WORLD RESOURCES INSTITUTE

Working Paper

Installment 1 of "Creating a Sustainable Food Future"

THE GREAT BALANCING ACT

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THREE NEEDS

How can the world adequately feed more than 9 billion people by 2050 in a manner that advances economic development and reduces pressure on the environment? This is one of the paramount questions the world faces over the next four decades.

Answering it requires a "great balancing act" of three needs—each of which must be simultaneously met.

First, the world needs to close the gap between the food available today and that needed by 2050. This gap is in part a function of increasing population and wealth. The United Nations Population Division (UNPD) projects that global population will most likely grow from 7 billion in 2012 to 9.3 billion by 2050.[1] At least 3 billion more people are likely to enter the global middle class by 2030,[2] and they will almost certainly demand more resource-intensive foods such as meats and vegetable oils.[3] At the same time, approximately 870 million of the world's poorest people remain undernourished even today.[4] When production falls short of people's needs, the world's rich can outcompete the poor and hunger increases.[5] Without successful measures to restrain food demand growth by the world's more affluent, available worldwide food calories[6] will need to increase by about 60 percent from 2006 levels if everyone is to be sufficiently fed.[7]

CONTENTS

Disclaimer: *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. Most working papers are eventually published in another form and their content may be revised.*

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Box 1 | **The World Resources Report**

The World Resources Report (WRR) provides decisionmakers from government, business, and civil society around the world with analysis and insight on major issues at the nexus of development and the environment. Spearheaded by the World Resources Institute, the WRR has been the product of a unique long-term partnership with the United Nations Development Programme (UNDP), the United Nations Environment Programme (UNEP), and The World Bank. This year, L'Institut National de la Recherche Agronomique (INRA) and Le Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD), two major agricultural research institutions in France, have joined as analytical collaborators. For more information about the WRR or to access previous editions, visit www.worldresourcesreport.org.

Second, the world needs agriculture to contribute to inclusive economic and social development. Although agriculture directly accounts for approximately 3 percent of global gross domestic product (GDP), it employs more than 2 billion people around the world, at least part-time.[8] Many of the world's poorest people are farmers or farm laborers. Growth of the agricultural sector can reduce poverty more effectively than growth arising from other economic sectors, in part by providing employment and in part by lowering the cost of food.[9] Agricultural growth can also generate benefits for women, who make up 41 percent of the agricultural workforce worldwide and the majority of agricultural workers in South Asia and sub-Saharan Africa.[10] Because increasing women's income has disproportionate benefits for alleviating hunger,[11] boosting opportunities for women in agriculture can have significant positive impacts.

Third, the world needs to reduce agriculture's impact on the environment and natural resources. Three environmental impacts are especially important:

- **ECOSYSTEMS.** Since the invention of agriculture 8,000–10,000 years ago, growing crops and raising livestock have been the primary causes of ecosystem loss and degradation.[12] Today, 37 percent of the planet's landmass outside of Antarctica is used to grow food—12 percent as croplands and 25 percent as grazing lands (Figure 1).[13] When deserts, permanent ice, and inland water bodies are excluded, the figure rises to just under 50 percent. Yet agriculture continues to expand and is the dominant driver of tropical deforestation, the conversion of carbon-rich peatlands,[14] and associated impacts on biodiversity.[15]

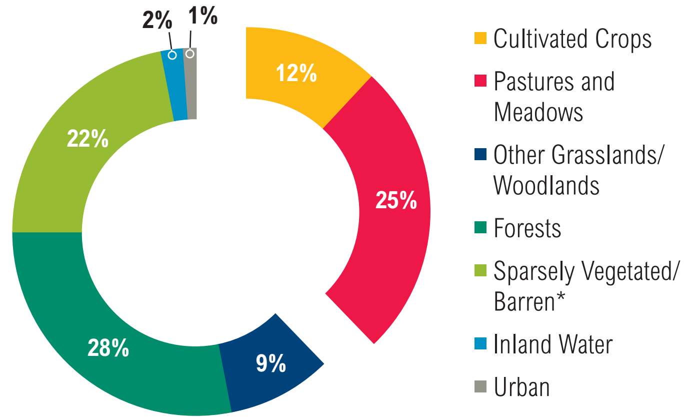
- **CLIMATE.** Agriculture accounted for approximately 24 percent of global greenhouse gas emissions in 2010. This figure includes 13 percent from agricultural production, namely methane from livestock, nitrous oxide from fertilizer use, and carbon dioxide from tractors and fertilizer production. Land use change, which is primarily driven by agriculture, contributes about another 11 percent.[16]

- **WATER.** Agriculture accounts for 70 percent of all freshwater withdrawn from rivers, lakes, and aquifers, and for 80 to 90 percent of such water that is actually consumed and not returned.[17] And nutrient runoff from farm fields can create "dead zones" and degrade coastal waters around the world.[18]

Failure to address these environmental impacts would in turn hamper food production in coming decades. Various methods estimate that land degradation affects approximately 20 percent of the world's cultivated areas, although these estimates can be difficult to define and measure.[19] Forest loss could lead to regional drying and warming, which could increase stress on agriculture.[20] Recent studies indicate that the higher temperatures, extended heat waves, flooding, and shifting precipitation patterns associated with climate change will have substantial adverse consequences for global crop yields (Figure 2).[21] Likewise, rising sea levels will reduce cropland productivity and viable cropland area in coastal regions.[22] Many crop-generating regions already struggle with significant water stress, leading to declines in crop production. The droughts of 2011 and 2012 in parts of Australia, East Africa, Russia, and the United States are cases in point. Water stress is likely to increase due to growing water demand coupled with climate change (Figure 3).

