Commission on Sustainable Agriculture and Climate Change

Evidence from Major Assessment Reports on Sustainable Agriculture and Climate Change

Background

A number of major reports have usefully investigated issues of food security, climate change and agriculture; however, they have not led to needed changes in policies and investments. A clear set of evidence-based policy recommendations is needed to guide decisive action.

In its 15 February 2011 meeting, the Commission requested the Secretariat to produce a matrix of evidence distilled from a set of sixteen major reports (see list below). The purpose was to compile unassailable evidence from across individual studies (noting that many studies draw upon the same underlying data) and to identify points of consensus among these reports as a basis for further work by the Commission.

The Commission also requested that the Coordinator conduct a structured telephone interview with each Commissioner to elicit perspectives on the major topics to be addressed by the Commission. A synthesized list of major topics was developed based on these Commissioner interviews and discussions during the 15 February meeting. This list of topics was refined based on feedback from Commissioners, and has provided a framework by which to consider the evidence from the individual studies.

The Commission released a Summary for Policy Makers in November 2011 and its full report in March 2012. The 16 reports are extensively cited in both reports, and the matrix provided a means of sorting, prioritizing and analyzing the findings of the 16 reports.

Methodology and process

Criteria used in compiling this matrix include:

- Consistent, efficient and transparent approach;
- Opportunity to add value to existing evidence and recommendations, and understand barriers to implementation;
- Provision of an authoritative resource document summarizing evidence base used to steer and inform the Commission’s report and underpin policy recommendations;
- Enables identification of robust recommendations and critical gaps in research activity and policy and institutional responses; and
- Special focus on major components and drivers of the current food system, with detail on case studies showing potential solutions.

The process used to develop this matrix was a desktop analysis implemented primarily by Christine Negra (Commission Coordinator). Several reports were reviewed by other contributing experts including: UK Foresight and Royal Society reports (Rebecca Fisher-Lamb, Elizabeth Warham, UK Government Office for Science), INRA/CIRAD 2011 report (Sandrine Paillard, INRA) and World Development Report 2008 (Paul Barnett, Frank Jensen, CSIRO).

A matrix template was developed and used to house evidence and recommendations collated during the review of each report (a separate Excel file was produced for each). Matrix columns included the following headings: Risks, opportunities, evidence, recommendations, gaps, case studies. Matrix rows represented each of the priority topics identified through Commissioner interviews.

A first “coarse grain” version was produced and shared with the Commission at its 10 May meeting. A revised version was produced and shared with several project advisors for critical review. The second version of the matrix, completed in July 2011, contains concepts and direct quotes compiled through a survey of the 16 reports.

Revisions included:

- Streamlining column headings (i.e., risks and barriers, opportunities, evidence, evidence-based recommendations, identified gaps) and merging related material;
- Aligning row titles based on revised guidance from the Commission regarding priority topics;
- Strengthening representation of “identified gaps” with particular focus on scientific knowledge and institutional responses;
- Cross-checking entries for "evidence-based recommendations" to emphasize recommendations with clear scientific evidence base; and
- Confirming appropriate citation of all entries.
- It was a foundational resource to the development of the Commission's zero order draft, which was reviewed by a diverse expert group through the Bellagio workshop.
- Subsequent iterations of the report were developed through the interactions of the Commissioners but many of the concepts drawn from the matrix were retained.

The final version of the matrix is the table below. This table has been used to inform the drafting of the final Commission report and to extract key ideas and recommendations.

Disclaimers

These sixteen reports vary in their approach (e.g., science synthesis, multi-stakeholder engagement, peer review), topical focus and geographic scope and were developed with different target audiences in mind. Due to these differences, there are likely differences in the degree of rigor applied in establishing the scientific evidence basis.

In reviewing the reports, information, ideas and quotes were selected based on relevance to the priority topics identified by the Commission. As a result, the matrix does not attempt to comprehensively summarize key messages from any of the reports, but rather extract evidence with relevance to the Commission’s mandate, and explore where there is synergy in the recommendations and solutions proposed.

Many of the extracts from the reports that are shown in the matrix are direct quotes, though the difference between direct and paraphrased quotes is not indicated.

List of reports

The table that follows contains excerpted findings and recommendations from the following sources (numbers in brackets in the table correspond to the list below):

1. Foresight. The Future of Food and Farming. 2011. Final Project Report. Futures. London, UK: Government Office for Science.

- Process / method: Focused on the global food system including governance at all scales, food production and processing, the supply chain, and consumer attitudes and demand with relevance for climate change mitigation, energy and water competition, and land use. A Project Lead Expert Group oversaw the technical aspects of the project with contributions by a high-level stakeholder group, a project advisory group, and an economics advisory group. Over 100 peer-reviewed evidence papers were commissioned and several hundred experts and stakeholders from across the world were engaged.
- Geographic coverage: Global
- Contributing organizations: UK Government Office for Science. Support provided by UK Department for Environment, Food and Rural Affairs (Defra) and Department for International Development (DFID) Lead Experts: Charles Godfray, Lawrence Haddad, David Lawrence, James Muir, Jules Pretty, Sherman Robinson, and Camilla Toulmin.

2. Lipper, L., Mann, W., Meybeck, A., and Sessa, R. 2010. "Climate-Smart" Agriculture: Policies, Practices and Financing for Food Security, Adaptation and Mitigation. Rome, Italy: UN Food and Agriculture Organization.

- Process / method: This paper examines some of the key technical, institutional, policy, and financial responses required for agricultural transformation in developing countries needed to meet the related challenges of achieving food security and responding to climate change. Building on case studies from the field, the paper outlines a range of practices, approaches and tools aimed at increasing the resilience and productivity of agricultural production systems, while also reducing and removing emissions. It also surveys institutional and policy options available to promote the transition to climate-smart agriculture at the smallholder level, considers current financing gaps and makes innovative suggestions regarding the combined use of different sources, financing mechanisms, and delivery systems.
- Geographic coverage: Developing countries
- Contributing organizations: This paper is the outcome of a collaborative effort between the Natural Resources Management and Environment Department, the Economic and Social Development Department, the Agriculture and Consumer Protection Department, the Fisheries and Aquaculture Department, and the Forestry Department of the FAO.

3. International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD). 2009. Agriculture at a crossroads: A synthesis of the global and sub-global IAASTD reports, eds. B.D. McIntyre, H.R. Herren, J. Wakhungu, and R.T.Watson. Washington, D.C.: Island Press.

- Process / method: Assessment (i.e., critical evaluation of information for the purpose of guiding decisions) peer-reviewed by governments and experts, and approved by a panel of participating governments focused on impacts of agricultural knowledge, science, and technology on hunger, poverty, nutrition, human health, and environmental and social sustainability in relation to both the past and the future.
- Geographic coverage: Global and sub-global assessments

- Contributing organizations: UN Development Programme (UNDP), UN Food and Agriculture Organization (FAO), UN Environment Programme (UNEP), United Nations Educational, Scientific and Cultural Organization (UNESCO), the World Bank, the World Health Organization (WHO), the Global Environment Facility. Edited by: Beverly McIntyre, Hans Herren, Judi Wakhungu, and Robert Watson.

4. Nelson, G.C., Rosegrant, M.W., Palazzo, A., Gray, I., Ingersoll, C., Robertson, R., Tokgoz, S., Zhu, T., Sulser, T.B., Ringler, C., Msangi, S., and You, L. 2011. Climate change: Impact on Agriculture and Costs of Adaptation and Food Security, Farming, and Climate Change to 2050. Washington, D.C.: International Food Policy Research Institute.

- Process / method: Research monograph developed through original research conducted at the International Food Policy Research Institute (IFPRI) and benefitting from extensive external and internal reviews and final approval by the IFPRI Director General. Scenarios for a range of plausible economic, demographic, and climatic futures developed through comprehensive empirical analysis using IMPACT model. Three combinations of income and population growth (a baseline scenario that is "middle of the road"; a pessimistic scenario that, while plausible, is likely to result in more negative outcomes for human well-being; and an optimistic scenario that would result in more positive outcomes) are subjected to four plausible climate futures that range from slightly to substantially wetter and hotter on average than the current climate as well as a perfect mitigation climate scenario.
- Geographic coverage: Global
- Contributing organizations: IFPRI. Financial support provided by UK Foresight Global Food and Farming Futures Project, the Bill and Melinda Gates Foundation, the European Union, and the Canadian International Development Agency.

5. INRA/CIRAD. 2011. Agrimonde: Scenarios and Challenges for Feeding the World in 2050. Versailles, France: Editions Quae.

- Process / method: Foresight approach led by an expert panel considered two contrasting scenarios for 2050 (built using Agribiom, FAOSTAT, and other databases) with common assumptions for demographic growth and migrations, and different trajectories for food and agricultural systems: (1) extension of current trends prioritizing economic growth, (2) focused on satisfying global food needs. Core interest: food biomass resource-use balance.
- Geographic coverage: Global
- Contributing organizations: INRA (French National Institute for Agricultural Research) and CIRAD (French Agricultural Research Centre for International Development). Coordinators: Sandrine Paillard, Sebastien Treyer, Bruno Dorin.

6. IFAD. 2011. Rural Poverty Report: New realities, new challenges: new opportunities for tomorrow's generation. Rome, Italy: International Fund for Agricultural Development.

- Process / method: An in-depth study of rural poverty developed in collaboration with dozens of experts in the field of poverty reduction (inside and outside the International Fund for Agricultural Development (IFAD)) and poor rural people (i.e., first-hand accounts from men and women living in rural areas of China, Egypt, Madagascar, Pakistan, Peru and Senegal). Focus: who poor rural people are, what they do, and how their livelihoods change?; challenges that make it difficult for rural people to overcome poverty; opportunities and pathways that could lead towards greater prosperity; and policies and actions that governments and development practitioners can take to support the efforts of rural people.
- Geographic coverage: Developing countries.

- Contributing organizations: IFAD. Report team: Edward Heinemann and Bettina Prato (IFAD), Andrew Shepherd (Overseas Development Institute). Financial support provided by: the Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD); and the Governments of Italy, The Netherlands, Sweden and Switzerland.

7. Millennium Ecosystem Assessment. 2005. Ecosystems and Human Well-being. Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-being: Synthesis. Washington, D.C.: Island Press.

- Process / method: The Millennium Ecosystem Assessment (MA) was called for by United Nations Secretary-General Kofi Annan in 2000. Governments subsequently supported the establishment of the assessment through decisions taken by three international conventions, and the MA was initiated in 2001. The MA was conducted under the auspices of the United Nations, with the secretariat coordinated by UNEP, and it was governed by a multi-stakeholder board that included representatives of international institutions, governments, business, NGOs, and indigenous peoples. Objective: To assess the consequences of ecosystem change for human well-being and to establish the scientific basis for actions needed to enhance the conservation and sustainable use of ecosystems and their contributions to human well-being. The MA developed four scenarios to explore plausible futures for ecosystems and human well-being based on different assumptions about driving forces of change and their possible interactions. The synthesis report integrates findings of the four MA Working Groups (Condition and Trends, Scenarios, Responses, and Sub-global Assessments).
- Geographic coverage: Global
- Contributing organizations: World Resources Institute. Co-chairs: Robert T. Watson (The World Bank), A.H. Zakri, (United Nations University). Director: Walt Reid

8. National Academy of Sciences. 2010. Toward Sustainable Agricultural Systems in the 21st Century. Washington, D.C.: The National Academies Press.

- Process / method: This report of the National Research Council Committee on Twenty-First Century Systems Agriculture reviews the state of knowledge on farming practices, technologies, and management systems that have the potential to improve the environmental, social, and economic sustainability of agriculture, and it discusses the tradeoffs and risks that might occur if more farms were to adopt those practices, technologies, and systems. The report also identifies knowledge gaps and makes recommendations for future actions to improve agricultural sustainability.
- Geographic coverage: United States of America with one chapter on lessons for sub-Saharan Africa
- Contributing organizations: National Academy of Sciences, Board on Agriculture and Natural Resources.

9. Royal Society. 2009. Reaping the Benefits: Science and the Sustainable Intensification of Global Agriculture. London, UK: The Royal Society.

- Process / method: Scientific assessment to describe how the prudent application of recent and prospective biological advances can contribute to the ‘sustainable intensification’ of agriculture. Study undertaken by a working group convened in July 2008, which issued a call for evidence from individual academics, research institutes, industry representatives, and non-governmental organizations. Oral evidence was taken at several workshops.
- Geographic coverage: Global
- Contributing organizations: The Royal Society. Working Group Chairman: Sir David Baulcombe FRS.

10. The Hague Conference on Agriculture, Food Security and Climate Change. 2010. Chair's Summary.

- Process / method: Participants from governments, international and regional organizations and institutions, the private sector, non-governmental organizations, philanthropic foundations, civil society, farmers, and the scientific community, met at the Global Conference on Agriculture, Food Security and Climate Change in The Hague, Netherlands from 31 October to 5 November 2010 to develop a roadmap for action.
- Geographic coverage: Global
- Contributing organizations: Government of the Netherlands, in close cooperation with the Governments of Ethiopia, Mexico, New Zealand, Norway, Vietnam, the World Bank, and the FAO.

11. Vermeulen, S.J., Aggarwal, P.K., Ainslie, A., Angelone, C., Campbell, B.M., Challinor, A.J., Hansen, J.W., Ingram, J.S.I., Jarvis, A., Kristjanson, P., Lau, C., Nelson, G.C., Thornton, P.K., and Wollenberg, E. 2012. Options for support to agriculture and food security under climate change. *Environmental Science and Policy* 15: 136-144.

- Process / method: Background paper prepared for The Hague Conference on Agriculture, Food Security and Climate Change to review the state of current scientific knowledge on the links between climate change, agriculture, and food security, in terms of anticipating impacts, managing climate variability and risks, accelerating adaptation to progressive climate change, and mitigating greenhouse gas (GHG) emissions from the agricultural sector.
- Geographic coverage: Global
- Contributing organizations: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Earth System Science Partnership (ESSP). Financial assistance provided by the European Union, Canadian International Development Agency, World Bank, United States Agency for International Development (USAID), New Zealand Ministry of Foreign Affairs and Trade, and Danida. Technical support provided by IFAD.

12. World Bank. 2010. Opportunities and Challenges for a Converging Agenda: Country Examples. Washington, D.C.: The World Bank.

- Process / method: This paper summarizes the challenges and the practical successes that a selected number of countries are experiencing in moving towards "climate smart" agriculture while addressing the needs of food security and broader development. Individual country summaries and notes.
- Geographic coverage: Countries were selected from every developing country region including middle-income export oriented countries (Uruguay, Brazil), middle-income countries which are facing a range of challenges, but which are also making progress in integrating climate into their agricultural strategies (China, Mexico), countries for which the greatest challenge is water stress (Uzbekistan, Morocco), countries most heavily exposed to climate risks (Albania, Bangladesh), and lower income countries facing critical food security challenges (Niger, Yemen), or with diverse agricultural sectors (Kenya).
- Contributing organizations: The World Bank. Prepared by Dipti Thapa and Marjory-Anne Bromhead from the Agriculture and Rural Development Department.

13. World Bank. 2008. World Development Report, 2008: Development and Agriculture. Washington, D.C.: The World Bank.

- Process / method: Prepared by the World Bank (Sustainable Development Network) and informed by consultations through meetings and regional workshops in 13 different countries as well as videoconferences and online interactions.
- Geographic coverage: Global; highlights two major regional challenges (Sub-Saharan Africa: accelerating agricultural productivity; Asia: overcoming widespread poverty and widening rural-urban income disparities).
- Contributing organizations: The World Bank. Support provided by multidonor programmatic trust fund (Knowledge for Change Program), the Canadian International Development Agency, Ford Foundation, France's Ministry of Foreign Affairs, Global Donor Platform for Rural Development, International Development Research Centre, IFAD, InWEnt (Capacity Building International), Japan's Ministry of Finance, Science Council of the Consultative Group on International Agricultural Research, Swedish International Development Cooperation Agency, Swiss Agency for Development and Cooperation, UK Department for International Development, USAID, and The William and Flora Hewlett Foundation. Core team led by Derek Byerlee and Alain de Janvry.

14. World Bank. 2010. World Development Report, 2010: Development and Climate Change. Washington, D.C.: The World Bank.

- Process / method: Prepared by the World Bank (co-sponsored by Development Economics and the Sustainable Development Network) and informed by consultations through meetings and regional workshops that brought together academics, policy researchers, government officials, and staff of nongovernmental, civil society, and private sector organizations in 38 different countries.
- Geographic coverage: Global
- Contributing organizations: The World Bank. Support provided by the Government of Norway, the UK Department for International Development, the Government of Denmark, the Government of Germany through Deutsche Gesellschaft für technische Zusammenarbeit, the Swedish Government through Biodiversity Centre/Swedish International Biodiversity Programme (SwedBio), the Trust Fund for Environmentally & Socially Sustainable Development. Core team led by Rosina Bierbaum and Marianne Fay.

15. Parry, M., Evans, A., Rosegrant, M.W., and Wheeler, T. 2009. Climate Change and Hunger: Responding to the Challenge. Rome, Italy: World Food Programme.

- Process / method: This report reviews current knowledge of the effects of climate change on hunger. It summarizes knowledge from global studies completed and provides an overview of actions that can be taken to address the challenge.
- Geographic coverage: Global
- Contributing organizations: Published by the World Food Programme (WFP), IFPRI, the New York University Center on International Cooperation, the Grantham Institute at Imperial College London, and the Walker Institute, University of Reading (United Kingdom).

16. Worldwatch Institute. 2011. State of the World: Innovations that Nourish the Planet. New York, NY, USA: W.W. Norton & Company.

- Process / method: Review of literature and desktop analysis. Site visits with farmers in 25 African countries.
- Geographic coverage: Global
- Contributing organizations: The Worldwatch Institute (Washington, D.C.). Project Directors: Danielle Nierenberg and Brian Halweil, Editor: Linda Starke.

Topics	Evidence
What are the major components and drivers of the current food system and what will this system look like in the future?	
Food price volatility and trade	Risks: Assistance/food aid can protect productive assets, foster investment and intensification through its insurance effect, and stimulate agricultural value chain development; but can contribute to price fluctuations, disincentives to agricultural production and market development, and a cycle of dependency. [11] IAASTD projections of the global food system indicate a tightening of world food markets, with increasing market concentration in a few hands and rapid growth of global retail chains in all developing countries, natural and physical resource scarcity, and adverse implications for food security. Real world prices of most cereals and meats are projected to increase in the coming decades, dramatically reversing past trends. Millions of small-scale producers and landless labor in developing countries and underdeveloped markets already weakened by changes in global and regional trade, with poor market infrastructure, inadequate bargaining capacity, and lack of skills to comply with new market demands, will face reduced access to food and livelihoods. [3] Unlike much of the 20th century, when real agricultural prices declined, our analysis suggests that real agricultural prices will likely increase between now and 2050, the result of growing incomes and population as well as the negative productivity effects of climate change. The likely price increase ranges from 31.2% for rice (in the optimistic scenario) to 100.7% for maize (in the baseline scenario). [4] Rising prices signal the existence of imbalances in supply and demand and growing resource scarcity, driven by demand factors such as growing population and income or by supply factors such as reduced productivity due to climate change. [4] Feeding a global population of just over 9 billion in 2050 will require a 70% increase in global food production. [6] High levels of volatility in global food markets are an issue because of the adverse effects they have on consumers and producers, because of the disruption they cause to the global food system, and, when particularly severe, because of the general economic and political instability that can occur. [1] The long downward trend in world market prices of such traditional exports as coffee and cotton threatens the livelihoods of millions of producers (p. 12). [13] Opportunities: World prices are a useful indicator of the future of agriculture. [4] Governments and regional systems of support (such as the EU) have a clear role in improving education and awareness of the options available to improve risk management. [1] In sub-Saharan Africa, reducing transaction costs and risks in food staples markets can promote faster growth and benefit the poor. Beyond investments in infrastructure, promising innovations include commodity exchanges, market information systems based on rural radio and short messaging systems, warehouse receipts, and market-based risk management tools (p. 12). [13]

Topics	Evidence
	Evidence: Agricultural commodities the world over are currently facing a secular decline in prices accompanied by wide fluctuations. [3] The price spikes of 2008 and 2010 both had important weather components. Agricultural trade flows depend on the interaction between comparative advantage in agriculture (as determined by climate and resource endowments) and a wide-ranging set of local, regional, national, and international trade policies. [4] From 1961 to 2003, world food trade increased from 1500 Gkcal/day to >7000 Gkcal/day. OECD and Latin America are net exporters of food calories. Asia is balanced between imports and exports. Middle East-North Africa is a major net importing region. [5] From 2006 to 2008, international food prices doubled; about 100 million poor rural and urban people were pushed into the ranks of the world's hungry. Much of the production response to higher prices has come from rich countries. [6] The effects of high volatility in food prices are most severe for low-income countries and the poor, and spikes in food price can be a major cause of increased hunger. [1] 73-105M more people became poor between 2005 and 2007 as a result of increases in food prices (World Bank, 2008). [15] Food prices worldwide are under strong upward pressure, driven by rapidly rising demand for meat in Asia, for wheat in Africa, for biofuels in Europe and North America, and other factors. [16] Recommendations: Robust international trade in agricultural products to offset locally severe effects of increased occurrences of extreme weather events in different parts of the world. [4] Protection of the most vulnerable groups from the worst effects of food price volatility should be a priority, especially those in low-income countries where market and insurance institutions are weak. This can be done indirectly through intervention to try to influence market prices, but is likely to be more effective through the provision of safety nets for poor consumers or producers that are designed to stabilize real incomes. Special measures for the most vulnerable countries include: Targeted food reserves for vulnerable (typically low-income) countries should be considered. There is a strong case for establishing an emergency food reserve and financing facility for the WFP to help low-income countries facing sudden increases in food import bills when price spikes occur. Poorest food producers need specific assistance to obtain insurance against risk and volatility. Safety nets will be required at times of unusually high food prices. [1] Gaps: What levels of volatility are considered 'acceptable', and should governments intervene to attempt to control volatility within defined bounds? How can the negative consequences of volatility be mitigated, and which interventions would be most effective? Is it better to develop mechanisms to protect producers or consumers from the effects of volatility and, if so, how? To what extent should collective action and planning at the international level (for example the G20) occur to protect the poorest from the worst effects of volatility? [1]

Topics	Evidence
	Case studies:
Domestic consumption vs. exports	Risks: Many export markets tend to exclude small-scale suppliers, a process that has intensified with the imposition of higher product and process standards by northern retailers. [6] Demand for food by rich countries will divert supplies away from poorer nations and international markets alone will not equitably and sustainably address global food insecurity. [9] In too many countries the rural poor simply cannot afford the price of food grown at home, particularly when those prices are driven up by the effects of food aid, dumping, and financial speculation (p. 173). [16] Opportunities: Domestic production combined with international trade flows determine domestic food availability; per capita income and domestic prices determine the ability of consumers to pay for that food. [4] In most developing countries, demand for agricultural products, particularly high-value ones, is increasing rapidly with increasing demand driven by the growing numbers and increased incomes of consumers in urban areas. [6] Evidence: By 2050: projections indicate substantial decline in net maize exports, principally because of negative climate impacts on U.S. maize production. Developed country wheat exports decline in all scenarios. Low-income developing countries remain large net importers of maize and wheat, but shift from net exporters to net importers of rice. [4] Exports of horticulture, livestock, fish, cut flowers, and organic products now make up 47% of all developing-country exports, far more than the 21% for traditional tropical products such as coffee, tea, and cotton (p. 60). [13] Recommendations: Align environmental and market incentives. Progress on achieving desirable environmental goals will be most easily achieved when they are congruent with market incentives. Include the environment in food system economics. [1] Gaps: Case studies: Scenarios project surplus food calories produced by OECD, Latin America, and former Soviet Union, and exported to Asia, Middle East-North Africa, and sub-Saharan Africa. [5]
Food availability and nutrition	Risks: Growing vulnerability of smallholder farmers (due to climate change, land grabbing, and demography). [5] In 2050 as it is today, the main challenge behind hunger reduction won't be a question of lack of production, but will remain

