1; and (4) multiply the result in step 1 by the ratio in step 3. In effect, we downscale each individual menu item so that the sum of menu items equals the combined effect of implementing multiple menu items at the same time.

   Because the GlobAgri-WRR model does not model emissions from existing peatland loss, we treated peatland emissions separately. GlobAgri-WRR, however, does account for new peatland conversions, so the effect of menu items in reducing new peatland conversions is counted as the effect of those menu items. For example, if reductions in waste lead to less growth in palm oil production, GlobAgri-WRR will project fewer emissions from additional peatland conversions to produce palm oil.

4. The GlobAgri-WRR model estimates that fully restoring 801 Mha would sequester 6.3 Gt CO_2e per year over 40 years. Therefore, to offset at least 0.6 Gt CO_2e per year and achieve the 4 Gt target would require restoring at least roughly 10 percent of that land, or 80 Mha. This calculation assumes that these carbon levels (approximating that of natural vegetation) could be achieved in 40 years. Many forests will continue growing and sequestering carbon over 40 years, but our estimates of carbon stocks for areas in natural vegetation do not assume restoration to pristine carbon stocks. Instead they are based on estimates of natural vegetation in turn based on measured carbon stocks of types of vegetation for these types and locations of ecosystems, and the great majority of the world's forests are already highly disturbed (Erb et al. 2017).

5. Rogelj et al. (2018), 60, Figure 2.26.

6. The GlobAgri-WRR model estimates that fully restoring 801 Mha would sequester 6.3 Gt CO_2e per year over 40 years. Therefore, to offset at least 4.6 Gt CO_2e per year and achieve a target of 0 Gt would require restoring at least roughly 73 percent of that land, or 585 Mha. See note 4 above for additional details on assumptions of carbon stocks in natural vegetation.

7. GlobAgri-WRR model.

REFERENCES

To find the References list, see page 500, or download here: www.SustainableFoodFuture.org.

PHOTO CREDITS

Pg. 402 Anguskirk, pg. 404 shankar s./Flickr, pg. 414 Elina Sazonova/Pexels, pg. 428 istockphoto.