The forthcoming World Resources Report (Box 1), *Creating a Sustainable Food Future,* seeks to describe how to meet all three of these needs at the same time and thereby achieve the great balancing act. "The Great Balancing Act" is the first working paper in a series that will culminate in the World Resources Report. This first paper frames the series by exploring the scope of the challenge and proposing a menu of potential solutions. We defer detailed discussion of the menu items, obstacles to their implementation, and promising policy responses to subsequent working paper installments (Box 2).

Figure 1 | **37% of Earth's Landmass (Ex-Antarctica) is Used for Food Production (100% = 13.3 billion hectares)**

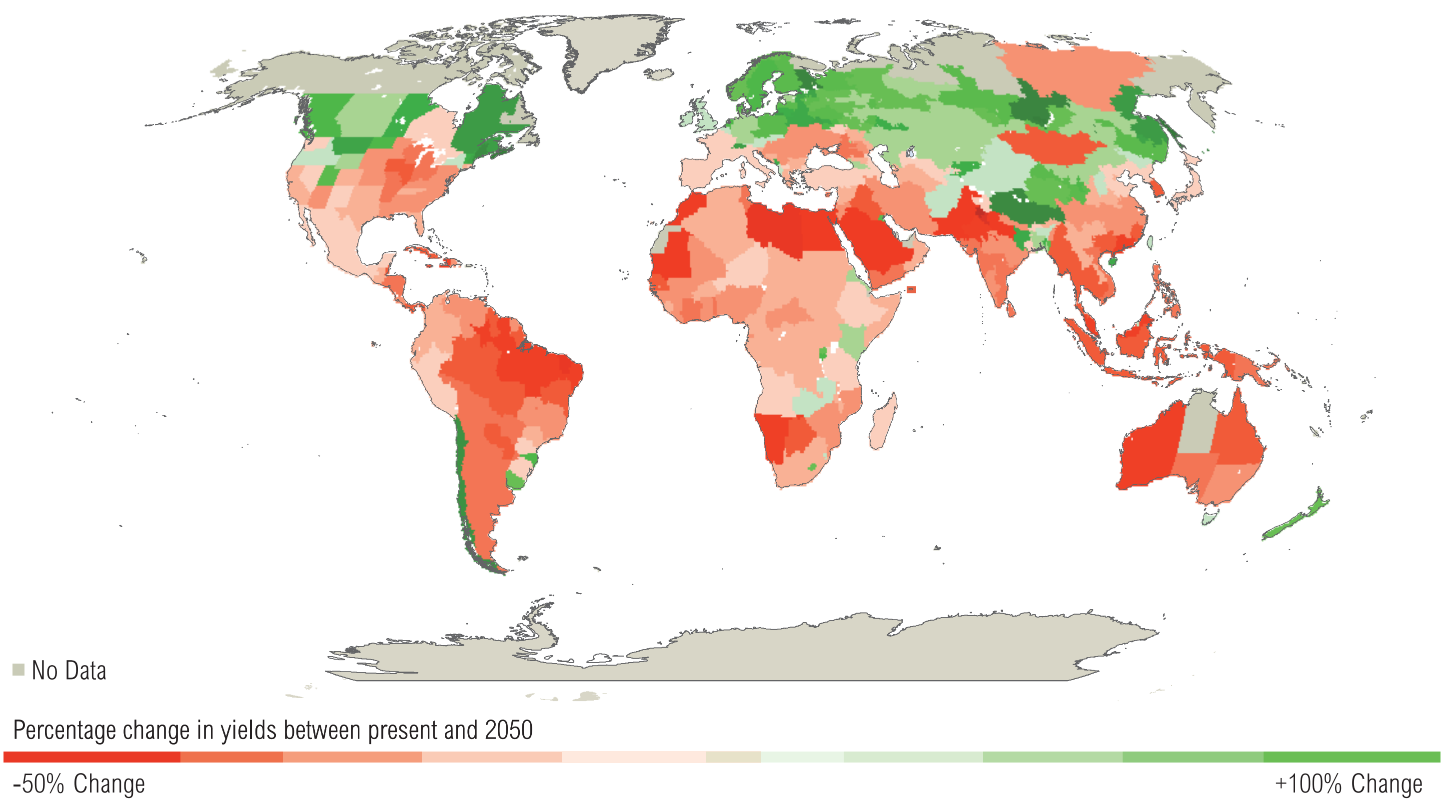


** Permanent ice cover, desert, etc.*

Note: Figures may not equal 100% due to rounding.