Topics	Evidence
	a problem of access to food by the poorest populations (p. 238). [5] Large proportions of people are poor only at specific points in time. Factors: (1) households: ill health, poor harvests, social expenses, conflict and disasters, education, physical assets; (2) other: economic growth and local availability of opportunities, markets, infrastructure and enabling institutions (tend to be unequally distributed within each country). [6] Food security is not achieved under any of the MA scenarios by 2050, and child malnutrition is not eradicated (and is projected to increase in some regions in some MA scenarios) despite increasing food supply and more diversified diets (medium certainty). [7] Combination of factors related to food supply systems (inadequate investments in food production and its supporting infrastructure resulting in low productivity increases, varying trade regimes) and food demand and accessibility (continuing poverty in combination with high population growth rates, lack of food infrastructure investments). [7] Lack of dietary diversity and poor diet quality lead to micronutrient malnutrition or hidden hunger even when energy intakes are sufficient. [13] Opportunities: Agro-ecology practices are affordable for small holders and they can contribute to anti-poverty strategies (p. 22, 78, 176-180) [5] Agriculture can be the primary means to generate income for the poor, securing their access to food. And through new and improved crop varieties, it can improve diet quality and diversity and foster the link between food security and nutrition security (p. 95). [13] Evidence: The highest incidence of undernourishment is in sub-Saharan Africa, where one in every three persons suffers from chronic hunger. The greatest number of undernourished is in South Asia (299 million), closely followed by East Asia (225 million) (p. 94). [13] Demand for cereals will increase by 70% by 2050, and will double in many low-income countries (FAO, 2006) -- larger populations and higher per capita consumption among communities with growing incomes, particularly in Asia. Supply-side drivers include efficiency gains associated with vertical integration in industrial food supply chains (Reardon et al., 2004). [11] Despite increased global food production over recent decades, under-nutrition is still a major global public health problem, causing over 15% of the global disease burden. Protein energy and micronutrient malnutrition remain challenges, with high variability between and within countries. Reduced dietary quality and diversity and inexpensive foods with low nutrient density have been associated with increasing rates of worldwide obesity and chronic disease. Poor diet throughout the life course is a major risk factor for chronic diseases, which are the leading cause of global deaths. [3] In 2003, global average daily consumption was ~3000 kcal/person. In OECD countries: ~4000 kcal/person, 30% from animal products, 125 g of protein/person. In Sub-Saharan Africa: 2500 kcal/person, <6% from animal products, 60 g of protein/person. [5]

Topics	Evidence
	In developing countries, 3.1 billion people (55% of total population) live in rural areas. From 2020 to 2025, the total rural population will peak and then start to decline, and the developing world's urban population will overtake its rural population. [6] Nutrient density of 43 garden crops (mostly vegetables) has been shown to have declined between 1950 and 1999 in the US, suggesting possible tradeoffs between yield and nutrient content. [8] At least 800M people worldwide depend on urban agriculture for most of their food needs (mostly Asia, but increasingly Africa). [16] <u>Recommendations</u>: Establish food safety nets. Improve food safety and quality. Development of food stock management, effective market intelligence and early warning, monitoring, and distribution systems. [3] Enhancing public health and veterinary capacity, and legislative frameworks, for identification and control of biological and non-biological hazards; Vertical integration of the food chain to reduce the risks of contamination and alteration; Supporting the capacity of developing country governments, municipalities, and civil society organizations to develop systems for monitoring and controlling health risks along the entire food chain. One example is a battery of tests that municipalities could use to monitor pesticide residues on fruits and vegetables that are brought to market. [3] Conventional solutions to food insecurity: higher-yielding seed varieties, dams to irrigate vast areas, and mountains of fertilizer to rejuvenate depleted soils. [16] <u>Gaps</u>: How to secure the environment for international trade to make up for domestic deficits and allow for overall increases in food production? [5] <u>Case studies</u>:
Eating habits	<u>Risks</u>: Access component is of critical importance, especially in relation to dietary diversity and nutrition. [11] Policies and programs to increase dietary diversity through development and deployment of existing and new technologies for production, processing, preservation, and distribution of food. [3] A major driver of food system's pressure on natural resources (p. 168; p. 234). Rapid increase of food consumption and the animal share in diets along with economic growth in emerging countries (p. 89-91). [5] Changing behaviors in diets is difficult but not impossible. [1] <u>Opportunities</u>: The balance between supply and demand can be influenced by measures aimed at influencing demand – changing people's diets. Different levers identified include: economic interventions, including taxing non-preferred food types; 'choice editing',

Topics	Evidence
	regulatory or voluntary actions, including purchasing guidelines by retailers and the food service sector to restrict choices by consumers or selectively enhance access to better foods; campaigns to change individual behavior involving public education, advertising, targeted programs in schools and workplaces, and the provision of better labeling to enable public to make informed decisions. [1] <u>Evidence</u>: Guiding principles for efforts to influence demand: better decisions are made by an informed consumer; simple, consistent and trusted information on food; and Government fiscal and regulatory intervention ideally requires societal consensus [1]. The informed consumer can effect change in the food system by choosing to purchase items that promote sustainability, equitability, or other desirable goals. Clear labeling and information is essential for this to happen. [1] Demand for food will also increase as more of the world's consumers switch to diets that are richer in meat, dairy products, and processed foods, all of which are substantially more resource-intensive (Von Braun, 2007). The World Bank estimates that demand for food will rise by 50% by 2030, even before the effects of biofuels are factored in (World Bank, 2008). [15] <u>Recommendations</u>: Focus on consumers and the importance of dietary quality as main drivers of production, and not merely on quantity or price. Strategies include fiscal policies (taxation, trade regimes) for health-promoting foods and regulation of food product formulation, labeling, and commercial information. [3] Influencing demand requires concerted and committed actions, possibly over long timescales [1]. Governments are likely to need to consider the full range of options to change consumptions patterns including raising citizen awareness, approaches based on behavioral psychology, voluntary agreements with the private sector, and regulatory and fiscal measures. Building a societal consensus for action will be key to modifying demand. [1] Empower citizens - Investment is needed in the tools to help citizens hold all other actors (and themselves) to account for their efforts to improve the global food system. Examples include the better provision and publication of information on the commitments of different groups, the extent to which they have acted on their commitments, and through information on a food system 'dashboard' a measure of their effectiveness. [1] <u>Gaps</u>: What are the levers of change in eating habits, including wastage? (p. 219-221) [5] <u>Case studies</u>: Most of the world's hungry are in South Asia and sub-Saharan Africa. These regions have large rural populations, widespread poverty and extensive areas of low agricultural productivity due to steadily degrading resource bases, weak markets, and high climatic risks. Farmers and landless laborers dependent on rainfed agriculture are particularly vulnerable due to high seasonal variability in rainfall, and endemic poverty forcing them to avoid risks. [11] Asia: rapid nutritional transition. [1]

Topics	Evidence
	UK Sustainable Development Commission identified guidelines for effecting changes to diets that will contribute the most to sustainability. [1] Oxfam's '4-a-week' report highlights need for a change in consumption in UK to mitigate against climate change and reduce global hunger. [1]
Food security (availability, access, nutrition)	Risks: Natural resources are not distributed in the same way as the human population (e.g. limited production potential in Middle East-North Africa (MENA), p. 172) and Asia (p. 184-185)). [5] Increase in global population suffering from hunger and 'hidden hunger' of not having enough vitamins and minerals. Increases in food production alone will not solve problems of poverty or hunger. [9] The international community is off track to meet the Millennium Development Goal (MDG) 1 commitment to halve the proportion of people who are 'undernourished' from 16% in 1990 to 8% in 2015. China achieved this goal in the early 2000s, but many countries in Africa and South Asia are unlikely to meet this target with the current global figure of 13.5%. [1] It is important not to view social protection policies uncritically - social protection competes with agriculture for political support, especially in government budgets. They are seen as simpler and more amenable to demonstrating impact, but typically only support the poorest 10% of the population, and politically difficult to sustain and can be divisive at the local level. Governments need improved data on hunger. [1] Difficulties in measuring hunger, under-nutrition and food security contribute to a shortfall in evidence and data available to inform policies. [1] Agriculture needs to be repositioned within governments as a profession dedicated to multiple ends, of which hunger and poverty reduction are central. [1] The data on undernourishment from FAO probably provide a very inaccurate picture of the true level and pattern of hunger. [1] During the 2008 price crisis, countries lacking productive capacity were too dependent on the global food market and lacked the proper controls to curb speculation and price volatility, leading to the huge spike in the number of hungry people (p. 180). [16] Opportunities: Calorie availability is an important component in our metric of human well-being – the number of malnourished children under the age of five. [4] In countries where hunger is most chronic agriculture can make a major contribution to its eradication. There is a new wave of donor interest in food and agriculture, and climate change has alerted many to the critical moderating or exacerbating role that terrestrial and aquatic food production can play, depending on policy choices. New thinking on options for technology and policy, creating space for more innovation and a tolerance for more unorthodox approaches. Growing commitments in many countries to give agriculture a higher priority. A new generation of flexible, adaptable, democratic, mobile technologies offers much potential in terms of monitoring, innovating, and responding to hunger. [1]

Topics	Evidence
	Smallholder farming, long neglected, is not a single solution, but an important component of both hunger and poverty reduction. [1] Women play a critical role in agriculture, and agriculture plays a critical role in women's livelihoods. [1] In the poorest countries, agriculture provides not only food for households, but also income generation. [1] Food production, whether from terrestrial or aquatic sources, has a powerful potential triple role in ending hunger: 1) Production is essential for physical access to food. Technologies, institutions, infrastructure, and information that support increases in productivity of agriculture that are sustainable (i.e. involve manageable amounts of risk for farmers and do not degrade environment) and equitable (i.e. desirable, available, and practical for poorest farmers to adopt) can increase supply of a diverse and locally desirable food, at affordable prices. 2) These technologies, institutions, infrastructure, and information sources can improve economic access by raising farm income, generating employment on and off farm, and reducing food prices. 3) Production can address issues of social access by deliberately empowering women and other socially excluded groups. [1] <u>Evidence:</u> Number of people suffering from chronic hunger has increased from under 800M in 1996 to over 1B in 2009 (FAO, 2009a). [11] Hunger intersects with food insecurity and under-nutrition in complex ways. Need broad view of nature and causes of hunger and its many impacts, including severe and long-lasting nature of effects hunger and under-nutrition, particularly in children. [1] 1% gain in Gross Domestic Product (GDP) originating in agriculture generates a 6% increase in overall expenditure of poorest 10% of populations, while equivalent figure for GDP growth originating in non-agricultural sectors is zero-growth. [13] For people to be free of hunger, three conditions need to be filled: 1) Physical access to food: it has to be hunted or foraged, or for most part, produced and available in fields, ponds and markets. This requires right mix of technologies, infrastructure, institutions, and incentives. 2) Economic access to food: a healthy diet has to be affordable. Well established in literature that food intake responds positively to income growth. 3) Social access, which manifests itself in many ways. Often exclusion of women from production, purchasing, and consumption decisions which aggravates hunger. [1] Although global food production is more than sufficient to feed 6.7 billion people, 1 billion are undernourished while 1 billion are overweight or obese (Alexandratos, 1995; FAO, 2009; World Health Organization [WHO], 2003). [15] <u>Recommendations</u>: Need stronger constituency for hunger reduction. International community must challenge ease with which hunger is ignored. [1] Agricultural development must be designed and incentivized with hunger reduction as a primary goal. [1] Monitor more appropriate outcomes - FAO and World Bank should develop a new set of hunger outcomes. [1] Monitor outcomes better and promote greater awareness of hunger - Governments need hunger data within year to adjust and respond. Monitor commitments and inputs: Index to measure commitments and spend on hunger reduction could

Topics	Evidence
	create government incentives to compete in achieving significant improvements. Enable greater strategic prioritization and sequencing of hunger reduction actions to address hunger and under-nutrition, recognizing interaction of factors, and avoiding laundry lists of actions. Support emergence of anti-hunger leaders committed to hunger maps, commitment indices and diagnostics. [1] Mobilize mechanisms for systems accountability in hunger reduction. [1] Social protections for food insecurity: Cash and in-kind transfers (e.g., Kenya's Hunger Safety Net Programme – by moving away from emergency relief responses towards predictable, guaranteed and sustained resource transfer; Ethiopia's Productive Safety Net Programme – transfers cash and food during seasonal food insecurity through employment in public works); Employment guarantee schemes (e.g., India's National Rural Employment Guarantee Act); Mother-and-child health & nutrition and school feeding programs; Weather-indexed crop insurance; Micro-finance services; Social pensions – non-contributory cash transfers independent of a record of contributions). [15] "Objective, sober analysis of the roots of food insecurity." [16] Gaps: What is the relationship among food supply, access, distribution, hunger, and national food self-sufficiency? [16] Case studies: National policy approaches from India [1]. Brazil's experience of the past 10 years shows that if the political will is present, poverty and hunger can be substantially reduced. [1] At local level there are many mechanisms for social accountability that have proved to be effective in improving service delivery and improving the agency of the poorest. At national level, articulation of a 'right to food' may strengthen the capacity of civil society to make claims and the capacity of the state to deliver. At a global level, the UN is leading a worldwide effort to build enforceable international law recognizing the 'right to food' and has created the role of a Special Rapporteur to promote the full realization of the right to food. [1]
Links to health and sanitation	Risks: Health concerns: presence of pesticide residues, heavy metals, hormones, antibiotics and various additives in the food system as well as those related to large-scale livestock farming. The incidence and geographic range of many emerging and reemerging infectious diseases are influenced by the intensification of crop and livestock systems. [3] Globalization of the food supply, accompanied by concentration of food distribution and processing companies, and growing consumer awareness increase the need for effective, coordinated, and proactive national food safety systems. Health concerns that could be addressed by agricultural knowledge, science and technology (AKST) include the presence of pesticide residues, heavy metals, hormones, antibiotics, and various additives in the food system as well as those related to large-scale livestock farming. [3]

Topics	Evidence
	Increase in the economic and social costs of unbalanced diets (p. 88-89, 204, 209, 214-221). [5] Cultivated systems provide only 16% of global runoff; although their close proximity to humans means that about 5B people depend for all or some of their water on supplies from cultivated systems. Such proximity is associated with nutrient and industrial water pollution. [7] In sub-Saharan Africa, poor health reduces agricultural productivity, and some agricultural practices contribute to health problems such as malaria, pesticide poisoning, and zoonotic diseases (p. 84). [13] In crowded cities, food security is weakened by the lack of clean, nutrient-rich soil as well as growing space available for local families. [16] Opportunities: Increasing the diversification of small-scale production and improve micronutrient intake; Increasing the efficiency and diversity of urban agriculture; Developing and deploying existing and new technologies for the production, processing, preservation, and distribution of food. [3] Relative to the baseline outcome in 2050, a 40% increment in productivity growth would reduce the number of malnourished children by an additional 37%. [4] Promising innovations include bio-fortification of staple food crops with micronutrients and the health conditionalities embedded in cash transfer. [1] Evidence: Nelson et al. (2009) used economic modeling to predict that prices of most cereals will rise significantly due to climatic changes leading to a fall in consumption and hence decreased calorie availability and increased child malnutrition. At the same time, there are reports indicating that the nutritional value of food, especially cereals, may also be affected by climate change (Ziska et al., 1997; Hesman 2002; Nagarajan et al. 2010). Climate change will also affect the ability of individuals to use food effectively by altering the conditions for food safety and changing the disease pressure from vector, water, and food-borne diseases. [11] The incidence and geographic range of many emerging and reemerging infectious diseases are influenced by the intensification of crop and livestock systems. Serious socioeconomic impacts can arise when diseases spread widely within human or animal populations, or when they spill over from animal reservoirs to human hosts. [3] Climate change increases the number of malnourished children in 2050 by 9-10%. [4] 1B people lack clean drinking water; 1.6B, electricity; and 3B, adequate sanitation. A quarter of all developing-country children are malnourished. [14] Recommendations: Increasing food safety can be facilitated by effective, coordinated, and proactive national and international food safety systems to ensure animal, plant, and human health, such as investments in adequate infrastructure, public health and veterinary capacity, legislative frameworks for identification and control of biological and chemical hazards, and farmer-

Topics	Evidence
	scientist partnerships for the identification, monitoring, and evaluation of risks. [3] Reduce *infectious* disease: strengthen coordination / capacity of agricultural, veterinary, and public health systems. Integrate multi-sectoral policies and programs across the food chain to reduce the spread of infectious diseases. Identify, monitor, control, and treat diseases. Reduce *chronic* disease: policies that explicitly recognize the importance of improving human health and nutrition, including regulation of food product formulation through legislation, international agreements and regulations for food labeling and health claims, and creation of incentives for the production and consumption of health-promoting foods. [3] Strengthened food safety measures in both domestic and export markets; can impose significant costs (monitoring and inspection) and costs associated with market rejection of contaminated commodities; some countries may need help. [3] Under-nutrition needs to be tackled by direct and indirect interventions. Include both direct nutrition interventions and nutrition-sensitive interventions. [1] Gaps: Case studies:
Food supply chains	Risks: Asymmetric development, unsustainable natural resource use, and continued rural and urban poverty. Global environmental and development crisis; consequences of these global changes have the most devastating impacts on the poorest, who historically have had limited entitlements and opportunities for growth. [3] The current global system pits small-scale, largely subsistence farmers in rainfed agricultures against farmers who during the past century have been assisted to increasingly capture economies of scale by specialization and externalizing social and environmental costs. [3] Context of (1) current social and economic inequities and political uncertainties about war and conflicts; (2) uncertainties about the ability to sustainably produce and access sufficient food; (3) uncertainties about the future of world food prices; (4) changes in the economics of fossil-based energy use; (5) the emergence of new competitors for natural resources; (6) increasing chronic diseases that are partially a consequence of poor nutrition and poor food quality as well as food safety; and (7) changing environmental conditions and the growing awareness of human responsibility for the maintenance of global ecosystem services (provisioning, regulating, cultural, and supporting). [3] Rural exodus triggered by increasing productivity per agricultural worker (e.g., due to motorization). [5] In the US, midsized commercial family farms that are important to rural community social and economic life are declining in number and importance. These trends can be partly attributed to technical innovations, economies of scale, and the increasing consolidation of food processing, distribution, and retailing sectors. [8] Growth rates of yields for major cereals are slowing in developing countries (p. 67). [13] In many developing countries, the long supply chain, poor access to roads and electricity, and inadequate infrastructure and services in physical markets add to the transaction costs and cause quality deterioration and high spoilage losses (p. 126).

Topics	Evidence
	[13] Opportunities: Relative economic and environmental vulnerability, differential state support, agribusiness systems, and market regulations determine the interconnectedness of the economic, social, and environmental functions of agriculture. [3] Value chains: means of creating demand for labor and services from other rural people. [6] Evidence: Gross global food production in 2003: ~33,200 Gkcal/day (multiplied by 2.5 since 1961). From 1961 to 2003, food calories produce per hectare increased by a factor of 2.2 (resulting from greater use of inputs); sevenfold increase in food production per agricultural worker. [5] Recommendations: Reduce risk and transaction costs along value chains. [6] Operational efficiency of processing, packaging, storage and transport. Transparent value-chain with better linkages of farmers to markets. Better informed consumers re: consumption patterns (e.g., certification schemes). [10] Market supply chains and infrastructure must adapt to more diversified production systems. [16] Gaps: How do we support the necessary tradeoffs among increasing the productivity of food and animal feed to meet changing food habits, and enabling fiber and fuel wood production, while satisfying increasing current and emerging energy demands, as well as environmental and cultural services by agro-ecosystems? [3] Case studies: In 1980s, Asia became leading producer of food of plant origin. OECD remains leading producer of food of animal origin. [5] Australia: ongoing development of national food plan along the whole supply chain, including domestic and international food security strategies. [10] Public-private partnerships are linking sustainable food supply chain initiatives with watershed and biodiversity management (e.g., Mars Corporation is promoting agro-ecological and agroforestry practices for sustainable cocoa production, as well as genetic improvement and biological corridors to sustain tropical forest biodiversity; Nestle is helping smallholder producers in Africa, India, and other developing countries manage local water resources and reduce GHG emissions. [16]
Energy / water / nutrient use	Risks: Unsustainable biomass-based smallholder energy sources. [2] Agriculture accounts for an estimated 69% of human water use. Current irrigation systems are frequently highly wasteful, with efficiency rates of only 25–40% in many countries (Postel and Vickers, 2004). [15]

Topics	Evidence
	Fossil fuel dependence. [16] Emerging economies are now investing heavily in the kind of cold storage supply chains used in the West, despite the high energy requirements. [16] <u>Opportunities</u>: Bioelectricity and bioheat are usually more efficient and produce less GHG emissions than liquid biofuels and fossil fuels (e.g., digesters, gasifiers, and direct combustion devices can be successfully employed in certain settings such as off-grid areas). [3] The world's irrigated area is concentrated in South and East Asia. In East Asia, increased precipitation from climate change (in most scenarios), along with changing consumer preferences away from rice, reduce the need for irrigated area between 2010 and 2050: any irrigation efficiency improvements have relatively small effects on food production (although critical for freeing up water for industrial and urban use). In South Asia, however, the benefits of more efficient irrigation are substantial. [4] <u>Evidence</u>: Water withdrawals from rivers and lakes doubled since 1960; most water use (70% worldwide) is for agriculture. [7] Since 1960, flows of reactive (biologically available) nitrogen in terrestrial ecosystems have doubled, and flows of phosphorus have tripled. More than half of all the synthetic nitrogen fertilizer, which was first manufactured in 1913, ever used on the planet, has been used since 1985. [7] Many of the regions facing the greatest challenges in achieving the MDGs coincide with those facing significant problems of ecosystem degradation. [7] Average per capita water use, which rose from 350 m^3 per person in 1900 to 642 m^3 in 2000 (Clarke and King, 2004). Total annual global water withdrawal grew from 579 km^3 in 1900 to 3,973 km^3 in 2000; it is projected to rise to 5,235 km^3 by 2025. Depletion of groundwater sources in many parts of the world (e.g., most states in India, northern China (Brown, 2005)) are threatening water availability – and hence food supplies – in countries that are home to 3.2 billion people (Brown, 2005). [15] More than half the people in the world burn wood and other biomass – including charcoal, agricultural waste, and animal dung – for cooking, boiling water, lighting, and heating. [16] <u>Recommendations</u>: Cost-effective monitoring of trends in the utilization of natural resource capital. [3] Desalinization of sea water, reuse of urban waste water for agricultural irrigation, water-saving policies (e.g., precision irrigation, improved water conveyance), rate innovations, watershed management units, virtual water trading. [5] Use solar heat to dry locally grown fruits (e.g., innovative project in West Africa on dried mangoes using a greenhouse solar dryer). [16] Fermentation is another low-input, locally appropriate preservation method (e.g., kefir in Africa). [16] <u>Gaps</u>:

Topics	Evidence
	What are underlying causes of declining productivity embedded in natural resource mismanagement? [3] Case studies:
Access to land / resources	Risks: The control of increasing areas of land for food production (such as in Africa) will be influenced by both past and future land-purchase and leasing agreements – involving both sovereign wealth funds and business. [1] While some forms of biofuels can play an important role in the mitigation of climate change, they may lead to a reduction in land available for agriculture. [1] In sub-Saharan Africa, as land gets divided through inheritance in a growing population, farm sizes become smaller (p85). [13] Those lacking land or livestock may be driven into low-value nonfarm employment (p79). [13] Small farmers' access to land in many parts of Africa and Asia is often obstructed by insecure property rights and illegal land seizures; high birth rates lead to smaller average farm sizes as holdings are divided through inheritance (World Bank, 2008a). [15] Opportunities: Access to land will be affected by changes in sea level and river flows, with new land at high latitudes becoming suitable for cultivation and some degree of increased carbon dioxide (CO_2) fertilization likely to take place (due to elevated atmospheric CO_2concentrations). [1] Evidence: Overall, relatively little new land has been brought into agriculture in recent decades. Although global crop yields grew by 115% between 1967 and 2007, the area of land in agriculture increased by only 8% and the total currently stands at approximately 4,600 million hectares. While substantial additional land could in principle be suitable for food production, in practice land will come under growing pressure for other uses. For example, land will be lost to urbanization, desertification, salinisation, and sea level rise, although some options may arise for salt-tolerant crops or aquaculture. Also, while it has been estimated that the quality of around 16% of total land area including cropland, rangeland and forests is improving, the International Soil Reference and Information Centre has estimated (2009) that of the 11.5 billion hectares of vegetated land on earth, about 24% has undergone human-induced soil degradation, in particular through erosion. In addition, with an expanding population, there will be more pressure for land to be used for other purposes. [1] Recommendations: More efficient use of increasingly scarce land, water, and biological resources requires investment in research and development of legal and management capabilities. [3] Strengthening rights to land and natural resources, such as water, fisheries, and forests should be a high priority [1].