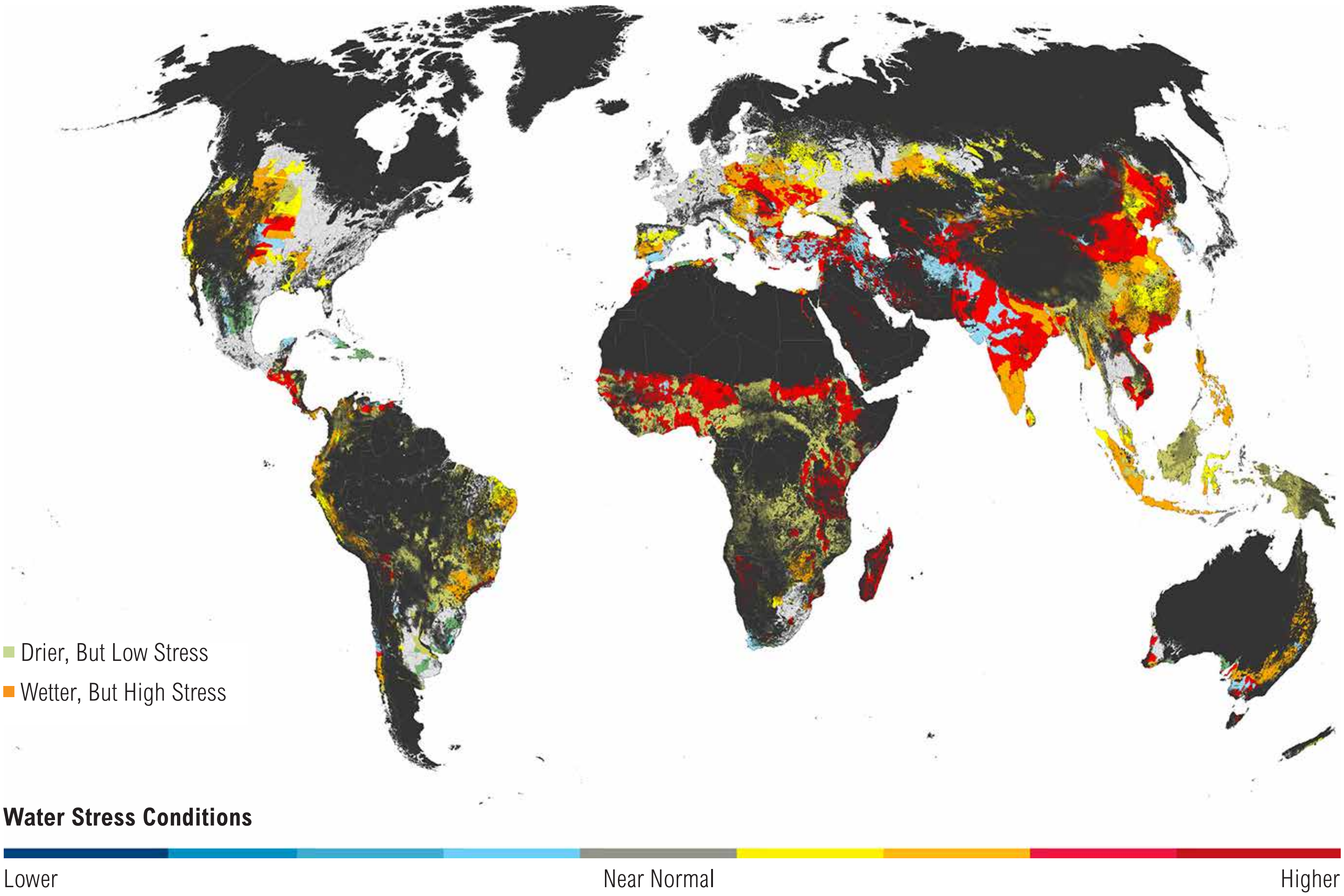
Source: FAO. 2011. *The State of the World's Land and Water Resources for Food and Agriculture.* Rome: FAO.

Figure 2 | **Climate Change is Projected to Impact Crop Yields (3° C World)**



Source: World Bank. 2010. *World Development Report 2010.* Washington, DC: World Bank.

Figure 3 | **Water Stress Will Increase in Many Agricultural Areas by 2025 (Based on IPCC Scenario A1B)**



Source: WRI Aqueduct 2012; Water stress data from The Coca-Cola Company. Cropped areas from Ramankutty et al. 2008. "Farming the Planet: 1. Geographic distribution of global agricultural lands in the year 2000." *Global Biogeochemical Cycles,* Vol. 22, Issue 1.

Box 2 | What's Next

During 2013 and 2014, WRI is releasing on a rolling basis a series of *Creating a Sustainable Food Future* working paper installments. Each installment will analyze a menu item from our proposed "menu for a sustainable food future" and recommend policies and other measures for implementation. The series will not, however, cover all menu items.

Questions each installment will consider include:

- What is the menu item?
- How big an impact could it make in food availability, economic development, and environmental benefits?
- Where might the menu item be most applicable?
- What are the three to five most promising, practical, and scalable approaches for achieving this menu item?
- What are the obstacles—economic, political, technical, or other—to implementing these approaches?
- How can these obstacles be overcome?
- What "bright spots" of success exist, and what can be learned from them?

Each installment will be coauthored by its own cohort of WRI researchers, WRR partners, and renowned experts. Authors will engage representatives from target audiences during the research and writing phases. After the series has concluded, WRI will consolidate the installments into a final World Resources Report. If you would like to participate in the research or dissemination of any of these *Creating a Sustainable Food Future* installments, please visit the WRR website at www.worldresourcesreport.org.