Topics	Evidence
	Uncertainty in such rights is a major disincentive to investment in food production in many low-income countries. They should be strengthened at the levels of individual local producers and communities, and should build upon customary rights. [1] Need for eradication of gender-based discrimination (such as land ownership and user rights) and steps to actively promote women's status (such as quotas for representation in agricultural decision-making bodies). [1] Gaps: Because small-scale farming is labor intensive, a critical question is whether densely populated Asian countries can efficiently produce cereals and other food staples on farms of current size, especially if rural wages rise (p. 236). [13] Case studies: Developments in China and Ethiopia provide examples of the effectiveness of measures to strengthen rights to land and natural resources. [1] Most poor farmers in sub-Saharan Africa face scarcities not only of water but of land, labor, and capital as well. [16] AVRDC – The World Vegetable in Taiwan works to identify varieties and strategies that minimize waste. [16]
Food waste/loss and storage	Risks: Post-harvest loss. [2] Investment and ongoing costs. New science and knowledge are likely to be needed merely to maintain, let alone increase yields, for example, in the face of new pests and diseases. [1] Food goes to waste because the link from farmer to market is slow, inefficient, or broken. [16] Negligence" with food: throwing away cosmetically "imperfect" produce on farms, discarding edible fish at sea, disposing of bread crusts in sandwich factories, over-ordering stock for supermarkets, and purchasing or cooking too much in the home. [16] In poorer nations, 25-50% of the harvest spoils or is contaminated by pests or mold. [16] Opportunities: Reduction of consumer waste in rich countries (currently 20 to 30% of food consumption) (p. 88, 216-217). [5] Large potential for reducing waste in food supply chains (regional variability) [1]. Facilities to dry and store crops and feeds. Investment in new, appropriate technology to reduce post-harvest waste. An example would be the use of modern scientific advances to produce crops that are less susceptible to pests and spoilage, or better fish-smoking kilns that reduce losses and demand less fuel. [1] Measures to prevent food from spoiling before it reaches the market developed over decades with the backing of governments, academic institutions, and large companies: refrigerated storage, pasteurization and preservation facilities, drying equipment, climate-controlled storage units, transport infrastructure, chemicals that inhibit sprouting, plant breeds designed to extend shelf life, and professional know-how. [16]

Topics	Evidence
	Beyond high-tech solutions: grain stores, drying equipment, fruit crates, refrigeration, and other essentials of post-harvest technology, traditional varieties adapted to local environments (e.g., lower moisture content in ripe grain and thicker husks that are resistant to rodents, insects, and molds). [16] Evidence: Climatic fluctuations are known to affect post-harvest losses and food safety during storage, for example by causing changes in populations of aflatoxin- producing fungi (Cotty and Jaime-Garcia, 2007). It is anticipated that more frequent extreme weather events under climate change will damage infrastructure, with detrimental impacts on food storage and distribution, to which the poor will be most vulnerable (Costello et al., 2009). [11] It has been estimated that as much as 30% of all food grown worldwide may be lost or wasted before and after it reaches the consumer. Some estimates have placed it as high as 50%. Addressing waste across the entire food chain will be critical in any strategy to feed around eight billion people sustainably and equitably by 2030, and nine billion by 2050. [1] Halving the total amount of food waste by 2050 is a realistic target. If the current global figure of 30% waste is assumed, this could reduce the food required by 2050 by an amount approximately equal to 25% of today's production. [1] In India it is estimated that fruit and vegetable post-harvest losses amount to about 40% of total annual production, equal to a year's consumption in the United Kingdom. (p. 126). [13] Under optimal weather conditions in rich countries today, staple grain crops such as wheat can be harvested with losses as low as 0.07%. [16] Recommendations: Waste in all areas of the food system must be minimized. [1] Making waste reduction a strategic target would benefit strongly from high-level international political support and being championed by an international body. [1] Reducing post-harvest waste, in low-income countries - Deployment of existing knowledge and technology (storage and transport infrastructure), investment in new technology, infrastructure, financial and market reforms. [1] Reducing consumer and food service sector waste, in high-income countries - campaigns (on the extent of waste and the financial benefits of waste reduction), development and use of cheap sensor technology to detect spoilage in perishable foods, better and appropriate packaging to extend shelf and storage life, recycling of surplus food (e.g. Fareshare schemes or as animal feed), spreading best practice. [1] Gaps: Case studies: Improved post-harvest storage (West Africa). Warehouse / receipting programs in African (e.g. WFP, USAID). [16]

Topics	Evidence
Retail and consumption	Risks: Evidence from the health sector shows that changing diets is difficult but not impossible. Constraints on modifying consumption include resistance from consumers, resistance from business and producers, and commercial interests undermining public good campaigns. [1] Opportunities: Creating simple, consistent and trusted information is critical to modify demand and 'traffic lights' systems have been most successful. [1] Government fiscal and regulatory intervention ideally requires societal consensus. (Tobacco provides several lessons.) Making the food chain more efficient will reduce pressure on resources required for food production, lower GHG emissions, and cut the need for further space set aside for landfill, which would reduce GHG emissions. [1] Evidence: In 2003, >70% of available plant food in sub-Saharan Africa and Asia was used by humans, compared with 35% in OECD. Share of plant calories used for non-food purposes is increasing in most regions. [5] Informed consumers can effect change in the food system by choosing to purchase items that promote sustainability, equitability or other desirable goals. [1] A number of different levers have been identified to achieve dietary change, including economic interventions, regulatory, or voluntary actions to restrict choices, public education, advertising, targeted programs in schools and workplaces, and provision of better labeling. [1] Recommendations: Dietary change benefits public health and environmental sustainability. Advocating the consumption of foods that use fewer resources (land, water, fertilizer, and other inputs) increases sustainability and reduces GHG emissions. [1] Governments need to consider a range of options to change consumption patterns including raising citizen awareness, improving food-literacy, promoting better diets and social marketing campaigns, creating simple, consistent and trusted information, voluntary agreements with the private sector, and building a societal consensus. [1] Demand for Meat – Policy-makers should recognize that more proactive measures affecting the demand and production of meat may be needed in the future. The triggers for further actions include a rising global demand for livestock products, creating higher food prices; failure to reduce increases in GHGs to avoid the risk of substantial climate change; and continuing deforestation to provide feed for livestock. [1] Gaps: Case studies:
Producer risk / incentives	Risks: Agriculture currently engages 2.6 billion people. The majority of the world's poor and hungry live in rural settings and are

Topics	Evidence
	directly or indirectly dependent on agriculture for their livelihoods. [3] Farming systems are very diverse and range between large scale capital intensive farming systems to small-scale labor intensive farming systems. Over the 20th century there was increasing farming system specialization in North America and Europe, largely due to the implementation of policies and measures aimed at expanding agricultural production (land reclamation, subsidies, price systems, border tariffs). In many regions, a high proportion of farmers are small-scale producers whose livelihood strategies include poly-cropping, tree products, and livestock as well as off-farm activities. In developing countries generally, limited rural and urban employment opportunities and the continuing dependence of cultivators on economically unviable small-scale holdings (increasing input prices; relatively stagnant agricultural output prices; cheap, subsidized imports; and limited surplus) have diminished the viability of subsistence production alone. [3] Need of poor rural people to manage the multiple risks they face constrains their ability to take up new opportunities. Increasing risks: natural resource degradation and climate change, growing insecurity of access to land, increasing pressure on common property resources and related institutions, and greater volatility of food prices. [6] The profitability of many U.S. farms, especially large grain producers, is partly determined by federal government commodity support programs. [8] <u>Opportunities</u>: Strengthen community-level organizations and assisting them to identify new mechanisms of social solidarity; promoting the expansion and deepening of a range of financial services to poor rural people; and supporting social protection programs. Corporate social responsibility agenda. Urbanization/growing integration of rural and urban economies. Liberalization/globalization: can create new employment and service opportunities in rural areas. Improved communication and information systems (e.g., mobile phone coverage). Increasing investment in decentralized and renewable-based energy systems. [6] <u>Evidence</u>: Uncertainty imposed by climate variability is a disincentive to investment in improved agricultural technology and market opportunities, prompting the risk-averse farmer to favor precautionary strategies that buffer against climatic extremes over activities that are more profitable on average (surveyed in Barrett et al., 2007; Hansen et al., 2010). [11] The proportion of women in agricultural production and postharvest activities ranges from 20 to 70%; their involvement is increasing in many developing countries, particularly with the development of export-oriented irrigated farming, which is associated with a growing demand for female labor, including migrant workers. In general, the largest proportion of rural women worldwide continues to face deteriorating health and work conditions, limited access to education and control over natural resources, insecure employment and low income. This situation is due to a variety of factors, including the growing competition on agricultural markets, which increases the demand for flexible and cheap labor, growing pressure on and conflicts over natural resources, the diminishing support by governments for small-scale farms and the reallocation of economic resources in favor of large agro-enterprises. Other factors include increasing exposure to risks related to natural

Topics	Evidence
	disasters and environmental changes, worsening access to water, increasing occupational and health risks. [3] >80% of rural households farm to some extent, and typically it is the poorest households that rely most on farming and agricultural labor. [6] Although on-farm productivity has been increasing, the aggregate value of net farm income received by farmers has not changed dramatically over the last 40 years, primarily due to rising prices of external inputs, including cost of hybrid and genetically engineered (GE) seeds, fuel, and synthetic fertilizers. [8] Recommendations: Better management of agricultural risks associated with increasing climate variability and extreme events, for example improved climate information services and safety nets. [11] Enhancing producer livelihoods though brokered long-term contractual arrangements, through commercial out-grower schemes or farmer cooperatives. They involve commodity chains that integrate microcredit, farmer organization, input provision, quality control, storage, bulking, packaging, transport, etc. [3] Increase support for public services and investment in rural areas in order to improve women's living and working conditions; giving priority to technological development policies targeting rural and farm women's needs and recognizing their knowledge, skills and experience in the production of food and the conservation of biodiversity; and assessing the negative effects and risks of farming practices and technology, including pesticides on women's health, and taking measures to reduce use and exposure. [3] Strengthen capacity of rural people to manage risk by supporting and scaling up the strategies and tools they use for risk management and for coping, and helping them to gain skills, knowledge and assets to develop new strategies. Contracts can build trust between smallholders and agribusiness and facilitate farmers' access to input credit and other financial services. More secure land tenure and expanded markets for environmental services. [6] Higher productivity and production, lower output variability and eco-efficiency, in the face of climate risk and risks of an agro-ecological and social-economic nature. [10] Governments and regional systems of support (such as EU) have a clear role in improving reduction and awareness of the options to improve risk management, particularly through providing advice through revitalized extension services. [1] Beyond just transferring technologies to farmers: putting in place the institutional structures – especially well-functioning input and output markets, access to finance, and ways to manage risks – that farmers need to adopt the technology. [13] Gaps: How variability among individual, household, farm, and regional-level characteristics affect farmers' response to incentives and disincentives. [8] Case studies: Government of Uruguay has five main instruments (programs) in place that directly support the agriculture sector in managing climate risks. All of these instruments require public sector budgetary resources to operate. [12]

Topics	Evidence
Climate change impacts and vulnerability	Risks: Many of the trends and impacts are highly uncertain at a range of spatial and temporal scales; we need significant advances in predicting how climate variability and change will affect future food security. Paucity and unreliability of basic information related to agricultural production (weather, land-use, and crop and livestock distribution data). [11] Climate change is affecting the distribution of plants, invasive species, pests and disease vectors and the geographic range and incidence of many human, animal and plant diseases is likely to increase. [3] Climate change as a threat multiplier. [4] Climate change will be a major driver of food production (and regional food dependence) through impacts on cultivation potential and yield (see chapters 6 & 7 for regional analysis). [5] Many of the regions facing the greatest challenges in achieving the MDGs coincide with those facing significant problems of ecosystem degradation. [7] Increased yields of crop production systems have reduced the pressure to convert natural ecosystems into cropland, but intensification has increased pressure on inland water ecosystems, generally reduced biodiversity within agricultural landscapes, and it requires higher energy inputs in the form of mechanization and the production of chemical fertilizers. [7] Climate change will have differentiated effects in the countries characterized by different levels of development and which are located in different climatic zones. [10] Global warming could occur faster than expected and add to water shortages, hitting irrigated agriculture with lower yields and increasing risk in rainfed agriculture. (p. 67). [13] The major implications of climate change are largely for the distribution of agricultural production (p. 65). [13] Climate change is already compromising efforts to improve standards of living and to achieve the MDGs. [14] Critical impacts of climate change on food security include the effects in terms of calorie availability and the increase in the number of malnourished children. [15] Opportunities: Cultivation potential among regions: evolution of cultivation potential with climate change and urbanization, availability of arable lands, soil fertility, irrigation capabilities, competition between food production and biofuel production. [5] Agriculture must undergo a paradigm shift at all levels (transition to climate resilient, low emitting production systems). [10] In a globalizing world, trade can address some of the necessary adaptation to climate change, if measures are in place to ensure alternative livelihoods of those most affected (p. 65). [13] Evidence: Even a 2 °C rise in global mean temperatures by 2100, in the range of the IPCC low emissions (B1) scenario, will destabilize current farming systems (Easterling et al., 2007). [11] In mid- to high-latitude regions moderate local increases in temperature can have small beneficial impacts on crop yields; in low-latitude regions, such moderate temperature increases are likely to have negative yield effects. Some negative impacts

Topics	Evidence
	are already visible in many parts of the world; additional warming will have increasingly negative impacts in all regions. [3] For all regions, the negative productivity effects of climate change reduce food availability and human well-being. Climate change results in even higher world prices in 2050. [4] Warming of 2 °C could result in a 4-5% permanent reduction in annual income per capita in Africa and South Asia (driven by impacts in agriculture) as opposed to minimal losses in high- income countries and a global average GDP loss of about 1%. [14] Climate change is likely to affect tens to hundreds of millions of people. Africa will be most affected (semi-arid regions north/south of the equator) due to projected increases in aridity and high vulnerability (low incomes). Poorest parts of southern/south-eastern Asia are likely to see strong negative impacts on agricultural production. Food production in other regions (e.g., Central America) may also be impacted. [15] Recommendations: Higher productivity and production, lower output variability and eco-efficiency, in the face of climate risk and risks of an agro-ecological and social-economic nature. [10] GHG emissions from the global food system need to be a focus of efforts to mitigate climate change. Equally, critically important for policies on climate change mitigation to take full account of their potential impact of the global food system, in view of its vital role in human survival and wellbeing and its influence on wider issues of sustainability. [1] Gaps: Case studies: Irrigated and rainfed wheat and irrigated rice are predicted to be especially hard hit. In China, some crops may fare reasonably well because higher future temperatures are favorable in locations where current temperatures are at the low end of the optimal temperature for the crop. India and other parts of South Asia are particularly hard hit by climate change. With the CO_2 fertilization effect the drop in production is lower in all regions; rainfed maize is projected to have a small improvement in production in developed countries; rainfed wheat production increases in Latin America and the Caribbean under some models. [15]
Food production	Risks: Increased incidence of pests, diseases, and alien/invasive species. [2] In mid- to high-latitude regions moderate local increases in temperature can have small beneficial impacts on crop yields; in low-latitude regions, such moderate temperature increases are likely to have negative yield effects. Some negative impacts are already visible in many parts of the world; additional warming will have increasingly negative impacts in all regions. [3] Climate change will tend to reduce global agricultural production, increase food prices and intensify the risk of hunger and malnutrition. The number of people at risk of hunger is projected to increase by 10-20% by 2050 as a consequence of climate change. [15]

Topics	Evidence
	Opportunities: Combine climate models with crop models in order to understand and project climate impacts. [11] Food production can address issues of social access by deliberately empowering women and other socially excluded groups. [1] Evidence: Future impacts on livestock production are likely to be both direct (e.g., productivity losses due to temperature increases) and indirect (e.g., changes in availability, quality, and prices of inputs) (Thornton, 2010). Impacts of carbon fertilization (and ozone interactions) will be felt on grassland productivity and species composition and dynamics, resulting in changes in animal diets and possibly reduced nutrient availability for animals (Thornton et al., 2009). [11] By 2050: developed and developing countries, the increase for maize is 20-59%, for rice production increases are often in the single digits and in some cases negative (largest in the low-income developing countries 17–33%). [4] Effects of climate change will further exacerbate the stresses (availability of water, pests, diseases and weed competition) on crop plants, potentially leading to dramatic yield reductions. [9] Climate change will depress agricultural yields in most countries in 2050, given current agricultural practices and crop varieties (Müller et al 2009; World Bank 2008). [14] ~65% of global total increase in climate-related hunger is projected to occur in Africa. [15] Recommendations: Sustainable intensification of global agriculture requires systems that are resilient in the face of changing climates across diverse economic, social and political conditions. [9] Promote sustainable intensification. This means simultaneously raising yields, increasing efficiency with which inputs are used, and reducing the negative environmental effects of food production. It requires economic and social changes to recognize the multiple outputs required of land managers, farmers and other food producers, and a redirection of research to address a more complex set of goals than just increasing yield. [1] Need for engineering solutions in support of sustainable food production. [1]Gaps: How will agriculture adapt to climate change (in particular: vulnerability of smallholders) and what will be the evolution of cultivation potential and yields given various scenarios of climate change? [5] Given expense and environmental impact of energy production, agricultural systems will be needed that achieve the necessary levels of production with substantially lower reliance on fossil fuel. [9] Case studies: Rice in Asia: rising temperatures, especially night temperatures, have had a severe effect on yields causing losses of 10-20% of harvests in some locations. Potential adaptations: altering cropping patterns, planting dates and techniques (e.g.,

Topics	Evidence
	embankments to protect from floods), drought and submergence tolerant rice varieties, composting residues/wastes. [2] Relative to the scenario of no climate change, agricultural GDP in sub-Saharan Africa (the region with the highest impact from climate change) could contract by anywhere from 2 to 9% (p. 65). [13]
Extreme weather events / changing climate regimes	Risks: Water scarcity and the timing of water availability will increasingly constrain production. Extreme climate events (floods and droughts) are increasing and expected to amplify in frequency and severity, and there are likely to be significant consequences in all regions for food and forestry production and food insecurity. [3] Increased water flow into rivers and wetlands due to changes in rainfall patterns. Reduced water availability due to reduced rainfall. Increased run-off due to heavy rainfall. Flooding damage to agricultural land. [9] A general prediction from climate models is that the frequency and severity of extreme weather is very likely to increase as the world warms and will be one of the first manifestations of climate change. These can lead to sharp fluctuations in food production in particular regions. [1] The economic costs of extreme weather events increase as production systems use more capital, unless that capital allows the use of risk-reducing technology (p. 90). [13] For much of the tropics, especially areas of sub-Saharan Africa negatively affected by climate change, trade can only partially compensate for climate change impacts and adaptation needs (p. 65). [13] Increasing arid conditions in countries that already import a large share of their food, along with more frequent extreme events and growth in income and population, will increase the need for food imports. Global food markets are thin (relatively few countries export food crops) so small changes in either supply or demand can have big effects on prices (small countries with little market power can find it difficult to secure reliable food imports). [14] Opportunities: Evidence: Climate change will impact the delivery and effectiveness of irrigation (Kundzewicz et al., 2007). The predicted increase in precipitation variability, coupled with higher evapotranspiration under hotter mean temperatures, implies longer drought periods and would therefore lead to an increase in irrigation requirements, even if total precipitation during the growing season remained constant. Anthropogenic climate change will be experienced largely as shifts in the frequency and magnitude of extreme events (Karl et al., 2008). [11] River basins will be losing natural water storage in ice and snow and in reduced aquifer recharge, just as warmer temperatures increase evaporation. [14] Recommendations: Policy-makers should anticipate major issues for water availability for food production. [1] Water can be used more efficiently through a combination of new and existing technologies, better information, and more

Topics	Evidence
	sensible use. [14] Gaps: Case studies: Bangladesh Climate Change Resilient Fund (BCCRF) established. Also a Pilot Program for Climate Resilience (PPCR) country: program will focus on climate resilient agriculture, water supply, afforestation, coastal bund protection, and related studies. [10] Bangladesh: World Bank is preparing an Emergency Cyclone Recovery and Restoration Project (ECRRP) (approximately US$ 109 million) which includes improving sustainable agriculture production in cyclone affected areas in the medium-to-long term, to enhance food security, support for agriculture recovery through sustainable crop, livestock and fisheries production and productivity enhancement in the cyclone affected areas. [12]
Changing / emerging land uses	Risks: Land competition will be acute especially where the cultivation potential is limited and the expected population growth is high (Asia, p. 184-188). [5] The most important direct drivers of change in ecosystems are habitat change (land use change and physical modification of rivers or water withdrawal from rivers), overexploitation, invasive alien species, pollution, and climate change; often synergistic (e.g., land use change can result in greater nutrient loading (if the land is converted to high-intensity agriculture), increased emissions of GHGs (if forest is cleared), and increased numbers of invasive species (due to the disturbed habitat)). Often, actions to slow ecosystem degradation do not address indirect drivers: population change (including growth and migration), change in economic activity (including economic growth, disparities in wealth, and trade patterns), sociopolitical factors (including factors ranging from the presence of conflict to public participation in decision-making), cultural factors, and technological change. [7] Improvements to agricultural production are complicated by a number of pressures on land availability. [9] Millions of hectares have been acquired by international buyers (e.g., Saudi Arabia, China) in the last decade, primarily to grow crops for people back home or elsewhere in the world. [16] Opportunities: Agriculture, including fisheries and forestry, has been the mainstay of strategies for the development of countries for centuries, providing revenues that have enabled investments in industrialization and poverty alleviation. Although the value of food production in 2000 was only about 3% of gross world product, the agricultural labor force accounts for approximately 22% of the world's population, half the world's total labor force, and 24% of GDP in countries with per capita incomes of less than $765 (the low-income developing countries, as defined by the World Bank). Opportunities for further expansion of cultivation are diminishing in many regions of the world as most of the land well-suited for intensive agriculture has been converted to cultivation. [7]