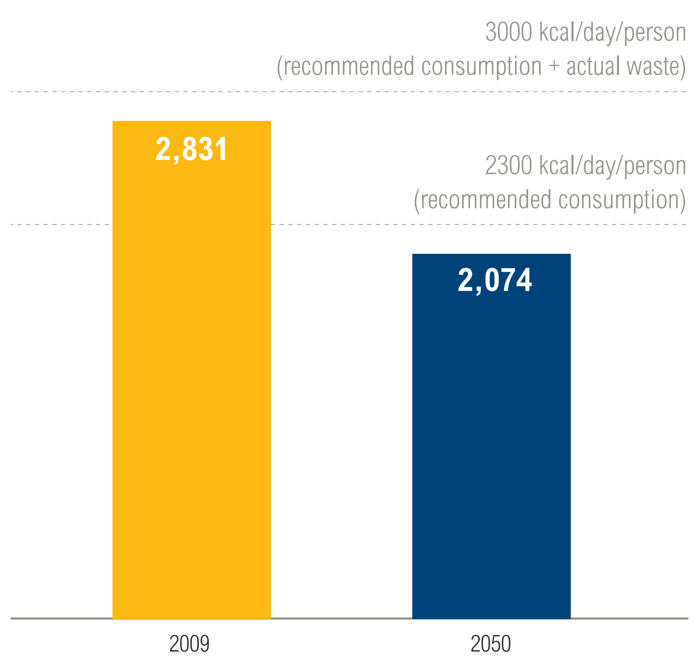
To avoid overlap with upcoming installments, this first working paper does not cover many of the issues that may be important for the food-development-environment nexus. For instance, it does not cover international investments in agricultural land ("land grabs"); the merits of small-scale versus large-scale agricultural systems; the influence of land tenure, property rights, and generational succession laws and norms on agricultural productivity; and policies for providing access to clean energy services for agriculture. Future installments will address some of these issues.

Many of the analyses in this series are global in nature and use global datasets. We recognize that they may not fully account for the ethical, cultural, and socioeconomic factors of specific locations. Moreover, the menu for a sustainable food future is designed for the long term; it is not a menu for tackling acute, near-term food shortage crises.

THE SCOPE OF THE CHALLENGE

Will the world really need more food? Given the enormously unequal distribution of food today around the planet, one might think that distributing food more equally could solve the food challenge. Yet, as Figure 4 shows, even if all the food calories available in the world today were equally distributed across the projected population for the year 2050 and no food calories were lost between the farm and the fork, those calories would still fall short of the Food and Agriculture Organization's (FAO) "average daily energy requirements"—2,300 calories (kcal) per person per day—by more than 200 kcal per person per day.[23] If the current rate of food loss and waste were to remain in 2050, the gap would grow to more than 900 kcal per person per day. In short, current global food availability is insufficient to feed the world in 2050.

Figure 4 | If All Food Produced in 2009 Were Evenly Distributed to All People in 2050, Not Enough Calories Would Be Available Per Person



Note: Data reflects food for direct human consumption. It excludes food crops grown for animal feed and biofuels. See endnotes for assumptions used to generate the global average daily energy requirement per person.

Source: WRI analysis based on FAOSTAT 2012. *Food Balance Sheets.* Rome: FAO; UN Population Division (UNPD). 2011. *World Population Prospects: The 2010 Revision*, medium growth scenario. New York: UNPD.

How much more food will the world need? To answer this question, we rely on an FAO projection of food demand and production by 2050 by long-time experts Jelle Bruinsma and Nikos Alexandratos, initially prepared in 2009 and revised in 2012.[24] They project a 55 percent increase in total direct human calorie consumption from 2006 to 2050. For two reasons that projection likely underestimates the amount of calories needed to adequately feed all people in 2050. First, it assumes that sub-Saharan Africa and South Asia will have insufficient calories to feed everyone adequately in 2050, and second, it uses an outdated U.N. population projection for 2050. When we adjust to assure production of sufficient calories for everyone and use the latest population projection of 9.3 billion people, the required increase in food calories directly available for human consumption rises to 60 percent.[25] This figure represents the food people eat, including a 74 percent rise in calories from animal products alone. It does not include the animal feed needed to produce animal products such as meat and milk.

Our modification of the FAO projection also yields a significant increase in the needed production of crops alone. This increase reflects not only growth in demand for crops that people eat directly, but also growth in demand for crops used for animal feed. It also includes a modest growth of crops for industrial uses, seeds, and biofuels from 2006. Our projection maintains the 2010 share of biofuels in global transportation fuel of 2.5 percent.[26] When including our modest food adjustments for population and the assurance of adequate calories in all regions, the FAO projection implies a 63 percent increase in required crop calories from 9,500 trillion kcal per year in 2006 to 15,500 trillion kcal in 2050.[27] The result is a 6,000 trillion kcal per year "gap" between production in 2006 and the need in 2050.

Without measures to limit demand, this projection implies that the world needs to increase crop production over the 44-year period from 2006 to 2050 by almost precisely the same amount—103 percent—as it increased crop production over the previous 44 years (1962–2006). Although the future need for cereal growth is slightly lower than the previous period's growth, the needed growth for many other crops—including oilseeds, potatoes, fruits, and vegetables—is higher than growth in the previous period.