Topics	Evidence
	Evidence: Crop area in low-income countries is expected to expand 2-49% (Balmford et al., 2005). [11] On average 35% of severely degraded land worldwide is due to agricultural activities. [3] Change in agricultural area by 2050: developed countries decline of 9-13%; middle-income developing countries small net changes, low-income developing countries increase of 18-25% (effects of climate change are not consistent). [4] More land was converted to cropland in the 30 years after 1950 than in the 150 years between 1700 and 1850. Cultivated systems (areas where at least 30% of the landscape is in croplands, shifting cultivation, confined livestock production, or freshwater aquaculture) now cover one quarter of Earth's terrestrial surface. More than two thirds of the area of 2 of the world's 14 major terrestrial biomes and more than half of the area of 4 other biomes had been converted by 1990, primarily to agriculture. [7] The area of global land used for agriculture has grown only slightly over the last fifty years. [11, 9] The area of land in agriculture went up by 8% (compared with crop yield growth going up be 115%). Estimates suggest that of the 13,400 million ha of land on earth, 3,000 million is suitable for crop production, but only approximately half (1400–1600 million ha) is cultivated. FAO estimates that, ignoring impacts on biodiversity and the carbon cycle, some 2,400 million ha is at least moderately suitable for wheat, rice and maize cultivation. Other studies have a wide range of estimates of land to be suitable for agricultural expansion. [1] Land use change, primarily deforestation, is responsible for as much as 18% of global GHG emissions. [9] Only in exceptional circumstances can conversion of forests (especially tropical rainforests), natural grasslands and wetlands to agricultural land be justified. [1] 16% of the world's productive land is already degraded (FAO/UNEP, 1997). Climate change will not only lead to further land degradation or desertification: it will reduce land availability because climate mitigation strategies – for example avoided deforestation, afforestation as a means of sequestering CO_2, and biofuel production – require land that might otherwise be used for food production. Further sources of demand for land include fiber production for paper, demand for timber and the world's growing cities, which tend to be sited on the best agricultural land. [15] Recommendations: The global food supply will need to increase without the use of substantially more land and with diminishing impact on the environment. [1] There are strong environmental grounds for limiting any significant expansion of agricultural land in the future (although restoration of derelict, degraded or degrading land will be important). In particular, further conversion of rainforest to agricultural land should be avoided as it will increase GHG emissions very significantly and accelerate the loss of biodiversity. [1] Gaps: Expand agricultural land to increase gross production, or increase yields sustainably on existing agricultural land? [9]

Topics	Evidence
	Case studies: Annual rate of expansion of cultivated areas (1961-2003): +1.13% in Latin America, +0.81% in Sub-Saharan Africa (these 2 regions use <20% of arable land), 0.54% in Asia (>80% of arable land used), -0.41% in former Soviet Union. [5]
Biofuels	Risks: Production of first-generation biofuels has been growing fast in recent years, primarily due to biofuel support policies since they are cost competitive only under particularly favorable circumstances. The diversion of agricultural crops to fuel can raise food prices and reduce our ability to alleviate hunger throughout the world. [3] Millions of people in developing countries depend on traditional bioenergy (e.g., wood fuels) for their cooking and heating needs, especially in sub-Saharan Africa and South Asia, posing considerable environmental, health, economic, and social challenges. [3] Commodity price increases due to expansion of first generation liquid biofuels, competition for land, water, other resources, and externalities (GHG emissions, lost ecosystem services). [1] Unclear whether farmers benefit financially from having the choice of using their land for food or fuel, or whether they suffer from becoming locked into contracts to supply biofuels. [1] Biofuels are acknowledged as one of the factors that led to an outstripping of supply by demand leading up to the 2007-08 food price spike, especially the boom in maize in the US for this purpose. In relation to economic factors which will have a bearing on future food price volatility, market forces will drive the production of first-generation biofuels if the ratio of energy prices to grain and oilseed prices increases, and could be a significant driver of volatility in food prices. Where biofuel production is a function of renewable energy policy, inflexible biofuel mandates may exacerbate volatility in grain prices, while flexible mandates could have the opposite effect. [1] Recent projections indicate real price increases of as much as 40% for maize by 2020, with spillover effects on substitute grains (wheat), given rapid growth in biofuels demand (p. 66). [13] Expanded production using the current generation of biofuels would displace large areas of natural forests and grasslands and compete with the production of food. [14] Opportunities: Bioenergy includes traditional bioenergy, biomass to produce electricity, light, and heat, and first and next generation liquid biofuels. The economics and the positive and negative social and environmental externalities differ widely, depending on source of biomass, type of conversion technology and local circumstances. [3] Increasing efficiency of land use to harvest solar radiation for food and energy through second-generation biofuels and the integration of biomass production. In the future, energy crops based on algae or macroalgae (seaweed) may be cultivated in integrated systems linked to terrestrial or aquatic food production. [1] Some biofuel systems have net positive effects for GHG emissions, but many first-generation biofuels do not contribute to

Topics	Evidence
	GHG reduction but reduce the area available to grow food. [1] Second-generation biofuels that rely on nonfood crops may reduce competition with agriculture by using more marginal lands. But they could still lead to the loss of pasture land and grassland ecosystems and compete for water resources. [14] <u>Evidence</u>: See regional scenario analysis of land dedicated to biofuel production (including production technologies and crop types) (p. 102-121). [5] There are important links between mitigation policies, biofuels, and the food system. Though some biofuel systems have net positive effects for GHG emissions, many first-generation biofuels do not contribute to GHG reduction but reduce the area available to grow food. The history of the introduction of biofuels illustrates the dangers of not considering all the consequences of a climate change policy, and the way they can be exploited by those with vested interests. [1] Although biofuels accounted for only 1.5% of demand for global liquid fuel in 2006-2007, the crops used to produce them accounted for half of the increase in consumption of major food crops, above all because of corn-based ethanol production in the United States (IMF, 2008). [15] <u>Recommendations</u>: Improve traditional bioenergy and accelerate the transition to more sustainable forms of energy. [3] Biofuel production will need to be considered in managing GHGs linked with agriculture, along with the interaction of agriculture with a range of other strategic and local land-use decisions, including land clearing and restoration, reforestation, agroforestry, and wetland management. This is particularly important where climate change and other vectors lead to land becoming more or less suitable for agricultural production, or where for example, the consequences of energy policies create dominant incentives for biofuel production. [1] <u>Gaps</u>: Next-generation biofuels (e.g., cellulosic ethanol, biomass-to-liquids) allow use of more abundant and cheaper feedstocks; potentially reduce agricultural land requirements per unit of energy produced and improve lifecycle GHG emissions. Not yet commercially proven and environmental and social effects are still uncertain. [3] How do crop and biofuel production coexist? Competition between food and biofuels. Need closer examination of biodiesel and agricultural markets, developing models of short-term price movements, further understanding role of oil as an agricultural commodity input, and fuller appraisal of the different types of biofuel policies and their impact on agricultural markets. [1] <u>Case studies</u>:
Urbanization	<u>Risks</u>: Urban populations affect distant ecosystems through trade and consumption and are affected by changes in distant

Topics	Evidence
	ecosystems that affect the local availability or price of commodities, air or water quality, or global climate, or that affect socioeconomic conditions in those countries in ways that influence the economy, demographic, or security situation in distant urban areas. [7] As cities grow they encroach on rural environments and often on high quality agricultural land. [9] Pace and scale of urbanization will affect global food consumption, changing the relationship between income and diet. [1] In Latin America and the Caribbean and in Europe and Central Asia, rising incomes and rapid urbanization have increased the demand for higher-value products, with domestic food markets growing even faster than in developed countries (p. 239). [13] Opportunities: It is estimated that up to 15% of the world's food is produced by urban agriculture and 70% of urban households in developing countries participate in agricultural activities (e.g., community gardens, private backyards, schools, hospitals, roof tops, window boxes and vacant public lands); can provide up to 60% of a family's food requirements: improves nutrition, conserves incomes, generates micro-enterprises. [2] Trends in urbanization and peri-urbanization, public policies towards urban densification, urban and peri-urban agriculture. [5] Economies of scale allow even relatively poor people in cities access to processed foods. Concentrations of people in cities can provide governments with the opportunity to promote initiatives. [1] Evidence: Highly divergent rates of urbanization: 36% in Asia and sub-Saharan Africa, >75% in Latin America and OECD in 2003. [5] Migration of some people out of marginal lands to cities or to agriculturally productive regions has helped reduce relative population growth in marginal lands (limited by poor economic growth in some cities, tighter immigration restrictions in wealthy countries, and limited availability of land in more productive regions). [7] Especially in the transforming and urbanized economies, dietary patterns are shifting away from cereals, roots, tubers, and pulses to livestock products, vegetable oils, fruits, and vegetables (p. 58). [13] Recommendations: Gaps: Case studies: Urban food production: agriculture practiced within urban boundaries contributes to food security in urban sub-Saharan Africa. [7] Urban/peri-urban agricultural projects (e.g., cities in Brazil, China, Cuba, Ghana, Kenya, India, Uganda, Venezuela, Vietnam). [16]

Topics	Evidence
Ecosystem services	Risks: There is a serious potential for future conflicts over habitable land and natural resources such as freshwater. [3] Wealthy populations cannot be insulated from the degradation of ecosystem services. Prospects for the forest, agriculture, fishing, and ecotourism industries are all directly tied to ecosystem services, while other sectors such as insurance, banking, and health are strongly, if less directly, influenced by changes in ecosystem services. Harmful effects of the degradation of ecosystem services (the persistent decrease in the capacity of an ecosystem to deliver services) are being borne disproportionately by the poor, are contributing to growing inequities and disparities across groups of people, and are sometimes the principal factor causing poverty and social conflict. [7] Sustainability cannot be pursued in the absence of food security. Much biodiversity can only be protected in relatively natural habitats, and sufficient land should be spared for wildlife, and for the ecosystem services these habitats provide. While some biodiversity can be maintained on land used for food production, a very significant fraction, especially in the tropics, requires relatively undisturbed non-agricultural habitats. [1] Sustainable intensification is a necessity. Pursuit of this agenda requires a much better understanding of how different policy options, both within and outside the food system, affect biodiversity and ecosystem services. [1] Need to address major knowledge gaps with further research - the ecological basis of many ecosystems services and their resilience to perturbation; the economic assessment and evaluation of ecosystem services and biodiversity; and the development of an analytical evidence base to judge between different management systems. Stewardship schemes are less frequent in low-income countries including those with centers of biodiversity, and should be encouraged. [1] Opportunities: Development gains have been achieved, however, at growing costs in the form of the degradation of many ecosystem services, increased risks of nonlinear changes in ecosystems, the exacerbation of poverty for some people, and growing inequities and disparities across groups of people. [7] Different national and international 'ecosystem assessments' seek to understand how various drivers of change will affect the provision of ecosystem services in the future [1]. Payments for environmental stewardship are a means of both supporting rural incomes and protecting the environment without distorting agricultural markets. [1] Understanding the challenges and opportunities of multifunctional uses, integrating land and water systems can help achieve multiple goals including food production, supporting rural economies, flood management and the protection of biodiversity. [1] Payments for environmental services can help overcome market failures in managing environmental externalities. Watershed and forest protection create environmental services (clean drinking water, stable water flows to irrigation systems, carbon sequestration, and protection of biodiversity) for which providers should be compensated through payments from beneficiaries of these services. Interest has been growing, particularly in Latin America (p. 16). [13]

Topics	Evidence
	<u>Evidence</u>: Conversion of forest to agriculture can significantly change the frequency and magnitude of floods, although the nature of this impact depends on the characteristics of the local ecosystem and the type of land cover change. [7] Changes in biodiversity influence the capacity of ecosystems to adjust to changing environments (medium certainty) (e.g., influencing the risk of crop failure in a variable environment and altering the potential impacts of pests and pathogens (medium to high certainty). [7] Some modern agricultural practices adversely affect soil quality by affecting soil physical, chemical, and biological factors through erosion, compaction, acidification, and salinization. They also reduce biological activity as a result of pesticide applications, excessive fertilization, and loss of organic matter. [8] Some of the most threatened and diverse habitats on earth exist in very low-income countries, and interventions to make farming more wildlife friendly, fishing less damaging, or to set land aside as reserves may affect the livelihoods of the very poorest people. Whatever strategies are adopted, the human impacts need to be understood and quantified as there are strong ethical arguments against imposing the costs of protecting biodiversity on those least able to pay them. [1] There are both economic and non-economic arguments for why ecosystem services and biodiversity should be integral parts of decision-making in the global food system. [1] Much significant biodiversity can only be protected with coordinated regional or international action. [1] <u>Recommendations</u>: Recognize farming communities, farm households, and farmers as producers and managers of ecosystems. [3] Address: (1) Inappropriate institutional and governance arrangements, including the presence of corruption and weak systems of regulation and accountability. (2) Market failures and the misalignment of economic incentives. (3) Social and behavioral factors, including the lack of political and economic power of some groups (such as poor people, women, and indigenous peoples) that are particularly dependent on ecosystem services or harmed by their degradation. (4) Underinvestment in the development and diffusion of technologies that could increase the efficiency of use of ecosystem services and could reduce the harmful impacts of various drivers of ecosystem change. (5) Insufficient knowledge (as well as the poor use of existing knowledge) concerning ecosystem services and management, policy, technological, behavioral, and institutional responses that could enhance benefits from these services while conserving resources. [7] Recognition at global and international levels that food security and environmental protection are interdependent. Need to develop mechanisms to reward countries that produce supranational environmental goods – international policy needs to ensure that countries obtain benefits from providing global goods, especially when costs are borne by low-income countries; avoid policies that have negative environmental impacts in other countries; coordinate the protection of biodiversity across administrative or national borders – At national and landscape levels: make land sparing work; develop new infrastructure sensitively; consider biodiversity in planning at landscape scale; implement realistic minimum environmental flows; consider setting aside marine and freshwater protected areas; and recognize the importance of ‘wild foods’ in low-income countries.

Topics	Evidence
	[1] Environmental protection and stewardship schemes should be designed so they support long-term maintenance of on-farm biodiversity and are robust to changes in economic and food system conditions. [1] Gaps: It is difficult to assess the implications of ecosystem changes and to manage ecosystems effectively because many of the effects are slow to become apparent, because they may be expressed primarily at some distance from where the ecosystem was changed, and because the costs and benefits of changes often accrue to different sets of stakeholders (e.g., eutrophication, climate change). [7] Preserving tropical rain forests, and biodiversity-sensitive fisheries. [1] Schemes for evidence-based, wildlife-friendly farming. [1] Managing terrestrial and aquatic ecosystems used in food production to achieve multiple goals. [1] Case studies: Further work into the economic assessment and evaluation of ecosystem services and biodiversity will need to build upon initiatives such as The Economics of Ecosystems & Biodiversity and World Bank program on Global Partnership for Ecosystems Services and Ecosystems Services Evaluation and Wealth Accounting. [1]
What does an alternative future food system look like and how can this system be brought into being?	
Agro-ecological approach to food production	Risks: Short-term tradeoffs/long-term synergies (e.g., land out of production/long run increased productivity). [2] Historically the path of global agricultural development has been narrowly focused on increased productivity rather than on a more holistic integration of natural resources management with food and nutritional security. Modern biological, chemical and mechanical technologies, in particular, are designed for farms and farming systems which have attendant entitlements and conditions that enable the production of tradable and vertically integrated commodities in value chains. [3] View of agriculture as an exclusively economic activity, measured in commodity-based, monetary terms. Focus of R&D on increased specialization of commodity production. [3] Environmental externalities of use of improved seeds and high levels of agrochemicals. [6] CGIAR spends 27% of its funding on genetic improvement of seeds, and most CGIAR centers are still organized around growing a particular crop – rice, wheat, corn, or potato. [16] Opportunities: Where the government and some private and civil society organizations have enabled appropriate scale effects as well as technical and financial support, small-scale farmers also have intensified their production systems and benefited from increasing market integration and achieving small and diversified farms with much higher productivity per unit of land and

Topics	Evidence
	per unit of energy use than large intensive farming systems in irrigated areas. [3] Farmers develop their own practices, capitalizing on their local knowledge as well as scientific research to address their specific problems. [6] Explore agro-ecosystems properties, such as complex cropping rotations, integrated crop and livestock production, and enhanced reliance on ecological processes to manage pests, weeds, and diseases. [8] There are a number of related processes and assessments in the realm of agriculture, food security, and climate change, such as the Convention on Biological Diversity (CBD), the UN Convention to Combat Desertification (UNCCD), the UN Framework Convention on Climate Change (UNFCCC), the UN Forum on Forests (UNFF) and IAASTD. [10] Ecoagriculture practices also increase agriculture's resilience to climate change along with farm productivity and incomes. [14] System dynamics models can integrate social, economic, and environmental factors and systematically explore management scenarios. [16] <u>Evidence</u>: <u>Recommendations</u>: Clean water access, tenure rights, disease management, technical guidance, distribution systems for peri-urban agriculture. [2] Improving nutrient, energy, water, and land use efficiency; improving the understanding of soil-plant-water dynamics; increasing farm diversification; supporting agro-ecological systems, and enhancing biodiversity conservation and use at both field and landscape scales; promoting the sustainable management of livestock, forest and fisheries; improving understanding of the agro-ecological functioning of mosaics of crop production areas and natural habitats; countering the effects of agriculture on climate change and mitigating the negative impacts of climate change on agriculture. [3] Improve soil fertility, structure and water-retaining capacity using a combination of organic, biological and mineral resources, and at using water more sparingly and efficiently. [6] Development, assessment, and diffusion of technologies that could increase the production of food per unit area sustainably without harmful trade-offs related to excessive consumption of water or use of nutrients or pesticides would significantly lessen pressure on other ecosystem services. [7] Work with ecological and biogeochemical processes and cycles to maximize synergistic interactions and the beneficial use of internal resources, minimize dependence on external inputs, and use added inputs efficiently. [8] Beyond seeds: building soils, growing crops other than grains, making better use of rainfed farms, and investing in other elements of the farm landscape. [16] <u>Gaps</u>: How do we increase productivity under marginalized, rainfed lands and incorporate them into local, national and global markets? [3]

Topics	Evidence
	Research in geographical, social, ecological, anthropological, and other evolutionary sciences as applied to diverse agricultural ecosystems. [3] Scaling up of agro-ecological practices and technologies. [5] <u>Case studies</u>:
Diversification of agricultural systems (e.g., agroforestry)	<u>Risks</u>: Environmental technologies such as integrated pest management (IPM), agroforestry, low-input agriculture, conservation tillage, pest resistant GM crops, and climate change adaptations, have often faced a policy gridlock with formal AKST, civil society, the state, private industry, and media taking highly polarized positions. Now as biofuels and plantation agriculture add to the competition for limited natural resources, the tradeoffs between production and environmental benefits must be increasingly scrutinized. [3] Studies that document the economic effects of modern strategies for enterprise diversification are sparse. [8] The agriculture-for-development agenda will not succeed without more sustainable use of natural resources – water, forests, soil conservation, genetically diverse crops and animal varieties, and other ecosystem services (p. 199). [13] <u>Opportunities</u>: Agroforestry systems and practices come in many forms, including improved fallows, taungya (growing annual agricultural crops during the establishment of a forest plantation), home gardens, growing multipurpose trees and shrubs, boundary planting, farm woodlots, orchards, plantation/crop combinations, shelterbelts, windbreaks, conservation hedges, fodder banks, live fences, trees on pasture, and tree apiculture. [2] Agroforestry: Carbon sequestration. Increased soil organic matter (and thereby, fertility, moisture retention). Source of fuel wood, timber. Risk-spreading. Economic resilience. Improved nutrition/income. "Greening" cities. [2] Rural households typically manage risk through diversification of farm and non-farm activities and asset accumulation (e.g., money, land). [6] In degraded lands, afforestation may deliver economic, environmental, and social benefits to communities and help reduce poverty and enhancing food security. [7] Changes in consumer diets – brought about by rapid income growth and increasing urbanization – are already driving diversification. Most food products in this new agriculture are perishable, and quality and safety standards are tighter, thus increasing the vertical integration of food systems (p. 58). [13] Poorer nations house most of the world's dwindling food biodiversity. [16] <u>Evidence</u>: U.S. agriculture has become increasingly dependent on large-scale, high-input farms that specialize in a few crops and concentrated animal production practices for most U.S farm products. [8] Linking disaster management and diverse agricultural sector/technology development (Bangladesh). [12]

Topics	Evidence
	<u>Recommendations</u>: Introduction of new plant types. Integrated crop/livestock and food/energy systems. Biogas. [2] Screen/match species to ecological zones/agricultural practices. Develop/distribute germplasm. [2] Diversified rotations, including crop varieties and species with different thermal/temperature requirements, better water use efficiency and resistance to pest/disease, and lower yield variability are an effective way to reduce risks and increase efficiency. [2] Diversify farm enterprises to provide multiple income streams for farming operations. [8] Nitrogen-fixing trees (Malawi). [16] <u>Gaps</u>: What combination of livelihood diversification, intensification, innovation and risk transfer has the best prospect for building resilience and reducing the long-term climate vulnerability of rural communities? [11] <u>Case studies</u>: Agroforestry parklands in Niger turn back the desert and restore livelihoods (p. 195). [13] Global Crop Diversity Trust. [16]
Crop production / land management approaches	<u>Risks</u>: Some sources suggest that globally, 5 to 10 million hectares of agricultural land are being lost annually to severe degradation (p. 63). [13] <u>Opportunities</u>: Increased carbon sequestration through integrated soil and vegetation management is promising. If the organic carbon pools in the world's soils were to be increased by 10% in the 21st century, it would be equivalent to reducing atmospheric CO_2 by 100 parts per million. [1] Using methods and practices that increase organic nutrient inputs, retention, and use are therefore fundamental and reduces the need of synthetic fertilizers which, due to cost and access, are often unavailable to smallholders and, through their production and transport, contribute to GHG emissions. [2] Ecological intensification innovations tend to increase or maintain yields while preserving ecosystems services. See regional analysis of models of spatial organization: (1) "segregationist" model: intensifying production systems and protecting natural areas, and (2) "integrationist" model: combining ecological and productive functions of agro-ecosystems within the same territory (p. 222-228). [5] Low fertilizer use is one of the major constraints on increasing agricultural productivity in sub-Saharan Africa (p. 12). [13] There is considerable room for land expansion in some sub-Saharan countries, but this will require large investments in infrastructure and human and animal disease control to convert these lands to productive agriculture (p. 63). [13]

Topics	Evidence
	Evidence: Conserve soil and moisture while enhancing productivity and competitiveness (Brazil, Mexico, China), and have addressed the particular concerns of drought-prone semi-arid areas (Kenya), improved agricultural water management (Uzbekistan, Morocco), addressed watershed management (China, Albania), deforestation (Brazil), sea-surges and coastal flooding (Bangladesh). [12] The green revolution in Asia doubled cereal production there between 1970 and 1995, yet the total land area cultivated with cereals increased by only 4%. (p. 180) [13] Recommendations: Green manures. Intercropping. Crop rotation. Agro-forestry. In forage legume/grass mixtures, nitrogen can be transferred from legume to grass varieties (e.g., 13 to 34% of fixed N). Used as a livestock feed, it can also increase food conversion ratios and decrease methane emissions. Legumes also provide a useful protein source for humans. [2] Change of technological paradigm given strong "lock-in" phenomena (p. 228). See regional scenario analysis for agro-ecological intensification (e.g., doubling green revolution). [5] Residue and manure and crop fertilization, agro-forestry, more precise matching of nutrients with plant needs, controlled release and deep placement technologies or using legumes for natural nitrogen fixation and carbon sequestration, in combination with efficient use of artificial fertilizers and carbon sequestration. Efficient use of fertilizers – manure storage and management of artificial fertilizers and aspersion techniques – must also contribute to reducing GHG emissions. [10] Use of animal manure, compost, green manure/cover crops. [16] Zero tillage. Precision agriculture. Controlled-release nitrogen through the deep placement of supergranules of fertilizer or the addition of biological inhibitors to fertilizers. [14] Biochar, a charcoal-type solid with a very high carbon content. [14] Minimum tillage, whereby ploughing is minimized to reduce soil erosion and increase the soil's capacity to hold water and sequester CO_2 (Brown, 2005). Use of biochar to store carbon in the soil and improve fertility (Lehmann, 2007). [15] Gaps: Case studies: Latin America (mainly Argentina and Brazil), zero tillage is used on more than 40 million hectares (p. 163). [13] Yield improvement through mulching, reducing tillage, and planting cover crops (Kenya, Ethiopia, Zambia, Tanzania). [16]
Livestock management (e.g., animal health / welfare)	Risks: Livestock-associated GHG emissions vary considerably among production systems, regions, and commodities, mainly due to variations in the quality of feed, the feed conversion efficiencies of different animal species and impacts on deforestation and land degradation. [2] Livestock intensification has also produced environmental problems linked to the move from dispersed production in rural

Topics	Evidence
	areas to specialized livestock units in urban and peri-urban areas, now happening on a grand scale in much of Asia. The major environmental threats are the pollution of water and soil with animal waste, especially nitrogen, phosphorous, and highly toxic heavy metals such as cadmium, copper, and zinc (p. 189). [13] A significant amount of meat is obtained from 'grain-fed' livestock, and diets high in this type of food have a large resource footprint. [1] Already more than one-third of the world's grain is fed to domestic livestock. Some suggest that demand for livestock products will double by 2050. [9] Intensive livestock agriculture that uses sub-therapeutic doses of antibiotics has led to the emergence of antibiotic-resistant strains of Salmonella, Campylobacter, and Escherichia coli bacteria. [7] Climate change is expected to threaten livestock holders in numerous ways: animals are very sensitive to heat stress; they require a reliable resource of water and pasture is very sensitive to drought. [3] In all regions of the developing world, there is a need for crop and livestock production systems to become more intensive if the world's growing population is to be fed, now and in the future. [6] <u>Opportunities</u>: Much livestock is maintained on grasslands that are unsuitable for arable crops. Such production systems will, if managed well, sequester and store significant amounts of carbon in their soil [1] Integrated crop and livestock systems increase the efficiency and environmental sustainability of both production systems [2] Accumulation of livestock assets can also serve as a buffer to face shocks, because livestock are relatively easy to sell in order to smooth consumption when food prices rise, expenditure needs increase or incomes fall [6] Livestock and other high-value activities offer considerable potential for employment generation and productivity growth. [13] <u>Evidence</u>: Livestock: world's largest user of land resources, with grazing land occupying 26% of the earth's ice-free land surface, and 33% of cropland dedicated to the production of feed. The quick expansion of the sector is a cause of overgrazing and land degradation and an important driver of deforestation. [2] There is also concern about the interactions between livestock production systems and the environment. The change from traditional mixed and extensive systems to intensive production systems has probably had negative effects on energy consumption, genetic diversity and water pollution [6] Livestock production in developing countries has increased rapidly over the past 30 years [6] Expansion of livestock production around the world has often led to overgrazing and dryland degradation, rangeland fragmentation, loss of wildlife habitat, dust formation, bush encroachment, deforestation, nutrient overload through disposal of manure, and GHG emissions. [7]

Topics	Evidence
	Reducing greenhouse gas emissions (and other negative externalities) from livestock production is an important global good; regulatory frameworks and incentives, and public-funded investment in research and development, aimed at reducing emissions and other environmental harm, is a priority [1] Substantial progress has been made in measuring livestock-related emissions which account for about half of all agriculture/land-related emissions, including CO_2, methane (CH4), nitrous oxide (N2O) and ammonia (NH3). [12] Livestock provide food and livelihoods for one billion of the world's poor, especially in dry and infertile areas where other agricultural practices are less practicable. [2] Production growth has been made possible by cheap inputs (including grains for feeds), technological change and gains in scale efficiency, all of which have resulted in lower prices for livestock products and stimulated rapidly growing demand among urban consumers. However, much of the increased production has come from vertical integration, which has sometimes led to the marginalization of small-scale and subsistence livestock production. [6] Livestock is agriculture's most economically important subsector. [16] Intensive livestock systems are burgeoning in the developing world, driven by the growth in demand for meat, milk, and eggs, a direct consequence of rising per capita incomes and urbanization [13] Recommendations: Efficient manure management. Reintegration of livestock and cropping. Grazing management. Fodder trees. Improved sanitation. Multinutrient blocks. [2] Pastoralist-grazing, breeding and fodder management, and improved management and re-use of animal waste (e.g., use of manure for biogas, fertilizer). [10] Feed subsidies have been quite successful in protecting livestock numbers and production during droughts (MENA). [13] Gaps: Case studies: Tackled the particular challenges of livestock (Uruguay, China). [12] Improving milk production (Cajamarca, Peru) [2] Control of animal diseases related to climate changes: Rift valley fever (Madagascar) [2] LEARN (Livestock Emissions and Abatement Research Network) – cost effective and practical GHG mitigation solutions for the livestock sector (New Zealand). [10] Mongolia's index-based livestock insurance: share risks among herders, insurance companies, and the government. [13]
Integrated landscape approaches	Risks: Agricultural expansion will continue to be one of the major drivers of biodiversity loss well into the twenty-first century. [7] Opportunities:

Topics	Evidence
	Evidence: Integrated landscape approaches have been key to success, together with support measures for managing weather risk, diversifying household income and improving market linkages (China, Albania, Kenya, Mexico). [12] Protected areas (already 12% of the earth's land) cannot be the only solution to maintaining biodiversity, because species ranges are likely to shift outside the boundaries of such areas. Instead, eco-agricultural landscapes, where farmers create mosaics of cultivated and natural habitats, could facilitate the migration of species. [14] Recommendations: Land use/resource assessments. Vulnerability/impact assessment. [2] Adjusting the mix of farming system types and the practices used in them at the landscape level to address major regional problems such as water overdraft and environmental contamination. [8] The fact that food production requires ecosystem services provided by both farmed and non-farmed land means that policy in these two areas needs to be developed and properly connected at global, national, and landscape scales. [1] Make land sparing work; develop new infrastructure sensitively; consider biodiversity in planning at the landscape scale; implement realistic minimum environmental flows; consider setting aside marine and freshwater protected areas; and recognize the importance of 'wild foods' in low-income countries. [1] Land will need to be managed for multiple functions, for example food production, supporting rural economies, flood management and protection of biodiversity. Aquatic zones, particularly in inland and coastal areas, require similar approaches. The challenges and opportunities of multifunctional uses, integrating land and water systems are critical for policy formulation. [1] Gaps: Case studies:
Water resource management	Risks: Less water available for crops and livestock as a result of decreased rainfall. In most cases, the major food exporters (USA, Canada and the European Union) have highly productive rainfed agriculture, while most importers rely on irrigation or low output rainfed systems. Traded virtual water may also be helpful in raising farm incomes and in increasing the potential for exports. However, potential disadvantages to virtual water trade include a higher risk of environmental impact in exporting regions, and possible impacts on the food security of poor people in exporting countries where water is not managed to meet both local and export needs. [1] Cost of investment. Lack of information. Storage ponds and reservoirs have rules and restrictions. Planning permission for reservoirs. The governance of capture fisheries in inland, coastal or open waters faces particular problems. Fishery resources are commonly held as public goods, at national level or by international treaty, but harvesters have insufficient incentives to resist overexploitation. Regulation is complex,

Topics	Evidence
	and monitoring, control and surveillance (MCS) is difficult and expensive to implement, and few authorities have the means or sanctions to control over-fishing. [1] The groundwater overdraft rate exceeds 25% in China and 56% in parts of northwest India (p. 64). [13] In particular, the expansion of irrigated agriculture has often been at the expense of other water users, biodiversity, and ecosystem services, damaging fisheries and wetlands (p. 185). [13] Irrigation contributes to the depletion of groundwater sources in many parts of the world, including most states in India and throughout northern China. [15] Opportunities: Evidence: Agriculture already currently consumes 70% of total global 'blue water' withdrawals from rivers and aquifers available to humankind. Demand for water for agriculture could rise by over 30% by 2030, while total global water demand could rise by 35-60% between 2000 and 2025, and could double by 2050 owing to pressures from industry, domestic use and the need to maintain environmental flows. In some arid regions of the world, several major non-renewable fossil aquifers are increasingly being depleted and cannot be replenished, for example in the Punjab, Egypt, Libya, and Australia. Estimates suggest that exported foods account for between 16% and 26% of the total water used for food production worldwide, suggesting significant potential for more efficient global use of water via trade, although there is the risk of wealthy countries exploiting water reserves in low-income countries. [1] With productivity growth and a modest growth in irrigated area of 0.2% annually, irrigated production is projected to account for nearly 40% of the increased agricultural production in the developing world by 2030 (p. 64). There now are many opportunities for economically investing in irrigation in sub-Saharan Africa and the irrigated area there is projected to double by 2030 (p. 64). [13] Recommendations: Water harvesting/retention. Water-use efficiency. Irrigation management tools (e.g., MASSCOTE). [2] Raised seedbeds, keyhole gardens using wastewater (Africa). Mini-sprinkler and drip systems, precision timing in plant watering and crop systems (e.g., intensive rice system). Improved water harvesting and retention. Water use efficiency. [10] Responsible fishing can also be incentivized by pressures from consumers and retailers, international initiatives for controlling illegal fishing, restricting landing locations, and campaigns to sanction non-compliant fleets. [1] The growing pressure on water supply for agriculture will come from higher demand for water from other sectors, the exhaustion of aquifers, and changes in precipitation patterns, higher sea levels and altered river flows caused by climate change. Incentives to encourage greater efficiency of water use and the development of integrated water management plans need to be given high priority. [1] Flexibly designed dams. Recycled water and desalination (expensive but high value if powered by renewable energy). [14] Rainwater harvesting and drip irrigation to improve water use efficiency (Postel and Vickers, 2004). [15]

Topics	Evidence
	Gaps: Case studies:
GHG mitigation	Risks: In 2005 agriculture contributed an estimated 10-12% of total anthropogenic emissions of GHGs. "Land sparing" effect of intensification is uneven in practice and requires policies and price incentives to strengthen its impacts (Angelsen and Kaimowitz, 2001); best outcomes where conservation set-aside programs are in place or price supports were eliminated and imported grains substituted for local production. Mitigation potentials remain uncertain as most have been estimated through highly aggregated data (Paustian et al., 2004). Smith et al. (2007b) estimate that less than 35% of the total biophysical potential for agricultural mitigation is likely to be achieved by 2030 due to economic constraints. [11] Despite the role of agriculture in GHG (over 30%), carbon payments related to agriculture have remained a very small part of the market. [12] There are many farmers and relatively small carbon payments per hectare per year (often below $10/ha/year), resulting in high transaction costs and limited incentives for land use change. [12] Long delays in certifying emissions reductions projects by UNFCC experts. [12] Settlement areas in tropical forests, although smaller in their extent and population, are another important category from an environmental perspective, with deforestation contributing to reduced global carbon sequestration and climate change (p. 190). [13] Richer countries' emissions of GHGs already undermine the productivity of farming systems essential to survival of the poor (p. 259). [13] Agriculture accounts for 70% of water withdrawals and 15% of GHG emissions (75% emitted by developing countries). [16] Opportunities: Full accounting of GHGs across all land uses will be necessary to account for leakage and monitor the impacts of intensification. Measurement technologies are well known, but monitoring of indicators and life cycle analysis can be expensive and interactions among farm practices difficult to assess. Current efforts of the Global Research Alliance are focused on research to measure and enhance mitigation in industrialized agriculture. Similar efforts are needed for smallholder farming in low-income countries, which are major contributors to emissions. [11] Soil carbon sequestration is estimated to have the highest economic mitigation potential (Smith et al., 2007a), although incentives for its adoption, as well as permanence, variability and monitoring need to be addressed. [11] Several upcoming technologies such as the system for Rice Intensification and Zero Tillage Agriculture allow for improvements in productivity while reducing GHG emissions. [12] African farmers could remove 50B tons of CO_2 from the atmosphere over the next 50 years, primarily by planting trees among crops and stewarding nearby forests (~75 projects in 22 countries across Africa). [16]

Topics	Evidence
	Evidence: Reducing N_2O and CH_4 emissions, increasing carbon sequestration, or avoiding emissions through use of biomass for fuels or reduced land clearing are technical options to reduce emissions (Smith et al., 2007a). [11] About 70% of anthropogenic nitrous oxide gas emissions are attributable to agriculture, mostly from land conversion and nitrogen fertilizer use. [7] Agriculture is estimated to contribute 12-14% of GHG emissions, including those associated with fertilizer production. Figure rises to 30% or more when costs beyond farm gate and especially land conversion are added. Low- and middle-income countries are currently responsible for about three-quarters of agricultural GHG emissions with their proportionate share increasing. Single most important contribution of agriculture to GHG emissions is through production and application of nitrogen fertilizers, and second most significant is from livestock production through enteric fermentation and manure. Four main ways to give impetus to reductions in food system: (1) creation of market incentives to encourage emissions reductions; (2) introduction of mandatory emissions standards or limits by direct regulation; (3) adoption of low-emission strategies through market pressure driven by consumer choice; (4) voluntary (non-profit driven) measures taken by industry as part of corporate social responsibility [1]. Reducing emissions can occur without loss of production or productivity. In some cases, emissions reduction can occur without loss of production or productivity or even with a gain in efficiency [1] Policies to mitigate climate change can incentivize the delivery of multiple public goods associated with the food system [1]. GHG emissions from food at every step in the food chain: farming, processing, packaging, transportation, wholesale/retail, food service, household consumption, and waste. [16] Changes in agricultural practices that affect net flux of GHG between land, aquatic margins, and the atmosphere could, depending on their direction, have significant positive or negative effects on global warming. [1] Recommendations: Sustainably intensify agricultural production. Avoid conversion of high-carbon landscapes. Develop methods for low-emissions food production. Develop inexpensive, on-farm measurement and monitoring to test real GHG budgets. Develop economically feasible incentives for changing farming practices without compromising investments in food security. Efficient use of inputs. More precise estimates of mitigation and its related effects on food systems. Full accounting of GHGs across all land uses will be necessary to account for leakage and monitor the impacts of intensification. [11] Efficient harvesting, storage, and food processing to reduce post-harvest loss. Integrated rice production (NH_4SO_4 supplements, urea deep placement, alternate-wetting-and-drying). Conservation agriculture. Improved animal husbandry. [2] Policy impact evaluation tools (e.g., EX-ACT carbon balance tool). [2] A comprehensive approach with an equitable regulatory framework, differentiated responsibilities and intermediate targets are required to reduce GHG emissions. The earlier and stronger the cuts in emissions, the quicker concentrations will

Topics	Evidence
	approach stabilization. Emission reduction measures clearly are essential because they can have an impact due to inertia in the climate system. [3] "Win-win" mitigation opportunities: land use approaches such as lower rates of agricultural expansion into natural habitats; afforestation, reforestation, increased efforts to avoid deforestation, agro-forestry, agro-ecological systems, and restoration of underutilized or degraded lands and rangelands and land use options such as carbon sequestration in agricultural soils, reduction and more efficient use of nitrogenous inputs; effective manure management and use of feed that increases livestock digestive efficiency. [3] Developing better and more comprehensive metrics of GHG emissions in the global food system should be a priority. [1] In designing, encouraging, and facilitating initiatives, it is essential to consider not only effects on GHGs but affect on amount of food produced, quantity of inputs required, and all other externalities of food system from ecosystem services to animal welfare [1]. In measuring how GHG emissions are affected by different strategies, it is critical to include not only the direct but also the indirect consequences, such as effects on land use conversion and those mediated by global trade. There is also a balance to be struck between comprehensiveness and simplicity that will vary across applications. [1] Land-based approach to assess soil carbon sequestration from improved land and water management practices. [12] Measure, Report, Validate (MRV) for REDD-style offsets: (1) An "activity- based" approach. (2) Transaction costs can be reduced by "aggregators," who combine activities over many smallholder farms. (3) Logistical help and strengthened extension services. [14] <u>Gaps</u>: What technologies and management systems can deliver reduction of emissions and sequestration of GHGs cost-effectively with maximum benefits to poverty alleviation, food security, and environmental health at the landscape level? What is the GHG abatement potential, technical feasibility, and economic feasibility of different agricultural mitigation practices among smallholders in low-income countries? [11] Mitigation roles for developing countries (and roles of food-importing countries). Recognizing the importance of land conversion (e.g. forest to farmland) and the broader context of emissions from all land use types in policies to reduce GHG emissions. [1] The importance of the link between mitigation policies, biofuels, and the food system. [1] Need to quantify potential for mitigation and financial rewards. High levels of uncertainty in the measurement of emissions from various agricultural activities. [1] <u>Case studies</u>: Initiatives working on MRV: FAO's Mitigation of Climate Change in Agriculture (MICCA) project, the Cool Farm Tool assessments of the Sustainable Food Lab, the Global Environment Facility's (GEF) Carbon Benefits Project, the UK-China Sustainable Agriculture Innovation Network (SAIN), IFPRI's Climate Change Mitigation and High Value Food Crops project,

Topics	Evidence
	and CCAFS. [11] Urea deep placement (UDP) technology for rice systems. Alternate-Wetting and Drying (AWD) to reduce methane emissions. [2] Kenya and BioCarbon Fund: Agricultural Soil Carbon Project: carbon sequestration in maize farming systems and the application of innovative carbon accounting and payment methods that allow large scale application and the inclusion of small holder farmers (2010-2015). [10] China: several biogas projects under Clean Development Mechanism (CDM), financed by the World Bank. [12]
Integrated use of existing and new technological interventions	<u>Risks</u>: There is a significant correlation between capital stock in agriculture and value added per worker. In many developing countries, the low capitalization of agriculture translates into low value added per worker, thus worsening the vicious cycle of agrarian and rural poverty. [3] Uncertainty of climate prediction means that climate-specific investments are not yet appropriate for the most part. [4] Many of the technologies and the knowledge needed are already available but their wider diffusion and uptake by farmers are key challenges. [10] Farming is knowledge-intensive, requiring information about crop characteristics, weather, microclimate, soil types, fertility, pests and disease threats, field rotation schemes, livestock / crop interactions, market demand, and other factors. [16] <u>Opportunities</u>: Developments in science or technology can influence and increase the efficiency of interventions to reduce GHG emissions. [1] The greatest impact on productivity is obtained through production ecology approaches that combine improved varieties and several management technologies, crop-livestock integration, and mechanical technologies to exploit their synergistic effects. [13] With small-scale adaptations such as changes in planting times, the estimated increase in hunger could be reduced to 5-50% (from 10-60%); with substantial adaptations such as increased irrigation it could be reduced to 5%. [15] Enhancement of soil carbon through for example conservation tillage or management of crop residues (Lal, 2004), and to a lesser extent agro-forestry (Verchot et al., 2007) or high productive grassland restoration (Smith et al., 2008; Olsson and Ardo, 2002; Batjes, 2004) are expected to have significant impacts on climate without compromising food production. [11] <u>Evidence</u>: Germplasm improvement, improved management of crops, livestock, aquaculture and natural resources, and enhanced agro-biodiversity have all been shown to decrease susceptibility to individual stresses (Jackson et al., 2007). [11] Many examples of the application of existing knowledge and technology to increase sustainable food production will also have positive effects on reducing GHG emissions. The creation of new knowledge to increase current yield ceilings in the

Topics	Evidence
	most sustainable way will also have the potential to make a contribution. Measures that are GHG emission-neutral, but which increase productivity, reduce demand or increase the efficiency of the food system are also beneficial for climate change mitigation because they reduce the pressure on the food system to expand, and therefore help to limit GHG increases that might otherwise occur. [1] Recommendations: Invest in databases and tools to inform policy and practice in the spheres of agricultural risk management, adaptation and mitigation; these need to be co-developed with users. [11] Develop and deploy suitable cultivars adaptable to site-specific conditions; improving access to resources; improving soil, water and nutrient management and conservation; pre- and postharvest pest management; and increasing small-scale farm diversification. [3] Options for action with proven contribution to achieving sustainability and development goals include collaboration in the conservation and development and use of local and traditional biological materials; incentives for and development of capacity among scientists and formal research organizations to work with local and indigenous people and their organizations; a higher profile in scientific education for indigenous and local knowledge as well as for professional and community-based archiving and assessment of such knowledge and practices. [3] Supporting investments in physical and human capital can begin immediately as a way of increasing the efficiency of land, water, and nutrient use, as essential factors in growth, climate resilience, and GHG mitigation. [4] Research the potential of new forms of production systems that represent a dramatic departure from (rather than incremental improvement of) the dominant systems of present-day American agriculture. [8] Major need to review the support for and provision of extension services, particularly in developing countries [9]. The revitalization of extension services to increase the skills and knowledge base of food producers (often women) is critical to achieving sustainable increases in productivity in both low-income and high-income countries. [1] Immediate deployment of energy efficiency and available low-carbon technologies, accompanied by massive investments in the next generation of technologies for low-carbon growth. [14] Give farmers access to: knowledge and innovation (increase research, Extension), assets (water, land; institutional capacity), markets (infrastructure, communications technologies; enable small farmers to aggregate output), credit (avoid predatory lending), risk management (increased turbulence in climate and food prices; crop storage systems; crop insurance, employment guarantee schemes). [15] Changes in the kind of food produced and improvement in its distribution: less meat production, use of more environmentally sustainable agricultural methods that do not rely on petrochemicals, and more local and regional production of food. [16] Gaps: Data, tools and models at spatial and temporal scales appropriate to decision-making. Significant knowledge gaps exist as to

Topics	Evidence
	what adaptations options are available, what their likely benefits or costs are, where and when they should be deployed, and what the learning processes are that can support widespread change under uncertainty. [11] Case studies: Ethiopia MoA, joint donors and international knowledge institutes: Committed to mainstreaming Climate Change mitigation and adaptation measures in the Agricultural Growth Strategy and supporting climate-smart agricultural best practices that improve productivity. [10]
Animal and crop breeding	Risks: Contentious issue: use of recombinant DNA techniques to produce transgenes that are inserted into genomes. Concern about present Intellectual Property Rights (IPR) instruments eventually inhibiting seed-saving, exchange, sale and access to proprietary materials necessary for the independent research community to conduct analyses and long term experimentation on impacts. [3] Investments in R&D on transgenics are concentrated largely in the private sector, driven by commercial interests in industrial countries. Locally important food crops are not included in transgenic R&D. [13] The 1950s and 1960s showed that genetic improvement technologies such as crop and animal breeds were often location specific and generally did not travel well from the temperate North to the tropical South (p. 159). [13] Barriers: Weak regulatory capacity. Limited access to proprietary technologies. Complexity of trade in transgenics. Concerns about possible food safety and environmental risks. [13] Opportunities: Biotechnology is a broad term embracing the manipulation of living organisms and spans the large range of activities from conventional techniques for fermentation and plant and animal breeding to recent innovations in tissue culture, irradiation, genomics and marker-assisted breeding (MAB) or marker assisted selection (MAS) to augment natural breeding (CBD and the Cartagena Protocol on Biosafety). Newer techniques: Use of in vitro modified DNA or RNA and the fusion of cells from different taxonomic families, techniques that overcome natural physiological reproductive or recombination barriers. Even newer techniques of modern biotechnology manipulate heritable material without changing DNA. [3] Yield stability is important for all farmers (p. 181). [13] Transgenic food crop technologies promise substantial benefits to poor producers and consumers. Most notable are traits for the world's major food staple, rice, including pest and disease resistance, enhanced vitamin A content (Golden Rice), and salt and flood tolerance. [13] Agricultural biotechnology has the potential for huge improvements (p. 162). [13] Genetic modification of crops has concentrated on improving resistance to biotic stresses such as weeds and pests, but in future it is likely to focus on improving the capacity of plants to cope with abiotic stresses. [15] Evidence: Overcoming abiotic stresses in crops through crop breeding has proven to be an effective means of increasing food