In the previous period, the Green Revolution—with its scientifically bred seeds, synthetic fertilizers, and doubling of irrigated area—drove increased yields. Even with vast increases in yields, cropland and pastureland expanded by roughly 500 million hectares (Mha), according to FAO data.[28] This expansion of agriculturally productive land and increased use of water, fertilizer, and pesticides significantly affected ecosystems, freshwater resources, and greenhouse gas emissions. If the world's agricultural system is to achieve the great balancing act, however, the next four decades must match previous achievements in food production growth without converting ecosystems and increasing water use. At the same time, it must find a way to reduce agriculture-related greenhouse gas emissions.

MENU OF POTENTIAL SOLUTIONS

In *Creating a Sustainable Food Future*, we explore a range of potential solutions that are part of a "menu for a sustainable food future." This menu of solutions is designed to close the gap of 6,000 trillion kcal per year by 2050, conceptually illustrated by Figure 5, while contributing to economic and social development and reducing environmental impacts. Calories, of course, provide only one measure of human food needs, but as long as we focus on ways of providing calories that simultaneously provide the broad balance of nutrients, calories can serve as a viable metric for measuring the gap and its solutions (Box 3).

We honed the menu to those solutions that can contribute to—or at least not negatively impact—economic and social development and environmental protection. Although there are numerous criteria relevant to economic and social development, we chose two:

- **POVERTY ALLEVIATION.** The menu should reduce poverty and advance rural development, while still being cost effective.
- **GENDER.** Given present inequities and women's disproportionate role in combating poverty and reducing food insecurity, the menu should generate benefits for women.

We also selected three criteria that represent the significant impacts of agriculture on the environment:

- **ECOSYSTEMS.** The menu should not result in agricultural expansion into remaining natural terrestrial ecosystems and, in the case of oceans, should reduce pressure on overstrained fisheries. As a result, it would help reduce loss of biodiversity.
- **CLIMATE.** The menu should help reduce greenhouse gas emissions from agriculture to levels consistent with stabilizing the climate.
- **WATER.** The menu should not deplete or pollute aquifers or surface waters.

Given the urgency of achieving the great balancing act, we focus primarily on menu items that could be implemented now or in the near future rather than game-changing but uncertain technological innovations.

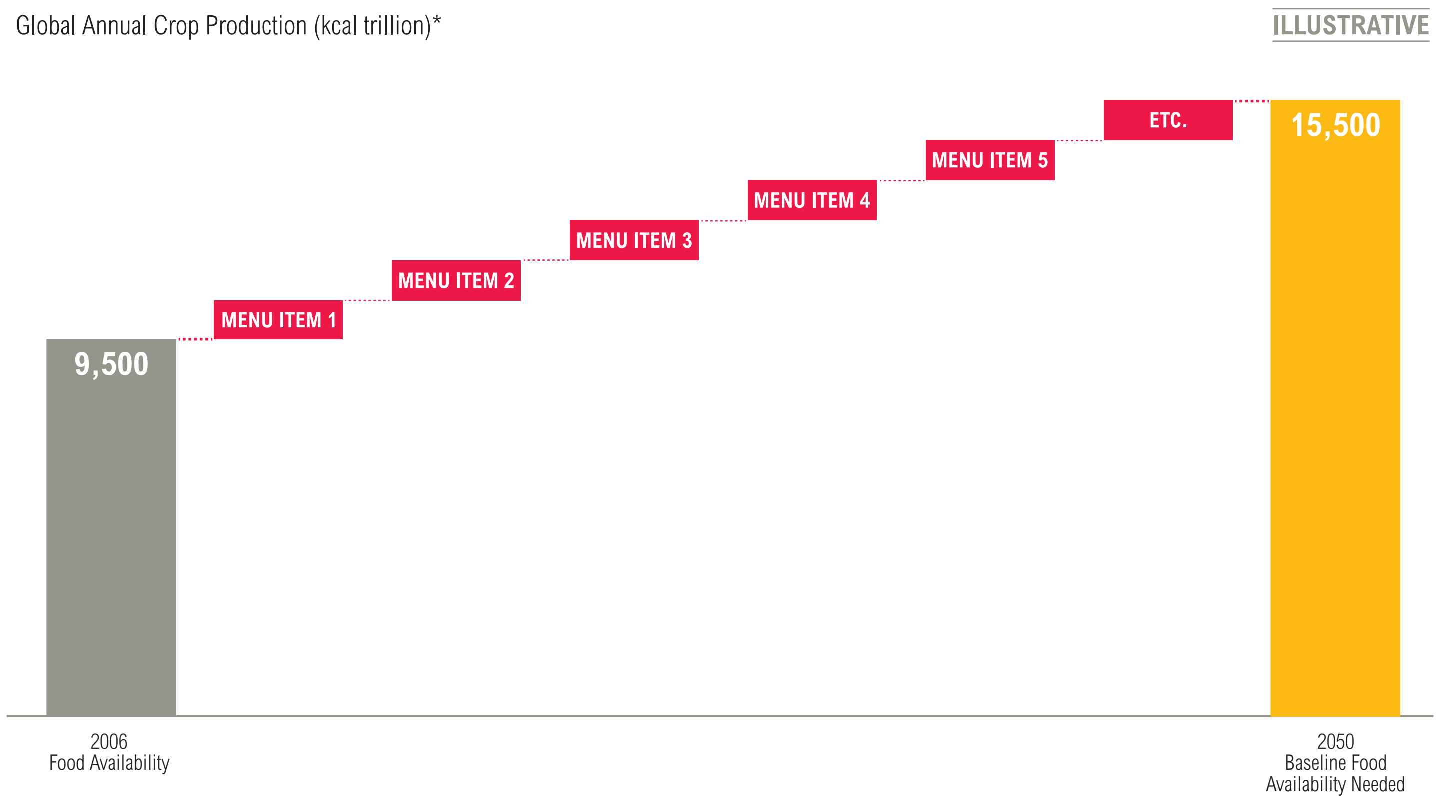
Box 3 | Why We Use Calories As Our Measure of the Food Gap

Food comes from a wide variety of crops and animal products, and provides not merely calories but also proteins, vitamins, minerals, fiber, and other nutritional benefits. There is no one perfect way to measure quantities of food or a "food gap." FAO's estimate in 2009 of a 70 percent food gap between 2006 and 2050, which many other papers have cited, measured food by its "economic value." But because prices change over time, economic value does not provide a consistent unit of measure. Food "volume" includes water, but water in food does not provide nutrition. "Nutrients" are not amenable to a uniform unit of measure because people need many types of nutrients. "Calories," however, are consistent over time, avoid embedded water, and have a uniform unit of measure. Data on calories is also globally available.

Even for calories, our analysis could focus on the total increase in calories from 2006–2050 from crop production, or the total increase in calories from all food available directly for human consumption. Measuring food directly available to people does not count calories in animal feed but does count calories in animal products. Each approach has its merits. As it turns out, the estimated food gap by either measure is almost identical, ranging from 63 percent for the needed increase in crop production to 60 percent for the needed increase in food calories available for direct human consumption.

The use of calories to measure the food gap would lead to distorted solutions if we considered solutions that provided calories at the expense of nutrients. For example, it might encourage the production of cereals with high yields in place of fruits and vegetables, beans, and animal products. But by focusing on solutions that provide at least comparable nutrition to those in our baseline projection, all the solutions include a balanced growth in food products. Calories then become a suitable means of measuring the food gap among nutritionally balanced alternatives.

Figure 5 | **A Menu of Solutions is Required to Sustainably Close the Food Gap**



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

Source: WRI analysis based on Bruinsma, J. 2009. *The Resource Outlook to 2050: By how much do land, water and crop yields need to increase by 2050?* Rome: FAO; Alexandratos, N., and J. Bruinsma. 2012. *World agriculture towards 2030/2050: The 2012 revision.* Rome: FAO.

Table 1 summarizes our preliminary menu and shows how individual menu items perform against the criteria. For example, reducing food loss and waste would make more food available, could improve the finances of small farmers and others in the food value chain, and should avoid a broad range of environmental impacts associated with food production. In contrast, some approaches to increase food production—such as converting natural forests and savannas into croplands or grazing lands—fail some of these criteria and therefore are not included in the menu.

The menu items for a sustainable food future group into three main courses: (1) items that help to close the food gap by reducing growth in food consumption; (2) items that help to close the food gap by increasing food production on existing agricultural land area; and (3) items that reduce the environmental impact of food production but do not necessarily close the food gap. For the third, we focus on those that would hold down the greenhouse gas emissions from agricultural production. Measures that address this concern will tend to help reduce other pressures on the environment, too.

The menu items must work together and not undermine each other. We do not presume that all items are likely to work equally well; their potential is what we explore in this working paper series. No item on the menu can achieve a sustainable food future by itself, and the relevance of menu items will vary between countries and food chains. In general, the more any single menu item is implemented, the less other items likely need to contribute. Finally, the menu only addresses the challenge of sustainable food supply and demand; it does not directly address additional dimensions that are critically important to food security such as enhancing food utilization, reducing poverty, and improving distribution (Box 4). Although we recognize these are critically important aspects of food security, they are beyond the scope of our analysis.

Table 1 | **A Menu for a Sustainable Food Future (Preliminary)**

COURSE	MENU ITEM	DESCRIPTION	PERFORMANCE AGAINST CRITERIA	
			POVERTY ALLEVIATION	GENDER
Hold down consumption	Reduce food loss and waste	Reduce the loss and waste of food intended for human consumption between the farm and the fork.	●	●
	Reduce obesity	Reduce the number of people who are overweight or obese.	●	●
	Eat fewer animal products (in general)	Reduce the share of animal-based foods in a person's daily diet.	●	●
	Shift meat consumption away from beef	Among animal-based foods, reduce the amount of beef consumed in a person's daily diet and substitute with fish and poultry.	●	●
	Achieve replacement fertility rates	Have the total fertility rate of every continent achieve the replacement rate of 2.1 children per woman by 2050.	●	●
	Reduce biofuel demand for food crops	Avoid the diversion of edible crops into biofuels.	●	○
Produce more food without land expansion	Boost yields through attentive crop and animal breeding	Increase yields through the steady annual selection and adoption of higher yielding seeds, supplemented by occasional technology breakthroughs.	○	○
	"Leave no farmer behind"	Bring inefficient farmers up to standard farming efficiency levels.	●	●
	Plant existing cropland more frequently	Plant and harvest crops more frequently on already existing cropland (more than one rotation per year), *where conditions are suitable*.	●	●
	Improve soil and water management	Increase crop yields on existing agricultural land by implementing improved soil and water management practices such as agroforestry, water harvesting, and biological nitrogen fixation.	●	●
	Expand onto low-carbon degraded lands	Expand resource-efficient crop or livestock production onto land that is currently not used to produce food, not biologically diverse, and neither stores nor is likely to sequester significant carbon.	●	○
	Increase productivity of pasture and grazing lands	Increase yields of milk and meat per hectare on existing pasture and grazing lands through sustainable intensification of grazing management and related practices.	●	○
	Reduce then stabilize wild fish catch	In overharvested fisheries, reduce wild fish catch from marine and freshwater systems until fish populations rebound.	○	○
	Increase productivity of aquaculture	Increase aquaculture production while increasing resource (feed, land, water, energy) efficiency.	●	●