Topics	Evidence
	production (Evenson and Gollin, 2003). Substantial biological potential for increasing crop yields through conventional crop breeding (Ortiz et al., 2008) and the development of transgenic crops supported by biotechnology (Godfray et al., 2010). [11] Maintaining and enhancing the diversity of crops genetic resources is vital to facilitate crop breeding and thereby enhance the resilience of food crop production. [9] Over 1980-2005 in the developing world, the annual off-take from a flock of chickens with a total live weight of 1,000 kilograms increased from 1,290 kilograms to 1,990 kilograms and that of pigs improved from 140 kilograms to 330 kilograms live weight (p. 162). [13] New maize varieties yield 20% more on average under drought conditions (p. 162). [13] The only transgenic widely adopted by smallholders has been Bt cotton for insect resistance. An estimated 9.2 million farmers, mostly in China and India, planted Bt cotton on 7.3 million hectares in 2006. Evidence of higher profits from adoption of Bt cotton, and also document substantial environmental and health benefits through lower pesticide use but impacts vary across years, institutional settings, and agro-ecological zones. [13] <u>Recommendations</u>: Investment in crop improvement to address specific characteristics of a progressively changing climate (e.g. heat, drought, waterlogging, pest resistance). [11] Preservation of genetic resources (crops, wild relatives). Generating breeds/varieties tailored to farm ecosystems. Seed certification systems. Improved livestock genetics. [2] Focus biotechnology investment on local priorities identified through participatory and transparent processes, and favor multifunctional solutions to local problems (requires new kinds of support for the public to critically engage in assessments of the technical, social, political, cultural, gender, legal, environmental and economic impacts). Use biotechnologies to maintain local expertise and germplasm so that the capacity for further research resides within the local community; emphasize participatory breeding projects and agro-ecology. [3] Preservation of genetic resources/account for IPR, breeder rights, role of farmers in preserving local crops and seeds. [10] Objectively evaluate potential risks and benefits of transgenics on the basis of the best available scientific evidence and taking into account public risk perceptions. Introducing transgenics requires a cost-effective and transparent regulatory system with expertise and competence to manage their release and use. Open information disclosure, labeling, where feasible, and a consultative process are critical for harnessing public support for transgenics. Strong regulatory capacity does not necessarily mean stringent standards on risks. [13] Seed selection and breeding for crop improvement and resilience, through both farmer-managed systems and advanced scientific methods, will continue to play a critical role in agricultural development, but with explicit attention to the incorporation of better seeds in diverse agro-ecological production systems. [16] <u>Gaps</u>: Understanding the circumstances under which different abiotic stresses dominate (e.g. Thornton et al., 2009; Challinor and

Topics	Evidence
	Wheeler, 2008) and matching crops to future climates in a way that accounts for uncertainties. [11] Better understanding of GM risks for increased broad uptake (p. 163). [13] Case studies: Mexico: National Center of Genetic Resources. [10] Disease-free sweet potatoes in China: improvements of 30-40% (p. 163). [13]
Staged transitions	Risks: Africa: wide variety of crops using diverse farming systems across a range of agro-ecological zones. Most systems are rainfed, and many soils are severely depleted of nutrients. External inputs are expensive. High transportation costs and lack of infrastructure often inhibit access to outside resources and markets. [8] Agricultural mitigation practices are highly context-specific (depending on type of ecosystem, crop, culture, country, etc). [1] Opportunities: Agriculture sector offers greatest synergies between food security and climate change. [10] Globally-relevant innovations (e.g., rooftop gardening). [16] Evidence: Recommendations: More intensive land use and higher yields. [6] Focus on production of food for local demand (75% of world's poor are living in rural areas). [10] Gaps: Sparse scientific knowledge as to how current farming systems can adapt, and which current farming systems and agricultural practices will enable adaptation. [11] Timing is important. How fast should the move be from the status quo to a sustainable food system? The challenges of climate change and competition for water and resources suggest a rapid transition is required, but it is also legitimate to explore the possibility that superior technologies may be available in the future, and that later generations may be wealthier and hence better able to absorb the costs of the transition than is currently the case. [1] Case studies: Africa: Soil organic matter management, reduced tillage, integrated fertility management, water harvesting, drip irrigation, stress-resistant crop varieties, improved animal breeds, integration of crops and livestock, and use of global information systems for landscape and regional analysis and planning. [8]

Topics	Evidence
Parallel processes and scaling up	Risks: Opportunities: Evidence: Successful programs have benefited from strong local ownership and participation, often within decentralized government structures (Kenya, Niger). [12] Recommendations: Financing: learn from related processes (e.g., REDD+), mainstream adaptation and mitigation measures in national strategies and policies, test, pilot and demonstrate such measures under different framework conditions. [10] Gaps: Case studies: Programs need to be adapted to local circumstances, implemented to scale, combined with social protection and food security measures as well as support or access to basic services. Long term commitment and strong local ownership, through bottom-up approaches, e.g., the Arid Lands Program in Kenya and the Community Action program in Niger. [12]
Support networks	Risks: Opportunities: Evidence: In many low-income countries agriculture has lost its infrastructure: agricultural parastatals, networks of extension agents, and national agricultural research have been depleted by structural adjustment. [1] Weather-related risk management insurance instruments (Mongolia, Malawi, OECD countries). [12] Recommendations: Market access. Initial/transition funding (e.g., carbon offsets). Reduced emphasis on marketing inputs/commercial services in Extension systems. Coordinated systems for fertilizer/seed supply, biophysical improvements (land restoration, water supply). Use/access/property rights systems. [2] Researcher should work with farmers and extension services in target countries to make sure the benefits are captured and made accessible to poorer farmers. [9] Farmers' organizations can promote dialogue between farmers/across sectors, support individual farmers, especially smallholders, and improve access to financial mechanisms, funding and carbon markets. Partnerships between small and large scale farmers and enterprises as regards technology transfer and access to markets throughout the whole value chain. [10] Revitalization of extension services to increase the skills and knowledge base of food producers (often women) is critical to

Topics	Evidence
	achieving sustainable increases in productivity in both low-income and high-income countries. [1] Gaps: Making agricultural extension services a key component of any strategy to ensure that science and technologies / best practices are appropriately developed and targeted. [9] Case studies: Europe and Central Asia Regional Program on Reducing Vulnerability to Climate Change in Agricultural Systems: three year program of analytical and advisory activities is designed to better determine the potential impacts of climate change on the agricultural sector in four countries, including Albania; develop practical recommendations on the actions these countries can take to increase the resiliency of their agricultural sectors in the face of climate change; enhance the ability of countries in the Europe and Central Asian region to mainstream climate adaption into agricultural policies, programs and investments. [12] African Agricultural Carbon Facility that could incubate mitigation projects and help connect them with buyers. [16] Network of Farmers' and Agricultural Producers' Organizations of West Africa. Chilean Asociacion Nacional de Mugeres Rurales e Indigenas. Bangladesh Agriculture Farm Labor Federation. National Federation of Fishworkers in Sri Lanka. [16]
What investments (technical, political, financial, social) are essential to an alternative future food system and who can make them?	
Integrated information & response systems	Risks: Extremely poor data sources in critical areas: (1) Biophysical data – current climate and future scenarios, land use, soil characteristics, ecosystem services; (2) Socioeconomic data – demand and supply parameters; links to and from agriculture to other sectors; macroeconomic trends. [4] Opportunities: Improvements to spatial and other data for modeling, scenario analysis, characterization of food production systems, monitoring, and impact assessment (e.g., CGIAR's Consortium for Spatial Information, HarvestChoice, International Household Survey Network). [11] AfSIS project will greatly improve the data on African soils. Various efforts underway to improve the quantity, quality, and accessibility of weather data, especially in developing countries. Living Standards Measurement Study-Integrated Surveys on Agriculture will improve socioeconomic household data in Africa. [4] Geographic information systems and remote sensing by satellites are opening new ways to synthesize complex and diverse spatial data sets, creating new collaboration among scientists, policy makers and farmers (p. 165). [13] Evidence: Recommendations:

Topics	Evidence
	Tailor agricultural climate impact predictions to the needs of decision-makers at household, district and national levels (e.g., AgMIP, EQUIP). [11] Development of food stock management, effective market intelligence and early warning, monitoring, and distribution systems. [3] Decision support: cost-benefit analysis, risk assessment, multi-criteria analysis, the precautionary principle, and vulnerability analysis, scenarios (characteristic uncertainty), active adaptive management (account for high levels of uncertainty for ; i.e., design of management programs to test hypotheses about how components of an ecosystem function/interact to accelerate reduction of uncertainty in coupled socio-ecological systems). [7] Integrate information about productivity, environmental, economic, and social aspects of farming systems to understand their interactions and address issues of resilience and vulnerability to changing climatic and economic conditions. [8] Developing better and more comprehensive metrics of GHG emissions in the global food system should be a priority. Government-backed schemes setting sector-wide sustainability standards would obtain strong support from industry and be a very positive contribution to increasing sustainability.[1] Inter-organizational coherence and politically sophisticated approaches that recognize that climate adaptation will rarely if ever be a purely technical endeavor. [15] <u>Gaps</u>: What combination of new products, services, delivery mechanisms and institutional arrangements offers the best opportunity to deliver useful, equitable, transferable and scalable climate risk-management in rural areas? [11] <u>Case studies</u>:
Monitoring, forecasting and warning systems	<u>Risks</u>: Lack of freely available, regularly repeated observations via satellite of the surface of the earth, at temporal and spatial resolutions that would make it possible to track changes in agricultural practices and land use more generally. [4] Natural disasters (floods, droughts and fires). Changes in weather patterns over time. Increased incidence of pests, diseases and weeds. [1] Many countries have under-invested in the key “public good” of weather and climate information: not available and easily accessible to a range of different users, including farmers and herders, foresters and fishermen; gaps in the collection, analysis and dissemination of basic hydro-meteorological monitoring parameters in many countries. [12] <u>Opportunities</u>: Advances include better remote sensing of weather information (including prospects to backfill missing daily weather data from historical records), validation of different land-use products using Wikis and Google Earth (“crowdsourcing”) and dissemination of information using mobile phone technology, to name just a few. But many of these things need to complement land-based observations, not substitute for them. [11]

Topics	Evidence
	Robust agricultural, public health, and veterinary detection, surveillance, monitoring, and response systems can help identify the true burden of ill health and cost-effective, health-promoting strategies and measures. [3] Plan for losses and take advantage of opportunities. Monitoring and forecasting pests/diseases. Parcel-scale decision support systems: shift beyond local maxima and balance long- and short-term considerations. [1] Remote sensing technologies for communicating precise information about soil moisture and irrigation needs can eliminate unnecessary application of water. [14] <u>Evidence</u>: Support to early warning systems (Kenya). [12] <u>Recommendations</u>: Linking climate models, crop models and economic implications to consider the interactions of different technical and policy sectors (e.g., agricultural intensification for both food production and mitigation). [11] Consistent/coherent projections of climate change impacts on determinants of food security. [2] Improved risk forecasting for livestock disease (e.g., field surveillance) and other threats. [2] Warning for drought, flood, pests, disease (e.g., EMPRES). Agrometeorological crop monitoring/yield forecasting (e.g., Crop Monitoring Box). Local climate estimate tools. Dynamic adaptation methodologies. [2] Cost-effective monitoring of trends in the utilization of natural resource capital. [3] Enable citizen data-gatherers, equipped with GPS-enabled camera phones and other measuring devices. [4] Collection, analysis and dissemination of basic hydro-meteorological monitoring parameters. Greater sharing of information between countries. [12] Improve surveillance and early-warning systems. [15] <u>Gaps</u>: How can information from global climate models and regional climate models be incorporated into support for adaptation processes that in agriculture and food systems are both location-specific yet robust enough to apply across the range of plausible climate futures? [11] <u>Case studies</u>: Kenya: The Arid Lands Resource Management Project helps agro-pastoralists in the north and north-east manage risk posed by drought and other factors through a mix of community driven technical and social interventions, including innovative early warning systems and drought contingency funds, and strengthening and institutionalizing natural resources and drought management systems. [12]

Topics	Evidence
New modeling tools / approaches	Risks: Opportunities: Evidence: Recommendations: For yield outcomes, include in models: investments in agricultural productivity by the public and private sectors; technology dissemination by research and extension agencies and input suppliers; and investments in infrastructure, such as rural roads. For change in agricultural area, include in models: exogenous (historical trends and assessments about future changes, including urbanization and other land use change) and endogenous (price-responsive) components. [4] Systematic comparison of different models of the food system is required to improve understanding of variation in methods and results. [1] Availability, coverage, quality and accessibility of spatially explicit datasets for global production and trade, land use and hydrology, which form the basis for model calibration and validation, require improvement. [1] Gaps: Case studies: New approaches to tailor agricultural climate impact predictions to the needs of decision-makers at household, district and national levels: e.g., Agricultural Model Inter-comparison and Improvement Project (AgMIP), a highly distributed climate-scenario simulation activity for historical model comparison and for future climate change conditions. AgMIP is being designed on the basis of the participation of multiple crop, livestock and world agricultural trade modeling groups around the world, with the goals of improving the characterization of food security due to climate change and to enhance adaptive capacity in both low-income and high-income countries; EQUIP (End-to-end Quantification of Uncertainty for Impacts Prediction, www.equip.leeds.ac.uk), a consortium project bringing the UK climate modeling, statistical modeling, and impacts communities together to work on developing risk-based prediction for decision making in the face of climate variability and change. [11] Recent food price spikes. Comparison between different results from dynamic computable general equilibrium models. [1]
Climate changes & biophysical responses	Risks: Growing consensus that by 2050 the world will become warmer, especially at higher latitudes; patterns of precipitation will change with lower latitudes and particularly equatorial regions likely to become drier and high latitudes wetter; there will be more frequent extreme weather events; droughts and temperature extremes will become more common; flooding events will increase in frequency; and there is also a small but real probability of significant climate-system disruption – a "tipping point" – before 2050. [1] These developments will have direct affects on food production, but also indirect effects through changes in flows of major rivers; rises in sea level; possible effects on the pests and diseases of agriculture; movements and changes in productivity in

Topics	Evidence
	fish stocks through changing coastal and oceanic water currents, temperature and salinity profiles, food availability, changing coastal and estuarine environments and inland flooding patterns. CO_2 itself has a direct effect on plant growth (CO_2 fertilization). [1] Because of global warming (and other issues) global, national, and local production shocks could become more frequent (p. 68). [13] Opportunities: Indirect effects of climate change through pests and diseases have been studied locally but a global assessment is not yet available. [1] Drought may be offset to some extent by an increased efficiency of water use by plants under higher CO_2 concentrations, although the impact of this is uncertain especially at large scales. [1] The world is poised for another technological revolution (GMO's) in agriculture using the new tools of biotechnology to deliver significant yield gains (p. 67). [13] Evidence: An increase in mean temperature can be confidently expected, but the impacts on terrestrial and aquatic productivity may depend more on the magnitude and timing of extreme temperatures. Mean sea level rise can also be confidently expected, which could eventually result in loss of agricultural land through permanent inundation, but the impacts of temporary flooding through storm surges may be large although less predictable. Fresh water availability is critical in all areas of food production, but predictability of precipitation is highly uncertain. Agricultural impacts in some regions may arise from climate change impacts elsewhere, due to the dependency on rivers fed by precipitation, snowmelt and glaciers some distance away. Availability of water at the land surface depends on evaporation, which itself is affected by climate change. Higher temperatures increase evaporation, so in the absence of other changes, a warming world would tend to dry the land surface more. [1] Recommendations: The potential severity of the effects of climate change, together with the long time constants expected for agriculture to adapt to new climatic conditions imply the need to develop policies and agricultural technologies and methods that are more robust and resilient to the range of future climatic uncertainties. Much more work is needed to improve the assessment of the potential impacts of various climate change effects on food production, particularly as climate models increase temporal and spatial resolution, providing better estimates of the location and timing of specific climatic events, and potential impact on agro-biodiversity. [1] Gaps: Understanding interactions among components of the farming system and the food system (e.g., outcomes from adaptive strategies), and effects on uncertainty about the range of plausible futures. [11] Making precise regional predictions about the course of climate change is not possible. [1]

Topics	Evidence
	Case studies:
Agricultural & socio-economic responses	Risks: Mismatch between farmers' needs and the scale, content, format, or accuracy of available information, products, and services inhibits widespread use of seasonal forecasts among smallholder farmers. [11] The measurement of, and learning about, the impact of agricultural interventions on human development outcomes is weak. This stems from confusion as to what agriculture is for, the long causal chains from intervention to human development outcome and the climate uncertainty that agriculture is subject to. But they are not insurmountable barriers. Mixed method approaches to agricultural monitoring and evaluation are available. They must be used to understand what works, why, how and when. Agricultural organizations need to be incentivized to use these methods and to learn from them. [1] Opportunities: Seasonal climate forecasts, in principle, provide opportunity for farmers to adopt improved technology, intensify production, replenish soil nutrients, and invest in more profitable enterprises when climatic conditions are favorable; and to more effectively protect their families and farms against the long-term consequences of adverse extremes. [11] Agro-ecology for poverty alleviation and natural resources preservation. [5] Most producers live in a world of imperfect information, and are subject to considerable uncertainty with regard to weather conditions, pest attacks, and market options; some of these could be mitigated by better access to ICT. [1] Evidence: If socio-economic, institutional and political conditions were more favorable to the uptake of new technologies and practices, there would be a growth in agricultural productivity. [1] Recommendations: Use climate-based forecasts of food production to better manage trade and stabilize prices, offers considerable potential benefits to both agricultural producers and consumers (Arndt and Bacou, 2000; Arndt et al., 2003; Hallstrom, 2004; Hill et al., 2004). [11] Extension services, farmer field schools and other initiatives have a critical role in promoting social learning, and should be encouraged. [1] Gaps: What is the feasibility and best strategy to use advanced information to target and initiate safety net interventions and responses to climate-related market fluctuations and emerging food crises? [11] Case studies:

Topics	Evidence
Adaptive learning & technology transfer platforms	Risks: Opportunities: Enable accelerated adaptation without threatening sensitive livelihood systems as they strive to cope with stress: analysis of farming and food systems, learning from community-based approaches, generation and use of new technologies, changes in agricultural and food supply practices including diversification of production systems, improved institutional settings, enabling policies, and infrastructural improvements, and above all a greater understanding of what is entailed in increasing adaptive capacity (Agrawal and Perrin, 2008; Tubiello et al., 2008). [11] Public investments in agricultural knowledge systems to promote interactive knowledge networks (farmers, scientists, industry and actors in other knowledge areas); improved access to information and communication technologies (ICT); ecological, evolutionary, food, nutrition, social and complex systems' sciences; effective interdisciplinarity; capacity in core agricultural sciences; and improving life-long learning opportunities along the food system. [3] Account for increased uncertainty and enhance adaptation to a variety of climate futures – not just "optimally" cope with the climate of the past. [14] Evidence: The function of providing need- and demand-based knowledge, skills, and technologies to farmers with the objective of improving their production and livelihoods; this encompasses a wide range of communication and learning activities delivered by professionals from different disciplines and institutions. [1] Recommendations: Transfer of best practices and technology from one site (e.g., grounded in local knowledge): agronomic innovations, planting strategies, improved livestock and fish management systems, pest and disease management, diversification of agriculture and livelihoods, and enhancement of agro-biodiversity (Easterling et al., 2007). [11] Platforms for collaborative action, information-sharing (e.g., weAdapt, WOCAT) among modelers, practitioners, donors. Data/tool portals (e.g., CLIMPAG). [2] Empower farmers to innovatively manage soils, water, biological resources, pests, disease vectors, genetic diversity, and conserve natural resources in a culturally appropriate manner. Combine farmers' and external knowledge through partnerships among farmers, scientists and other stakeholders. Connect globalization and localization pathways that link locally generated knowledge and innovations to public and private research. [3] Public investments in agricultural knowledge systems to promote interactive knowledge networks (farmers, scientists, industry and actors in other knowledge areas); improved access to information and communication technologies (ICT); ecological, evolutionary, food, nutrition, social, and complex systems' sciences; effective interdisciplinarity; capacity in core agricultural sciences; and improving life-long learning opportunities along the food system. Develop networks of farmer organizations, NGOs, government, and private sector to facilitate long-term natural resource management. [3]

Topics	Evidence
	Mixed-method approaches to agricultural measurement and evaluation are available. They must be used to understand what works, why, how, and when. Agricultural organizations need to be incentivized to use these methods and to learn from them. [1] Traditional and indigenous knowledge needs to be linked with modern technologies with the latest scientific knowledge about climate-smart agriculture. [10] Knowledge platform to combine different sources of rural/agricultural development finance and to support climate resilience, low carbon, and agricultural productivity/food security objectives together (UNDP, World Bank). [12] <u>Gaps</u>: How to effectively manage the collaborative generation of knowledge among increasingly heterogeneous contributors and the flow of information among diverse public and private research activities and institutions? [3] <u>Case studies</u>: Leading ICT provision to farmers in India (p. 176). [13] ProInnova-supported projects where farmers share information via workshops, meetings, photographs, and the Internet. [16]
Holistic risk / opportunity assessment & management	<u>Risks</u>: <u>Opportunities</u>: The total economic value associated with managing ecosystems more sustainably is often higher than the value associated with the conversion of the ecosystem through farming, clear-cut logging, or other intensive uses. [7] Long-term, large-scale integrated management and flexible planning can satisfy increased demands on natural resources for food, bioenergy, hydropower, and ecosystem services while conserving biodiversity and maintaining carbon stocks in land and forests. [14] <u>Evidence</u>: <u>Recommendations</u>: Develop tools for modeling of systems and patterns for multipurpose economic, aesthetic, and environmental impacts to enhance community well-being and assist in planning, local policy making, market identification, and farmer decision making. [8] In measuring how GHG emissions are affected by different strategies, it is critical to include not only the direct but also the indirect consequences, such as effects on land use conversion and those mediated by global trade. [1] Jointly evaluate development, adaptation, and mitigation actions, all of which draw on the same finite resources (human, financial, and natural). [14]

Topics	Evidence
	Gaps: Case studies:
Regional capacity building	Risks: A big challenge in integrating farmer organizations into technological innovation is that their leaders are at an educational and social disadvantage level relative to scientists and technical advisors (p. 172). [13] Opportunities: Regional Climate Outlook Forums (RCOFS), which bring national meteorological services and a set of users from a region together to produce authoritative consensus seasonal climate forecasts, and discuss their potential application (Dilley, 2001). [11] Developing managerial capacity for high value chains (p. 156). [13] Evidence: Recommendations: Improved information access/knowledge sharing. Climate information "translators" to practitioners, policy makers. Sustainable financial models for agricultural extension, farmer field schools. [2] Producer organizations with international memberships (p. 155). [13] Gaps: Case studies:
R&D investments	Risks: Among the rich countries, just two, the USA and Japan, accounted for 54% of public spending in 2000, and three developing countries, China, India and Brazil, accounted for 47% of the developing world's public agricultural research expenditures. Meanwhile, only 6% of the agricultural R&D investments worldwide were spent in 80 mostly low-income countries whose combined population in 2000 was more than 600 million people. In the industrialized countries investment by the private sector has increased and is now higher than total public sector investments. In 2000, private firms invested only 6% of total spending in the developing world. [3] Research on the economic and social dimensions of agricultural sustainability complementary to research on productivity and environmental sustainability is scarce. [8] Global agriculture demands a diversity of approaches, specific to crops, localities, cultures and other circumstances. [9] No technological panacea. There will always be trade-offs and local complexities. [9] Underfunding of agricultural sector in developing countries. OECD agricultural subsidies (USD 260B/yr). [12]

Topics	Evidence
	Growth in public spending on R&D, after rapidly increasing in the 1960s and 1970s, has slowed sharply in most regions in the past decade or more, opening a knowledge divide between poor countries and rich countries and within the developing world between a handful of "star performers" and most of the others. Intensity of public investment (in relation to agricultural GDP) is five times higher in industrial countries. [13] Few companies have figured out ways to profit from encouraging the rebuilding of soils or aquifers. Since 1986, of the total US investment in agricultural research, the public sector contribution declined from 54% to 28%. [16] Only 9 African nations allocate even 10% of their national budgets to agriculture. [16] <u>Opportunities</u>: Address the needs of small-scale farmers in diverse ecosystems and create realistic opportunities for their development. [3] High rates of return per unit of investment in agricultural R&D have been documented in all regions, especially in crops and in farming systems that have been the focus of the AKST apparatus. Some of the conditioning factors for high rates of return lie outside agriculture and AKST in complementary investments such as rural infrastructure or microcredit units that reduce market transaction costs or provide appropriate institutions or norms. [3] The AKST apparatus tends to focus on mainstream, input-intensive, irrigated monocropping systems – mainly cereals, livestock and other trade-oriented commodities, to the relative neglect of arid/dryland agriculture, mountain ecosystems, and other non-mainstream production systems. [3] There are opportunities for research in all sectors with relevant expertise existing within the public, private, and charities sectors. [9] Translation and application of new and previously executed basic research. [9] Recent scientific and technological advances offer significant new opportunities to address major environmental challenges. [1] Making R&D more responsive to farmers and the market (p. 172). [13] <u>Evidence</u>: Private farmers have played a key role in innovation, especially where the enabling environment has been favorable. [12] 94% of the agricultural R&D in the developing world is conducted by the public sector. Developing countries as a group invested 0.56% of their agricultural GDP in agricultural R&D in 2000 (including donor contributions), only about one-ninth of the 5.16% that developed countries invest. Part of this disparity is because private investment makes up just over half of R&D spending in industrial countries but only 6% in the developing world. In the 1990s, public R&D spending in sub-Saharan Africa fell in nearly half the 27 countries with data, and the share of agricultural GDP invested in R&D fell on average for the whole region. [13] <u>Recommendations</u>: Link investments in technological innovation and agricultural intensification strategies to increased efficiency of inputs, and to comprehensive land use policies and payments for environmental services that discourage forest conversion and negative environmental impacts. [11]

Topics	Evidence
	Incorporation of climate change into agricultural research programs. [2] Revisit emphasis on: R&D to deliver component technologies to increase farm-level productivity; continuous innovation to reduce farm gate prices and externalize costs. Redirect science and technology toward multi-functionality in agriculture. Greater focus on management systems – from crop to whole farm to natural resource area, landscape, river system, and catchment scales. Management systems require sophisticated understanding of the institutional dimensions of management practices and of decision processes that must be coordinated across variable spatial, temporal, and hierarchical scales (e.g., legal and policy frameworks). Public-private partnerships for improved commercialization of applied knowledge and technologies where market risks are high and where options for widespread utilization of knowledge exist. [3] Changes in agricultural education, research, and advisory systems to develop greater knowledge and capabilities around issues of agricultural markets, sustainability, risk and cost reduction, and farm systems – in addition to technology and inputs. [6] Continuous research, extension, and experimentation by researchers and farmers are necessary to provide the toolkit necessary for farmers to adapt their systems to the changing environmental, social, market, and policy conditions to ensure long-term sustainability. [8] Training in agricultural sciences and related topics needs more policy attention and support. [9] Novel research methods have the potential to contribute to food crop production through both genetic improvements of crops and new crop and soil management practices. [9] No techniques or technologies should be ruled out. [9] Regular calls for research to allow phased research activities for pursuing successful ideas in the field or in new countries. [9] Support for joint initiatives between public sector and industry with explicit aim of translating and applying basic research. [9] Development of new technologies for agriculture requires a cross-disciplinary approach in which mathematics, physics, chemistry, ecology, and the crop sciences (including genetics, pathology, entomology, and soil science) are integrated, and the outcomes of research linked with social and economic science. [9] Reversal of the low priority accorded to research on agriculture, fisheries, and the food system in most countries [1]. Ways to increase investment in R&D: Forming coalitions of producers and agribusinesses around particular commodities or value chains to lobby for more public funding and for producers and agribusiness to co-finance R&D. Institutional reforms to make investing in public R&D organizations more attractive – and more effective. Remove barriers to private investment (e.g., weak demand from smallholders for improved technologies because of risks, credit constraints, and poor access to information) (p. 168-169). [13] Focus on reduction of pre- and post-harvest losses (better storage and processing in rural areas), increased farm productivity (e.g., agro-ecological farming) and increase in R&D, capacity for sustainable agriculture. [16] Gaps: Development of a pluralistic research portfolio. New incentives to incentivize R&D that meets needs of low income countries

Topics	Evidence
	and where at least initial returns on investment will be low. [1] <u>Case studies</u>: The pace of technology generation and adoption has been highly uneven. North America and Europe continue to dominate in the volume and variety of agricultural exports, extended value chains, and the generation of agricultural technologies (high-yielding varieties, synthetic fertilizers, pesticides, and mechanization technologies) as well as recent advances in organic and sustainable production. [3] China has demonstrated the effectiveness of agricultural research in raising productivity. [1] China, India, and to a less extent, Brazil – have rapidly increased their spending on agricultural R&D over the past two decades. Their shares in developing country public spending in agricultural R&D increased from a third in 1981 to almost half in 2000. Including spending on science and technology for all sectors, these three countries accounted for 63% of the total – which is meaningful, because an increasing share of agricultural R&D is carried out in general science and technology organizations. The private sector also has a growing presence in these countries, where expanding agricultural input markets provide incentives to invest. [13] In recent years, CGIAR has added centers focused on agroforestry, IPM, and irrigation (with nearly 25% of the CGIAR's budget). [16]
Scientific basis of climate-friendly farming and food systems	<u>Risks</u>: Lack of information on the economic viability of practices and approaches to improving environmental and social sustainability and on how markets and policies influence the economics of those practices. [8] <u>Opportunities</u>: Credible commitment by high-income countries to drastically reduce their emissions would stimulate the needed R&D of new technologies and processes in energy, transport, industry, and agriculture. [14] <u>Evidence</u>: <u>Recommendations</u>: Field-test technical compatibilities on farms. [11] Comparative study on GHG emissions and nutrient balances associated with different field management practices for animal wastes and other organic amendments such as green manures and organic mulches and composts. [8] Address major knowledge gaps that urgently require further research. They include the ecological basis of many ecosystem services and their resilience to perturbation; the economic assessment and valuation of ecosystem services and biodiversity; the development of a more analytical evidence base to judge amongst different management alternatives. [9, 11] <u>Gaps</u>: Need improved modeling of agricultural sensitivity for climate change. [1]

Topics	Evidence
	Case studies:
Plant, animal and aquatic breeding / selection	Risks: The use of patents for transgenes, in developing countries especially, may drive up costs, restrict experimentation by the individual farmer or public researcher while also potentially undermining local practices that enhance food security and economic sustainability. [3] Industrial confinement of livestock systems is associated with the decline in a number of minor breeds and the accelerated development of genetically similar hogs, poultry, and beef and dairy cattle. [8] Long lead times for breeding programs. [9] Hybrid crop seeds: intellectual property can be protected by trade secrets. Farmers must purchase hybrid seed frequently to maintain its yield advantage, providing a steady market for private seed companies. [13] Public investment is especially important for funding agricultural R&D where markets fail because of the difficulty of appropriating the benefits. Seeds of many improved varieties can be reused by farmers and sold or shared with neighboring farmers (non-excludable). Information on improved management practices can be freely exchanged (non-rival). IPRs have partially overcome these market failures in industrial countries, but few technologies of importance to poor farmers can be cost-effectively protected by IPRs. [13] Public-private research partnerships focused on genetic engineering influence biosafety and IP rules and dominate research institutions to the disadvantage of farmer-led agro-ecological innovations. [16] IP regimes tend to favor large corporations as patent holders. [16] Opportunities: New crops and breeds. New adaptation traits. New diversified feed and forage crops. [9, 11] Genetic methods have the potential to introduce radical and highly significant improvements to crops by increasing photosynthetic efficiency, reducing the need for nitrogen or other fertilizers and unlocking some of the unrealized potential of crop genomes. [9] Capitalizes on recent advances in biosciences. Maintains genetic bank of variation that can be used in selection of novel traits [1]. Improvement in efficiency and sustainability of animal production (both livestock and aquaculture) and crop production [1]. GMO's ensure continuing yield gains through better resistance to disease and tolerance for drought and other stresses (p. 67). [13] Evidence: Recommendations: Expanding use of local and formal AKST (e.g., conventional breeding, participatory decentralized breeding, and

Topics	Evidence
	biotechnology) to develop and deploy suitable cultivars (millets, pulses, oilseeds, etc.) and better agronomic practices that can be adapted to site-specific conditions [CWANA; ESAP; SSA]. Breeding and improvement work on some minor crops in different subregions. [3] Enhancing in situ and ex situ conservation of agro-biodiversity through broad participatory efforts to conserve germplasm and recapture the diversity of plant and animal species traditionally used by local and indigenous people. [3] Governments should support public sector crop breeding and genomics programs to understand, preserve and enhance germplasm of priority crops and train the next generation of plant breeders. Public sector support for breeding needs to emphasize longer term strategic approaches that can be expected from the private sector and develop traits from public sector research. [9] Support long-term high-risk approaches to high-return targets in genetic improvement of crops (e.g. improved photosynthetic efficiency or nitrogen fixation; reduced environmental impact through using less fertilizer or grown as perennials, etc). [9] Varieties, including livestock, which are more robust to drought and flood. [10] Development of new varieties or breeds of crops, livestock and aquatic organisms [1]. Preservation of multiple varieties, land races, rare breeds, and closely related wild relatives of domesticated species [1]. Consultative processes are critical for harnessing public support for transgenics policies (p. 178). [13] "Revision of intellectual property laws toward a more equitable system that recognizes farmers' rights to save, use, exchange, and sell seed." (p. 174) [16] Gaps: How can climate-driven shifts in the geographical domains of varieties, cultivars, wild relatives, pests and diseases, and beneficial soil biota be anticipated and best managed to protect food security, rural livelihoods and ecosystem services? [11] Case studies: Fund under the International Treaty on Plant Genetic Resources for Food and Agriculture. [10]
Agronomic and soil management practices	Risks: Relatively neglected in recent years [1]. Opportunities: Research on a broad range of subjects, including areas that have received less investment in recent years, is critical to improving yields and sustainability at the same time [1]. Technological revolutions in crop management via zero tillage (p. 164). [13] Evidence: Recommendations:

Topics	Evidence
	Innovations needed: (1) to maintain yields while using much less chemical fertilizers and pesticides (especially in OECD and ASIA) and to increase yields in spite of climate change in regions such as MENA or LAM; (2) to overcome biodiversity loss and GHG emissions caused by large land conversion; (3) to make agriculture attractive. [5] Assessment of the effectiveness of cover crops in providing ecosystem services such as biological control of agricultural pests and weed suppression, and nutrient and water retention. Assessment of water reuse systems, surface and subsurface drainage systems, and advanced livestock waste management systems that improve the effectiveness of wetlands, enhance water quality and water conservation, and reduce GHG emissions. [8] Increase support for ecosystem-based approaches, agronomy and the related sciences that underpin improved crop and soil management. [9] Funding support needed for scientific and technological advances in soil science and related fields [1]. Targeted research in modern crop and animal science, agro-ecology, agricultural engineering, and aquaculture management [1]. Gaps: Case studies:
Pest / disease management	Risks: Intensification increases the opportunity for diseases to spread, and globalization heightens the risk that these agents are transported around the world. Keeping pace with evolving threats such as the emergence of new and more virulent pests and diseases. [1] Zero tillage makes the control of pest and diseases more complex. [13] Opportunities: Minimize pesticide use through IPM strategies and timing of crop planting. [1] Recent scientific advances (for example, in entomology, disease resistance, immunology, and vaccine development) offer great potential to develop new ways to protect food production. Continuing improvements in crop protection and biotechnology may increase yield stability, through resistance to new and newly emerging pests and diseases. [1] Use of modern scientific advances to produce crop varieties that are less susceptible to pests and spoilage, and to develop natural and synthetic insecticides to manage storage pests. In addition, development of simple low-cost technologies such as mini combine harvesters, grain-drying equipment, mechanical rice threshers/winnowers, or better fish-smoking kilns that reduce losses and demand less fuel. [1] Evidence: Recommendations: Research and development of nonchemical alternatives (for example, biological control, biofumigation, induced resistance,

Topics	Evidence
	and soil suppressiveness) for managing weeds, pests, and disease as a complex. [8] Research is required to maintain productivity at current levels because weeds, pests, diseases, and pathogens continually evolve. [1] Gaps: Case studies: Rothamsted Research Station (UK) and International Center on Insect Physiology and Ecology: ecologically based pest management solution for stem borers and striga weed in East African grain production. [16]
Socio-economic interventions (e.g., nutrition / eating habits)	Risks: Opportunities: Evidence: Innovations in S&T are strongly related to innovations in spatial and social organization (p. 222-228). [5] Recommendations: Policies and programs to diversify diets and improve micronutrient intake. Develop and deploy existing and new technologies for the production, processing, preservation, and distribution of food. [3] Foster effective organizations to create opportunities for poor rural people in agriculture and the non-farm economy: to work with youth; to promote improved risk management; to conduct education and training where the state is absent; and to support the organizations of poor rural people. [6] Assessment of how production practices might affect food attributes (such as pesticide residue, taste, nutritional quality, and food safety). [8] Gaps: How do social, cultural, economic, and institutional factors mediate adaptation processes at the local level and how can these be mobilized to improve resilience? [11] Case studies:
Policy experimentation	Risks: Decision-makers need not just a holistic view of the system but rather a strategic approach that focuses on key dependencies and processes. [11] Recent decades: low global food prices coupled with low levels of investment in agriculture, inappropriate policies, thin and uncompetitive markets, weak rural infrastructure, inadequate production and financial services in developing countries. [6] Unclear land rights. Lack of infrastructure. [12]

Topics	Evidence
	Opportunities: Improve livelihoods through: access to microcredit and other financial services; legal frameworks that ensure access and tenure to resources and land; recourse to fair conflict resolution; progressive evolution and proactive engagement in IPR regimes and related instruments; long-term land and water use rights/tenure. Promote agro-insurance. [3] Developing countries would benefit from the removal of barriers for products in which they have a comparative advantage; reduction of escalating tariffs for processed commodities; deeper preferential access to markets; increased public investment in rural infrastructure and the generation of public good agricultural knowledge; improved access to credit, knowledge resources, and markets for poor producers; compensation of revenues lost as a result of tariff reductions. [3] Domestic food markets: rapidly expanding, becoming more differentiated in many countries (new opportunities/risks for smallholders). International trade and markets: growing integration of global agricultural supply chains, emergence of large economies like Brazil, China and India as massive sources of both demand and supply of agricultural products. In many developing countries, rural and urban areas are ever more interconnected. Proportion of people of working age in developing country populations is increasing. [6] Integration of monetary resources, knowledge resources, capacity development, public support, and awareness. [10] Continuous horizon scanning to identify future issues, combined with reviews were appropriate, models and experiments, should improve capacity to make decisions when the evidence is available. [9] Models like IFPRI's IMPACT model, which integrates climate, crop, water, and economic modeling, will become key policy tools in helping policymakers to consider the resilience of food production and agricultural markets to future changes in climate. [1] Programs to develop efficient fertilizer markets and agroforestry systems to replenish soil fertility through legumes need to be scaled up (p. 233). [13] Evidence: Agriculture needs to be placed centrally in a number of long-term policy challenges, including global food security, land use, and renewable energy. [1] Recommendations: Policies that improve access and rights to water through investments in storage facilities or community-managed irrigation systems could aid rural communities in overcoming short- or long-term periods of drought (IWMI, 2009). [11] Index insurance mechanisms (weather-based indices). Social safety nets (public sector/NGOs). Payments for environmental services. [2] Fundamental shift in science, technology, policies, institutions, capacity development, and investment. [3] Special and differential treatment accorded through trade negotiations can enhance the ability of developing countries to pursue food security and development goals while minimizing trade-related dislocations. [3] Market and trade policies to facilitate the contribution of AKST to reducing the environmental footprint of agriculture include

Topics	Evidence
	removing resource use-distorting subsidies; taxing externalities; better definitions of property rights; and developing rewards and markets for agro-environmental services, including the extension of carbon financing, to provide incentives for sustainable agriculture. [3] Ensure a sustained flow of development funding to the rural sector. Ensuring a positive rural investment climate; ensuring an enabling policy framework for rural investors and rural enterprises – both agricultural and non-farm – to operate; providing infrastructure, particularly transportation, but also energy and water; strengthening public utilities and telecommunications; improving rural services, from education and health care to financial, advisory, and business development services; and ensuring that policies are implemented, public utility works and laws are respected, in an overall environment of good governance. [6] Removal of production subsidies that have adverse economic, social, and environmental effects. Investment in and diffusion of agricultural science and technology that can sustain the necessary increase of food supply without harmful tradeoffs involving excessive use of water, nutrients, or pesticides. Use of response polices that recognize the role of women in the production and use of food and that are designed to empower women and ensure access to and control of resources necessary for food security. Application of a mix of regulatory and incentive- and market-based mechanisms to reduce overuse of nutrients. [7] Addressing climate change and achieving sustainability in the global food system need to be recognized as dual imperatives. Nothing less is required than a redesign of the whole food system to bring sustainability to the fore. [1] Policy makers need to prioritize where to focus efforts, and how best to deploy scarce resources. [1] It is important to develop a strong evidence base upon which to make informed decisions, and to consider all potential policy options without excluding any options. [1] Clear, simple legal, fiscal and institutional frameworks (adapted to country circumstances; easy to understand/enforce). [12] Re-orient agricultural support programs: do not distort private farmer production patterns; enhance "underlying drivers" of sustainability and competitiveness, such as support for improved soil and water management, infrastructure, energy, communications to improve market access, research and knowledge (EU Common Agricultural Policy). [12] Extend the green revolution in food staples to areas bypassed by technological progress and with large numbers of poor, including many of the extreme poor, and provide safety nets. Promote livestock activities among the landless and smallholders as a substitute for land. [13] Integrated assessments of financing needs for climate change adaptation, agriculture, food security and development aid, taking into account the overlaps. [15] <u>Gaps</u>: What are the consequences of international, national and local policy and program options for improving environmental benefits, enhancing livelihoods, and boosting food security in the face of a changing climate? [11] <u>Case studies</u>:

Topics	Evidence
	Uzbekistan: Water Saving and Rational Water Use in Irrigated Land Tenure Strategy. [12] Local/state food policy councils (e.g., Canada, India, the Netherlands, UK, USA). [16] Ombudsman/independent authority for reconciling divergent agricultural development models (e.g., International Finance Corporation (IFC), Multilateral Investment Guarantee Agency (MIGA) in World Bank). [16]
New global funds / policies	Risks: Countries have historically responded to extreme seasonal or annual production shocks by restricting trade or pursuing large purchases in international markets (e.g. Chinese rice in 2008, Russian wheat in 2010). Risk of conflicting policies and investments contributing to maladaptation. [11] Estimated costs for agricultural adaptation (>USD 2.5B/yr), mitigation (>USD 12-14B/yr) in developing countries. Weak existing financing mechanisms (e.g., CDM, GEF) and risk of fragmentation of new mechanisms. [2] Current global aid architecture in general and the aid effectiveness agenda specifically, have not yet shown great success in the agricultural sector or in reducing rural poverty. [6] Context specificity of drivers, risks and opportunities for development in rural areas of the developing world. [6] Path dependence: donor governments have used existing aid channels. Environmental issues are being given much higher priority than in the past at all levels, but this must be continued and strengthened. [1] Agriculture not eligible for CDM. Carbon finance has supplemented other finance so far to a limited extent, and mostly in middle income countries. [12] Despite the recent effervescence of institutional innovations across a broad range of countries and markets, huge institutional gaps remain in supporting the competitiveness of smallholders. Land markets are still incomplete and inefficient. Financial markets are still laden with asymmetries of access and information. Insurance against risk is available to only a few individuals and communities. Input markets are inefficient as a result of small scale and distorted by subsidies that tend to benefit more the larger landholders. Producer organizations are only beginning to represent the interests of poor smallholders (p. 157). [13] Most investments are focused on increasing global food supply, expanding the role of agribusiness and expanding trade rather than reinvigorating local markets and smallholder producers. [16] Investments in agricultural development by governments, international lenders, and foundations are near historic lows. [16] Opportunities: Counting agricultural GHG reductions towards countries' emissions reductions commitments could create an important policy incentive (Paustian et al., 2004). [11] L'Aquila G8 (USD 20B). Copenhagen Accord Fast Start funds (USD 30B for 2010-12; USD 100B by 2020). Existing multi-/bi-lateral funds (USD 8B/yr.). Proliferation of new mechanisms (~20). [2] The international donor community has taken a number of initiatives that demonstrate a commitment to support developing countries' efforts to promote agriculture (notably smallholder agriculture) and rural development. [6]

Topics	Evidence
	Key role for development organizations will include piloting new approaches and ways of working as a route for learning; supporting policy analysis and reform; and working with governments to learn the lessons of small-scale initiatives and assisting them to scale up successes through larger, in some cases national, programs. [6] At global and international levels food security and environmental protection are interdependent. International policy needs to ensure that countries obtain benefits from providing global goods, especially when costs are borne by low-income countries, and avoid policies that have negative environmental impacts in other countries. [1] Food self-sufficiency is not a viable option for nations to contribute to global food security. Crafting food system governance to maximize the benefits of globalization and to ensure that they are distributed fairly. [1] New funds: Global Agriculture and Food Security Program. Global Food Crisis Response Program. Pilot Program for Climate Resilience. Forest Investment Program. Climate Funds supported by GEF, UNDP, others. Existing funds/ foundations scaling up climate smart agriculture and agricultural research: WFP. International Fund for Agricultural Development. Gates Foundation. Arab Funds. [12] High-income countries must provide financial and technical assistance for both adaptation and low-carbon growth in developing countries. Current financing for adaptation and mitigation is less than 5% of what may be needed annually by 2030, but the shortfalls can be met through innovative financing mechanisms. [14] Full liberalization of world food trade could reduce the estimated numbers at risk of hunger by a fifth in relation to a world unaffected by climate change. [15] Fundamental policy shift in regional and global trade arrangements (e.g., enforce anti-monopoly and fair competition policy). [16] Evidence: Critical importance of interconnected policy-making. Other studies have stated that policy in all areas of the food system should consider the implications for volatility, sustainability, climate change, and hunger. Policy in other sectors outside the food system also needs to be developed in much closer conjunction with that for food. These areas include energy, water supply, land use, the sea, ecosystem services, and biodiversity. Achieving much closer coordination with all of these wider areas is a major challenge for policy-makers. [1] World Bank group commitments to agriculture: <US$ 2.5 billion in the 2001-2005 period; averaged US$ 4.1 billion annually in the 2006-2008 period (US$ 1.2 billion from IFC, US$ 2.9 billion from IBRD/IDA); in FY 2009 US$ 7.3 billion committed but reduced to US$ 6.1 billion (US$ 4.1 billion from IDA/IFC). [12] Recommendations: Global strategies may be necessary to address agricultural price volatility (Battisti and Naylor, 2009) and to manage impacts such as large-scale land acquisition for food production for foreign markets (Cotula and Vermeulen, 2009). [11] Blending different sources of public, private funding with innovative sources (e.g., % of developed country GNP, levies on transport emissions, carbon taxes, bonds, cap-and-trade auctions). Ensure agricultural eligibility. [2]

Topics	Evidence
	Policy options for GHG mitigation: financial incentives to maintain and increase forest area through reduced deforestation and degradation and improved management and the development and utilization of renewable energy sources. The post-2012 regime has to be more inclusive of all agricultural activities such as reduced emission from deforestation and soil degradation to take full advantage of the opportunities offered by agriculture and forestry sectors. [3] Increase donors working together on key issues (e.g., Global Forum on Agricultural Research and Global Forum for Rural Advisory Services can bring stakeholders together) especially to reinvest in rural education. [6] Most international assistance will be needed at the country level and below, depending on the spatial distribution of drivers for rural growth and rural poverty reduction; strong emphasis on country ownership. [6] Shift away from generic blueprints and large-scale categorizations. [6] Avoid introduction of export bans at time of food stress. [1] Future reform of international institutions such as World Trade Organization (WTO) cannot ignore the issues of sustainability and climate change. However, there is the risk that allowing sustainability to be reflected in trade rules may lead to environmental protectionism. Whether or not trade rules eventually do change, reaching agreement between low-, middle-, and high-income countries on baseline standards for sustainability in food production and processing that can be implemented at national scale will be an important first step. [1] Greater powers need to be given to international institutions, such as G20, to prevent trade restrictions at times of crisis. [1] An essential first step towards a more equitable global trading system for poor agricultural producers is the realization of a genuinely pro-development Doha Development Agenda agreement via the negotiations of the WTO. [1] Blend new funds with ongoing support programs/synergy between food security, climate smart agriculture (Niger, Haiti, Yemen, Bangladesh, China). [12] Forge an equitable and effective global climate deal that recognizes varying needs and constraints of developing countries, assists them with the finance and technology to meet the increased challenges to development, ensures they are not locked into a permanently low share of the global commons, and establishes mechanisms that decouple where mitigation happens from who pays for it. [14] Scale up humanitarian assistance capacity, social protection systems. Mainstream disaster risk reduction throughout national development programs. [15] <u>Gaps</u>: <u>Case studies</u>: International action: Comprehensive Framework for Action developed through the United Nations High-Level Task Force on the Global Food Crisis and the 2009 L'Aquila Food Security Initiative. [6] Member countries of the Comprehensive Africa Agriculture Development Programme (CAADP) are committed to increase the proportion of their public expenditure on agriculture to 10% of the public budget. [10] Comprehensive Framework for Action (CFA) on food and agricultural policy reform in 2008. FAO's Committee on World Food Security. World Bank in 2009: Global Agriculture and Food Security Program (i.e., food security trust fund). [16]