● = positive ○ = neutral/it depends ⊗ = negative

PERFORMANCE AGAINST CRITERIA					
ECOSYSTEMS	CLIMATE	WATER	COMMENT	↑ FOOD AVAILABILITY	↓ GHG EMISSIONS
●	●	●	One out of every four calories produced is lost or wasted between the farm and the fork.	X	X
●	●	●	More people in the world today consume too much food than consume too little.	X	X
●	●	●	In most of the world except sub-Saharan Africa, consumption of animal products is already high and leads to more protein intake than is necessary for human health.	X	X
●	●	●	Among animal-based foods, beef stands out for human health impacts (e.g., cholesterol, saturated fat) and environmental effects.	X	X
●	●	●	This menu item can be achieved via improving girls' education opportunities, increasing access to reproductive health services, and reducing infant and child mortality, especially in Africa.	X	X
●	●	●	The challenge of feeding the planet gets harder as alternative uses for food (and the land used to grow food) emerge.	X	X
○	○	○	Whether or not the impacts are positive, neutral, or negative will depend on the environmental performance and property rights aspects of the seed varieties.	X	X
●	●	●	This menu item implies focusing on the least efficient farms rather than bringing already high-yielding farms up to nearly perfect standards from a yield perspective.	X	X
○	●	○	Whether or not the water and ecosystem impacts are positive, neutral, or negative will depend on the management practices used.	X	X
●	●	●	This strategy is applicable across most farming regions, has particular benefits for sub-Saharan Africa, and can complement strategies that utilize input technologies (e.g., fertilizer micro-dosing).	X	X
●	●	○	Water impacts will be a function of the watering regime. Some areas often called "degraded land" are not low cost from an environmental perspective (e.g., forests will grow back if left on their own), and therefore should not be considered for restoration into agriculture.	X	X
●	●	○	Water impacts will be a function of how livestock water supplies are managed.	X	X
●	○	●	Impacts may be negative (e.g., reduced food quantity, lower local income) in the short term for those whose catch is reduced, but positive over the long run as the strategy prevents fishery collapse.	X	
○	●	○	Water recycling, type of feed, and other factors will determine whether this strategy's impacts on water and ecosystems are positive or negative.	X	X

Table 1 | **A Menu for a Sustainable Food Future (Preliminary), continued**

COURSE	MENU ITEM	DESCRIPTION	PERFORMANCE AGAINST CRITERIA: POVERTY ALLEVIATION	PERFORMANCE AGAINST CRITERIA: GENDER
Reduce emissions and other impacts from other agricultural activities	Improve the feed efficiency of ruminant livestock	Reduce the amount of greenhouse gas emissions and other pollutants per unit of meat and dairy output via improved livestock breeding, feeds, fodder digestibility, and more.	●	○
	Make fertilization more efficient	Reduce overapplication of fertilizer and increase plant absorption of fertilizer.	●	○
	Manage rice paddies to reduce emissions	Reduce methane emissions from rice paddies via species selection and improved water, soil, and straw management.	●	○

Box 4 | **Food Security and Sustainability**

According to FAO, "food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life."* The Committee on World Food Security identified four main "pillars of food security:"**

- *Availability* is ensured if adequate amounts of food are produced and are at people's disposal.
- *Access* is ensured when all households and all individuals within those households have sufficient resources to obtain appropriate foods for a nutritious diet (through production, purchase, or donation).
- *Utilization* is ensured when the human body is able to ingest and metabolize food because of adequate health and social environment.
- *Stability* is ensured when the three other pillars are maintained over time.

Several experts have argued for a fifth pillar based on environmental sustainability, where food production and consumption patterns do not deplete natural resources or the ability of the agricultural system to provide sufficient food for future generations.***

The sustainability dimension is an oft-overlooked but important pillar, particularly since it underpins many of the others. For instance, production of crops is dependent on supplies of freshwater at appropriate times during the growing season. Degradation of soils undermines agricultural productivity. Natural ecosystems provide pollination, wild foods, natural pest controls, and more. Climate change, left unabated, is likely to have dramatic impacts on food production both on average and in particular locations through exceptional droughts, heat waves, and floods.

This WRR working paper series focuses on the interplay of food availability and sustainability. Both touch on the pillars of stability and access by influencing prices. But although assuring availability and sustainability are critical to food security, they are not sufficient. And there are many issues related to income, distribution, nutrient balance, and disaster interventions that are important for food security but that we do not address in this series.