Topics	Evidence
	New US food security and agriculture initiative (Feed the Future) proposes to invest $20 billion in African agriculture in the next decade. [16] Alliance for a Green Revolution in Africa (Gates Foundation). [16]
National policies	Risks: Most National adaptation programs of action (NAPAs) are not based upon scientific evidence as to the range of relevant adaptation options and impacts in different environments, or of the critical role institutions play in future adaptation of rural livelihoods (Agrawal and Perrin, 2008). [11] Experimentations in land ownership and tenure policies to facilitate multiple land uses. Rural development policies. Urban and land use planning. [5] Opportunities: Participative mapping of impact pathways (Douthwaite et al., 2007; Reid et al., 2010), negotiation tools informed by research (van Noordwijk et al., 2001), social network analysis, innovation histories, cross-country analyses and game-theory modeling (Spielman et al., 2009). [11] NAPAs/Nationally appropriate mitigation actions (NAMAs). National development strategies. Poverty reduction strategy papers. CAADP agricultural development/investment strategies. [2] Risk reduction measures (safety nets, credit, insurance, etc). [3] Preserving national policy flexibility allows developing countries to balance the needs of poor consumers (urban and rural landless) and rural small-scale farmers. [3] Adoption of many natural resource management practices requires collective action at community or higher levels (p. 195). [13] Shift from dependence on export-led growth and international markets for overall food supply toward small-scale producers. [16] Evidence: Recommendations: Integration of food security, safety net, adaptation policies and climate science, and risk assessment. Insurance products. Price stabilization policies (e.g., buffer food stocks). National funds (e.g., Brazil, Indonesia, Mexico). [2] Fiscal policy (e.g., market feeder roads, postharvest storage facilities, and rural value-added agrifood production) to develop infrastructural capacity, and increasing the percentage that small-scale farmers receive for export crops. [3] Food consumption policies (nutrition, waste, eco-friendly). [5] Expand social protections. Greater land tenure security (for both women and men) and easier access to land through markets. [6] Research to improve understanding of the intended and unintended consequences of federal farm, food, and environmental

Topics	Evidence
	policies that can affect the use of agricultural practices designed to improve sustainability. [8] Public and stakeholder dialogue - with NGOs, scientists and farmers in particular - needs to be part of all governance frameworks for innovation in agriculture. [9] Emissions policy for agriculture must be developed within the broader context of emissions from all land use types. [1] Move food further up policy agendas, taking a broad view of the whole food system and its links and influence on other policy areas. [1] Develop and harmonize food system data and data standards. [1] Develop and apply effective, climate-resilient land use and water resource strategies and policies for national food systems, to ensure rational, efficient, and sustainable allocation and use. [1] Increase the priority of research and capacity building in the food system[1] Develop informed and market-oriented strategies for waste reduction, energy efficiency, GHG mitigation, environmental services, and biodiversity enhancement through the supply chain, service outlets, and consumer action, to promote and build sustainable food systems. [1] Secure land rights (China, Albania). Focus on research and knowledge dissemination. Public policy measures which favor sustainable land and water management rather than price support or energy subsidies, and which provide an enabling environment for value added, commercialization and trade (Brazil, Mexico, China, Uzbekistan). For the poorest countries productive social safety nets which support investment in land management. [12] Promote high-value activities to diversify smallholder farming away from land-intensive staples as urban incomes rise and diets change. Provide infrastructure to support the diversification of agriculture and of rural economies. Promote the rural nonfarm economy to confront the rural employment problem, and invest massively in skills for people to migrate to the rapidly growing sectors of the economy. [13] Invest in production and infrastructure for food reserves (restore market confidence; contribute to food security), improve food storage to reduce waste, increase access to credit (e.g., use crop inventory as collateral). [16] International mechanism through virtual reserves or a global governance body to monitor stock levels and prices. [16] Gaps: How interventions can be made in a way that pursues national policy priorities in the most effective, least costly, and most sustainable manner? [6] Case studies: Incentives to promote IPM and environmentally resilient germplasm management. Payments to farmers and local communities for ecosystem services. Facilitating and providing incentives for alternative markets such as green products, certification for sustainable forest and fisheries practices and organic agriculture, and the strengthening of local markets. Long-term land and water use rights/tenure, risk reduction measures (safety nets, credit, insurance, etc.) and profitability of recommended technologies are prerequisites for adoption of sustainable practices. Common pool resource regimes and modes of governance that emphasize participatory and democratic approaches. [3]

Topics	Evidence
	Payment for ecosystem services (PES) (e.g., Costa Rica). [7] National Platforms on Disaster Risk Reduction. [10] India: National Action Plan on Climate Change with a national mission for sustainable agriculture; focuses on dry lands, risk management, access to information and biotechnology. [10] Brazil: pattern of public support, investing in research and support measures, which are adapted to tropical soils and restore rather than mine them, as opposed to providing commodity subsidies, is highly effective in increasing productivity in a "climate responsible" way. Brazil has provided the enabling environment for private farmers to take advantage of the "triple win" of increasing productivity, increasing resilience, and reducing emissions from the agricultural sector. [12] Decentralization in Bolivia, stipulated by the 1994 Law of Popular Participation, significantly increased public spending on education, rural infrastructure, and water and sanitation, but average investment in agriculture fell as a share of total investment (p. 256). [13] Southern African Development Community (SADC) has a regional food reserves facility. ASEAN + 3 East Asia Emergency Rice Reserve. [16] Farmer advocacy groups (GRAIN, The Land Coalition) are mobilizing to prevent corporate and foreign acquisitions of agricultural land (Ethiopia, Madagascar). [16]
Coordination across sectors, regions	<u>Risks</u>: One fifth of the world's freshwater renewable resources are shared between countries (including 261 transboundary river basins, home to 40% of the world's people and governed by over 150 international treaties that do not always include all riparian states). [14] <u>Opportunities</u>: <u>Evidence</u>: Governance approaches in fisheries are strongly connected with those for the food system, in issues such as marketing, government investment, development of new technology, and the critical need to improve sustainability. Also, many people gain their livelihoods from a combination of crop production, animal husbandry, and in seasonal fishing. [1] Thriving rural input supply retailers as agrodealers in Africa (p. 153). [13] <u>Recommendations</u>: Integration of food security, agricultural development, climate change policy/finance. Mechanisms for cross-sectoral policy engagement (e.g., Indonesian roadmap). [2] 'Joined-up' government across different ministries, and a breaking down of some traditional distinctions between social and economic policies and programs. [6] New institutional arrangements at the landscape scale might be needed to avoid continued drawdown of water resources. [8]

Topics	Evidence
	The critical importance of interconnected policy-making: Policy in other sectors outside the food system needs to be developed in much closer conjunction with that for food. These areas include energy, water supply, land use, the sea, ecosystem services and biodiversity. Achieving much closer coordination with all of these wider areas is a major challenge for policy makers. [1] In high-income countries, food production subsidies and related interventions act as a disincentive to efficient global food production, raise consumer prices in protected countries, and are ultimately harmful to global food security. The current trend to reduce them [for example in the last decade's reform of EU's Common Agricultural Policy (CAP)] should be accelerated to encourage the self-sustaining improvements in productivity necessary to meet future increase in demand sustainably. [1] Coordination, regular communication among organizations/processes at national, regional, and international level (e.g., Committee on Food Security, Scaling Up Nutrition, UNFCCC, Rio+20 process). Support for local stakeholders and groups to participate in national, regional and global processes. [10] Scale up cooperation on international water bodies through new international treaties or the revision of existing ones. The system of water allocation will need to be reworked due to the increased variability, and cooperation can be effective only when all riparian countries are involved and responsible for managing the watercourse. [14] Gaps: Case studies: CAADP: Framework for accelerated agriculture-led development focused on land management, infrastructure, food supply, research. [12] The Mexican Carbon Program (PMC) was established in 2005 to coordinate scientific activities related to the carbon cycle in Mexico, assisting in the design of public policy aimed at tackling and adapting to climate change. Among the participants in the Program are 27 governmental, non-governmental, and academic institutions, including some from the agricultural sector. [12] Development of agricultural input supply pipelines in rural Kenya, Malawi (p. 153). [13] Special features of agriculture in Europe and Central Asia (p. 240). [13]
Markets	Risks: Uncertainty of carbon offset prices and the policies supporting them also presently limit the technical potential for implementing mitigation. [11] Agricultural trade can offer opportunities for the poor, but current arrangements have major distributional impacts among, and within, countries that in many cases have not been favorable for small-scale farmers and rural livelihoods. Opening national agricultural markets to international competition before basic institutions and infrastructure are in place can undermine the agricultural sector, with long-term negative effects for poverty, food security, and the environment. [3] Mechanisms to protect producers from price fluctuations and enable access to and compliance with new market practices or

Topics	Evidence
	trade requirements: market-based instruments such as futures trading, which small-scale producers find difficult to access; commodity boards and price regulation which large buyers find too limiting to meet their needs. The emergence of regional and preferential trade agreements and trading blocs among developing countries reveals an increasing mistrust and untenable nature of global trade regimes, given the perception of an unequal playing field. [3] Distorted global regime for trade in agricultural products, with its roots in the agricultural subsidies of OECD countries, remains a major problem. It does not work in the interests of poor rural producers in developing countries, and it actually makes many of them poorer. [6] Increased trade lessens pressures on ecosystem services within the importing region; it increases pressures in the exporting region. [7] In sub-Saharan Africa, food markets poorly serve millions of smallholders, especially in remote areas with weak infrastructure, so these areas must rely on their own production for food security (p. 229). [13] Developing countries worry that they will be excluded from the export markets because they lack in-country administrative and technical capacities to comply with the requirements and that costs of compliance will erode their competitive advantage (p. 130). [13] Weak links between farmers and markets creates inefficiency, price volatility (e.g., strong local yields suppress farm profitability). [16] <u>Opportunities</u>: Index insurance payouts are based on a meteorological index (e.g. rainfall or modeled water stress) correlated with agricultural losses, rather than observed losses; overcomes problems with moral hazard, adverse selection, high cost of verifying losses (Skees and Enkh-Amgalan, 2002; Hess and Syroka, 2005; Barrett et al., 2007). [11] Development of regional markets in sub-Saharan Africa. [5] In 2000, agriculture accounted for 5% of gross world product; importance of other non-marketed ecosystem services has grown (largely not captured in national economic statistics) (e.g., economic value of water from forested ecosystems near urban populations now sometimes exceeds the value of timber in those ecosystems). [7] "Value-trait" products (e.g., sustainable methods). [8] Spreading best practice relating to access to capital – such access enables producers to invest in new and better farming or fishing methods, diversify into new activities such as aquaculture or specialist crops, and access markets. [1] The emergence and continued growth of new food superpowers, notably Brazil, China, and India. Russia is already significant in global export markets, and likely to become even more so, with a large supply of underutilized agricultural land. [1] Greater price predictability and stability would benefit developing countries that rely on agricultural exports. [16] <u>Evidence</u>: National schemes for payments for environmental services programs to farmers, such as those that exist in EU, Australia, Canada, Japan, Norway, Switzerland, and US (Tilman et al., 2002). [11]

Topics	Evidence
	In many low-income countries food markets function poorly or only very locally. [1] <u>Recommendations</u>: Develop a framework for targeting particular index insurance products to particular agricultural systems, build capacity to manage index insurance in the private sector, bundle insurance within broader suites of services, and develop indices that reduce basis risk particular where meteorological data are sparse. [11] Increase the full range of agricultural exports and imports, including organic and fair trade products. Reduce transaction costs for small-scale producers. Strengthening local markets. Increase the value captured by small-scale farmers in global, regional, and local markets chains. Remove barriers for products in which developing countries have a comparative advantage. Reduce escalating tariffs for processed commodities in industrialized and developing countries. Deepen preferential access to markets for least developed countries. Increase public investment in rural infrastructure and the generation of public goods. Improve access to credit and markets for poor producers. Compensate for revenues lost as a result of tariff reductions. [3] Strengthening developing country trade analysis and negotiation capacity, and providing better tools for assessing tradeoffs in proposed trade agreements. Public/private arrangements that allow producers to sell through urban supermarkets. [3] Food trade will be necessary to secure regional food needs on two conditions: (1) a fair and secure trade regulation system must be established, combined with environmental regulation, (2) local opportunities for wealth creation must be developed to guarantee access to food and in many developing countries these opportunities are mainly to be found in agriculture (p. 229-231). [5] Stimulate the market to provide new risk-reducing technologies and services for smallholders and poor rural people. [6] Shape the terms on which small rural producers are integrated into dynamic markets and their prospects for food security, whether as producers or as consumers. From OECD countries in particular, greater coherence between their international commitments and aid policies and their positions on trade issues. [6] Institute taxes or user fees for activities with “external” costs (tradeoffs not accounted for in the market) (e.g., taxes on excessive application of nutrients or ecotourism user fees). Creation of markets, including through cap-and-trade systems. Mechanisms to enable consumer preferences to be expressed through markets (e.g., certification schemes). [7] Development of appropriate price signals or incentives to farmers who seek to improve the sustainability of their farms. [8] Improving the functioning of markets and providing market access, particularly in low-income countries. [1] Business and financial reform designed to facilitate entrepreneurship in the food production sector can increase food production, household revenue, livelihood diversification, and the strength of rural economies. [1] Favorable trade regimes to access new markets. [12] Action by high-income countries to create a sufficiently large and stable carbon market. Create an improved trade system less prone to large price shifts: facilitating access to markets for developing countries by reducing trade barriers, weatherproofing transport (for example, by increasing access to year-round roads), improving procurement methods, and providing better information on both climate and market indexes can make food trade more efficient and prevent large price

Topics	Evidence
	shifts. Price spikes can also be prevented by investing in strategic stockpiles of key grains and foodstuffs and in risk-hedging instruments. [14] Appropriate protection measures (e.g., safeguards against market manipulation; tariffs to limit food imports and prevent flooding of domestic markets and production). [16] Use of Special Safeguard Mechanisms. In the USA, Wall Street Reform and Consumer Protection Act of 2010 may restrict excessive speculation on agriculture commodity futures and mandate public and regulated exchanges. [16] <u>Gaps</u>: How to link the outputs from marginalized, rainfed lands into local, national, and global markets? [3] <u>Case studies</u>: In Liberia, Sierra Leone, Zambia, and several other nations in sub-Saharan Africa (as well as in Asia and Latin America), WFP is not only buying locally, it is helping small farmers gain the skills necessary to be part of the global market. [16] ECOWAS initiative for regional market integration and regulation. [16]
Subsidies & regulation	<u>Risks</u>: Industrialized country agricultural subsidies and advantages in agricultural added value per worker close off options for the export of agricultural commodities from sub-Saharan Africa and distort their domestic markets, thereby suppressing producer incentives to adopt new technologies and enhance crop productivity. [3] Fertilizer subsidies without overall systems (e.g. food storage) can lead to oversupply, market dumping and low prices (e.g., Zambia). [5] Although removal of perverse subsidies will produce net benefits, it will not be without costs. Compensatory mechanisms may be needed for poor people who are adversely affected by the removal of subsidies, and removal of agricultural subsidies within the OECD would need to be accompanied by actions designed to minimize adverse impacts on ecosystem services in developing countries. [7] Pitfall: Commodity support payments and risk management policies can incentivize monocropping, extensive hydrologic modification of landscapes, and increased input use. [8] Subsidized chemical fertilizers could mask the impact of infertile soils for a while, if the fertilizers are heavily subsidized (e.g., up to 75% in Malawi) but cannot repair soils bereft of organic matter and can be a disincentive for traditional organic matter management. [16] Pitfall: fertilizer subsidies may reduce incentive to invest in agro-ecological approaches. [16] Fertilizer subsidies without overall systems (e.g. food storage) can lead to oversupply, market dumping and low prices (e.g., Zambia in 2010). [16] <u>Opportunities</u>: Subsidies and incentives for crop substitution or expensive farming inputs (e.g. agrochemicals, bovine vaccines), as well as

Topics	Evidence
	investment plans for improved infrastructure for food systems (e.g. transport). [11] Remuneration of ecosystem services (p. 227-228). Promotion of multifunctionality. [5] Financial incentives (e.g., credit lines, crop insurance, income tax exemptions, green procurement policies, PES) combined with taxes on environmentally harmful practices can encourage conversion to sustainable farm practices. [16] Evidence: Government subsidies paid to the agricultural sectors of OECD countries between 2001 and 2003 averaged over $324 billion annually, or one third the global value of agricultural products in 2000. A significant proportion of this total involved production subsidies that led to greater food production in industrial countries than the global market conditions warranted, promoted overuse of fertilizers and pesticides in those countries, and reduced the profitability of agriculture in developing countries. Many countries outside the OECD also have inappropriate input and production subsidies, and inappropriate subsidies are common in other sectors such as water, fisheries, and forestry. [7] In 1995 to 2006, US Farm Bill legislation paid nearly USD 3B in direct subsidies to large-scale livestock producers. Between 2003 and 2005, corn producers received USD 17.6B in subsidies, and soybean producers another USD 2B. Feed costs usually account for >60% of total cost of production for most factory farm operators. 67% of U.S. corn and nearly all of the soybean meal are used for domestic or overseas livestock or fish feed. [16] Recommendations: Ending subsidies that encourage unsustainable practices. [3] Food trade regulation coupled with environmental regulation (p. 229-231). [5] Elimination of subsidies that promote excessive use of ecosystem services (and, where possible, transfer of these subsidies to payments for non-marketed ecosystem services). [7] Governance of innovation for agriculture needs to maximize opportunities for increasing production, while at the same time protecting societies, economies, and the environment from negative side effects. Regulatory systems need to improve their assessment of benefits. [9] Intellectual property systems need to be reviewed to ensure that patenting or varietal protection of new seed varieties does not work against poverty alleviation, farmer led innovation, or publicly funded research efforts. [9] EU partner countries should work together over next five to ten years to develop a system of regulation for new agricultural processes and products, based on shared principles. [9] Carbon taxes applied to both energy and land-use change to incentivize intensification of crop production on a more limited land area, protection of forests and grasslands. [12] Gaps: Case studies: Niger: productivity enhancement through supporting intensification and enhancing access to technology, value chains and

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	financial services. The ongoing Agri-Sylvo-Pastoral Exports and Markets program (US$ 43 million) supports improved access to finance and matching grants for producer organizations and cooperatives in cereal, horticulture, and livestock production and processing, irrigation rehabilitation and seed production and supports development of mechanisms such a warehouse receipts, leasing of farm equipment, and input credit. [12] Interaction of farmer subsidies, tariffs with rice self-sufficiency in Indonesia. [16]
Multi-benefit development policies	<u>Risks</u>: Impact of climate change on hunger will be more profound where social inequality in development is maintained. [15] US currently donates only U.S.-grown crops, disrupting food supply systems in recipient areas by lowering prices for locally grown food and by crowding producers in neighboring areas out of nearby markets. [16] <u>Opportunities</u>: Development of communal plans and strategies, such as pooling of financial resources or food storage facilities. [11] Develop high-value and underutilized crops in rainfed areas. [3] Policy-makers need to appreciate a range of trade-offs affecting decisions involving the food supply and ecosystem services. Important trade-offs include yield versus ecosystem services; trade-offs between different ecosystem services; land sparing versus wildlife-friendly agriculture; and the relationship between biodiversity and the needs of the poor. [1] Policies to mitigate climate change can incentivize the delivery of multiple public goods associated with the food system. [1] Generating more rural employment opportunities. [13] <u>Evidence</u>: <u>Recommendations</u>: Use market/other mechanisms to regulate and generate rewards for agro/environmental services (e.g., incentives to promote IPM, environmentally resilient germplasm management, payments to farmers and local communities for ecosystem services, facilitating and providing incentives for alternative markets such as green products, certification for sustainable forest and fisheries practices and organic agriculture, and the strengthening of local markets. [3] Value farmer knowledge, agricultural and natural biodiversity; farmer-managed medicinal plants, local seed systems and common pool resource management regimes. Increase domestic farm gate prices for small-scale farmers: fiscal and competition policies; improved access to knowledge resources, novel business approaches; enhanced political power. [3] Improve rural conditions: infrastructure/utilities (roads, electricity, water supply, and renewable energy), services (education, health care, financial services, communication), and good governance. Strengthen collective capabilities (e.g., membership-based organizations). [6] Much of technology development taking place at greater distances from farmer's plot, stronger mechanisms are needed to ensure representatives of poor farmers and groups experiencing chronic hunger are included in local and national fora [1]. Strengthen the culture of monitoring, impact and learning in agriculture – to allow farmers and consumers to give feedback

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	on what is working and not working in hunger reduction efforts. [1] Engage farmers, particularly women, youth, smallholder farmers, indigenous peoples, and other relevant natural resources dependent people in transition to climate-smart agriculture. [10] Cost-effective food aid: purchase the food in or near recipient countries. [16] Gaps: Case studies: Vietnam: 2009 agricultural strategy continues development goal of food security, farm land reform, rural infrastructure development, productivity, and environmental sustainability and protection of delta farm lands and aquatic resources from saline intrusion. [10] Morocco: Plan Maroc Vert (PMV) seeks to make agriculture the driving force for economic growth and to double agriculture's value added within a decade through a comprehensive overhauling of the sector's structure in terms of cropping patterns, land tenure, and agricultural taxation. PMV promotes high growth in the irrigated, competitive sector of high-value exports, opening the sector economy to international trade and aims to reduce rural poverty in the low productivity rainfed sector. [12] A women's cooperative in India (p. 211). [13] Rights-based approach to food taken up by governments (e.g., Brazil, Ecuador, Malawi, Nepal). [16]
Sustainability standards	Risks: Efforts to develop indicators to assess social dimensions of agricultural sustainability are sparse. No agreed-upon standards regarding which indicators to use under different conditions. Few indicators have been validated by scientists, farmers, and the public. [8] Opportunities: Some of the indicators being used, such as production energy costs and levels of implementation of best management practices, are useful at many levels of aggregation from farm-level assessments to regional and national accounting. [8] There is considerable scope for the food industry to play a significant role in facilitating greater sustainability. Extending best practice in the food supply chain has the potential to make radical improvements in sustainability across the food system. [1] Agribusinesses and the food industry are also beginning to consider the benefits of agro-ecological practices. They are concerned about the long-term sustainability of their sources of supply, as well as about responding to consumers' and governments' demand for social and environmental corporate responsibility. The rapid growth of market demand for organic and eco-certified products has attracted the attention of business investors. [16] Evidence: Recommendations:

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	Mixture of resistance, resilience, and adaptability of the coupled biophysical and socioeconomic system. [8] UK Food industry leaders have called for a 'level playing field' in standardizing best practice in sustainability. These behavioral shifts will entail government support for the development of new metrics of sustainability, strong direction setting, and a consensus for action amongst diverse actors. [1] Government-accredited national schemes that set standards for sustainability. Key to success would be setting a level playing field in this intensively competitive sector, and putting in place the definitions of standards for a sufficient time to encourage investment in sustainability. [1] Gaps: Case studies: In Nicaragua, payments induced a reduction in the area of degraded pasture and annual crops by more than 50% in favor of silvopastoralism, half of it by poor farmers. Environmental certification of products also allows consumers to pay for sustainable environmental management, as practiced under fair trade or shade-grown coffee (p. 16). [13] Corporate audits of social and environmental impacts by independent parties (e.g., Ben & Jerry's). [16] Principles on Responsible Agricultural Investment drafted by World Bank Group, FAO, IFAD, UNCTAD. [16]