* *FAO (2006).*
** *The following definitions are paraphrased from Gross et al. (2000).*
*** *Richardson (2010).*

● = positive ○ = neutral/it depends ⊗ = negative

PERFORMANCE AGAINST CRITERIA					
ECOSYSTEMS	CLIMATE	WATER	COMMENT	↑ FOOD AVAILABILITY	↓ GHG EMISSIONS
●	●	●	Poor livestock quality and inadequate feed leads to more methane emissions per kg of milk or meat because more feed is turned into methane in livestock stomachs and because livestock grow less fast or produce less per kg of feed.		X
●	●	●	This strategy is of particular relevance to regions in China, India, the United States, and Europe.		X
●	●	●	Rice is of particular importance given the number of people who depend on it as a basic food crop, the amount of area dedicated to its production, and its sizable contribution to greenhouse gas emissions—10 percent of all global agricultural production emissions.		X

Can the world's agricultural system achieve the great balancing act? Over the course of the installments that build the foundation for the World Resources Report, our assessment is sober but hopeful. With the right combination of approaches and unwavering commitment, the world can feed its 9 billion future inhabitants while simultaneously securing economic and social development and protecting the environment. The challenge is undeniably complex and may be underappreciated. But by shedding light on the defining challenges and offering a menu of solutions, we hope the forthcoming World Resources Report will embolden governments, the private sector, and civil society to act quickly and with conviction.

ENDNOTES

1. United Nations Population Division (UNPD). 2011. 9.3 billion people in 2050 reflects the medium growth scenario.
2. "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).
3. Foresight (2011).
4. FAO, WFP and IFAD (2012).
5. FAO, WFP and IFAD (2012).
6. The UN Food and Agriculture Organization (FAO) measures food in terms of "food availability." Food availability reflects edible food intended and available for human consumption. In general, it is the amount of food produced or, alternatively, the sum of food consumed, food lost after harvest, and food wasted up to the point of consumption.
7. This figure is based on WRI adjustments to FAO projections. The next section articulates the FAO projections and WRI adjustments.
8. World Bank (2012).
9. World Bank (2008).
10. FAO (2007); World Bank, FAO and IFAD(2009).
11. FAO (2011a).
12. Millennium Ecosystem Assessment (2005).
13. Figures exclude Antarctica. FAO (2011b).
14. Kissinger et al. (2012).
15. Millennium Ecosystem Assessment (2005). In this paper, we treat the negative impacts on ecosystems to imply a negative impact on biodiversity, as well.
16. WRI analysis based on UNEP (2012), FAO (2012), EIA (2012), IEA (2012), and Houghton (2008) with adjustments.
17. Foley et al. (2005).
18. Selman and Greenhalgh (2009).
19. Bai et al. (2008). This paper defined land degradation as areas with declining annual plant production, which was estimated by 23 years of data from remote sensing, with efforts to control for other alterations, such as rainfall pattern changes. Various other methods, all with major limitations, have also been used to assess land degradation. See Gibbs (2010).
20. Paeth et al. (2009).
21. IPCC (2007).
22. IPCC (2007).
23. Based on the FAO Food Balance Sheets, daily calorie availability from both plant- and animal-based foods in 2009 was 2,831 kcal/person. Multiplying this figure by the 2009 global population of 6,817,737,000 yields a total daily global calorie availability of 19,301,013,795,000 kcal. Spreading this amount of calories evenly among the projected 2050 global population of 9,306,128,000 people results in a daily calorie availability of 2,074 kcal/person. FAO's suggested average daily energy requirement (ADER)—the recommended amount of caloric consumption for a healthy person—for the world in 2010–12 was 2,248 kcal/person/day. For developed countries, the ADER was 2,510 kcal/person/day. We assume that in 2050 the global ADER will not increase to current developed country levels but will slightly increase to 2,300 kcal/person/day as people currently undernourished become taller as their diets improve. To determine how much food needs to be available in order for people to consume 2,300 kcal per day, we factored in the current global average rate of food loss and waste of 24 percent, thereby arriving at approximately 3,000 kcal/person/day. This figure assumes that no person is overconsuming calories.
24. Bruinsma (2009); Alexandratos and Bruinsma (2012).
25. This adjustment does not reduce calorie consumption in any region. In sub-Saharan Africa and India, where FAO projects calorie availability less than 3,000 calories per person, we assume increased consumption equal to the availability of 3,000 calories per person, including food lost and wasted.
26. To be precise, biofuels contributed 2.5 percent of world transportation energy in 2010 (authors' calculations presented in Heimlich and Searchinger (forthcoming)). For this comparison with FAO projections, we use data provided by FAO for the crops used for biofuels in 2050 and back-calculated the quantity of ethanol and diesel.
27. There is no one perfect measure of the production increase challenge. This figure does include the rise in crops fed to livestock measured in calories, rather than the calories in the livestock products themselves. Doing so recognizes that animal products only return a small percentage of the calories in crops fed to them. However, this calculation does not reflect the additional feeds provided to livestock, and the calories those livestock products provide, that derive from pasture and other feeds. This number has the advantage of fully estimating the total increase in crop production, including that for feed and biofuels. But it leaves out the increase in pasture and other feeds that must be generated to produce the additional animal products.
28. Alexandratos and Bruinsma (2012), Table 4.8. FAO data estimate an increase in arable land in use of 220 million hectares from 1962 to 2006. According to FAOSTAT, pasture area has increased by 270 million hectares since 1962.

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