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INTERGOVERNMENTAL PANEL ON climate change

WMO UNEP

IPCC Expert Meeting on Climate Change, Food, and Agriculture

Dublin, Ireland
27-29 May 2015

Meeting Report

Edited by:
Michael D. Mastrandrea, Katharine J. Mach, Vicente R. Barros, T. Eren Bilir, David J. Dokken, Ottmar Edenhofer, Christopher B. Field, Taka Hiraishi, Susanne Kadner, Thelma Krug, Jan C. Minx, Ramón Pichs-Madruga, Gian-Kasper Plattner, Dahe Qin, Youba Sokona, Thomas F. Stocker, Melinda Tignor

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Preface

At its 39th Session, the IPCC Panel considered a request from the Consultative Group on International Agricultural Research (CGIAR) for a technical report on climate change, food, and agriculture. The Panel discussed three options: preparation of a Technical Paper, organization of an Expert Meeting, and preparation of a Special Report. The IPCC Chair requested the Secretariat to approach CGIAR for more details and clarification and to consult with other UN organizations. Informed by these consultations, the Panel at its 40th session decided to organize an IPCC Expert Meeting on Climate Change, Food, and Agriculture during 2015, with the mandate to consider existing IPCC information on climate change, food, and agriculture and to recommend to the Panel possible further action, including the options of producing a Technical Paper or a Special Report, or to address the matter otherwise in the forthcoming assessment cycle. The meeting was held in Dublin, Ireland, from 27-29 May 2015, with the generous support of the government of Ireland.

This report summarizes the presentations and discussions of the Expert Meeting. It includes points raised regarding future IPCC activities and other efforts to advance understanding of the many interactions among climate change, food, and agriculture, including in the context of climate change responses. The report also contains reports of the meeting's Breakout Group discussions and abstracts for the meeting's plenary presentations, as well as a selection of recent literature on climate change, food, and agriculture suggested by meeting participants as important for consideration in future assessment of these issues. It is expected that this report will inform future Panel discussions and provide valuable information to the broader scientific community.

We thank Ireland's Environmental Protection Agency for hosting the meeting in Dublin, with special thanks to Dr. Frank McGovern. We also thank Ireland's Department of the Environment, Community, and Local Government and Department of Agriculture, Food, and the Marine for their support of the meeting. The meeting could not have succeeded without the efforts of the steering committee, whose guidance was critical in all aspects of meeting planning and implementation, as well as in preparation of this meeting report. We thank all the meeting participants for their contributions to three days of rich and constructive dialogue. Finally, we thank the Technical Support Units of the three IPCC Working Groups, who provided professional support for the preparation, execution, and summary of the Expert Meeting.

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1 Future Options for Climate Change, Food, and Agriculture

Future Options for Climate Change, Food, and Agriculture

The mandate of this Expert Meeting was to consider existing IPCC information on climate change, food, and agriculture and to recommend to the IPCC Panel possible further action, including the options of producing a Technical Paper or a Special Report, or to address the matter otherwise in the forthcoming assessment cycle.

Building on the presentations and discussions throughout the Expert Meeting, participants considered several options, which are not mutually exclusive:

- A scientific literature product (e.g., perspective, review paper, journal special issue) to support scoping and assessment in the IPCC Sixth Assessment Report (AR6) cycle
- An IPCC Technical Paper based on material in the IPCC Fifth Assessment Report (AR5)
- An IPCC Special Report early in the AR6 cycle
- Input to the scoping process for the AR6 Working Group contributions and Synthesis Report.

Discussions emphasized the robust scientific understanding, emerging perspectives, and policy relevance of climate change, food, and agriculture. Options for next steps differ in their comprehensiveness, timeliness, potential partners, and connections to policy needs. A synopsis of points raised for each option follows.

A high profile perspective, review paper, or journal special issue in the scientific literature would lay out key research topics and encourage scientific activities to support assessment throughout the AR6 cycle. Such a product would require coordination within the scientific community and would have limited connections with policymaking.

An IPCC Technical Paper could compile material currently spread across many sections of the AR5 Working Group contributions. A Technical Paper would not allow inclusion of post-AR5 literature, constraining opportunities to incorporate new knowledge.

An IPCC Special Report would integrate AR5 findings and new material relevant to all Working Groups, enhancing transdisciplinary assessment in the AR6. As part of a continuing series of IPCC products, a Special Report would be a timely way to assess new knowledge in a policy-relevant product.

Scoping of the AR6 could be enhanced to integrate treatment of these issues across chapters and Working Groups, including through, for example, cross-Working Group chapters. This approach offers possibilities for improving multidisciplinary assessment, over a longer timeframe and in the context of a much broader assessment report.

The topics below emerged in discussions of outlines for possible future IPCC products or efforts in the scientific community:

- Climate change, food, and agriculture
  – Food production, including agriculture, livestock, fisheries, and other food systems
  – Direct and indirect links between climate change, climate change responses, and food security
  – Interactions among climate, water, economies, nature, and food
- Adaptation, mitigation, food security, and their interactions
  – Resilient food systems
  – Healthy diets
  – Synergies and tradeoffs: production and consumption
- Managing fundamental limits: land and water resources
  – Competition for land and water: food vs. other uses
  – Policies
- Sustainable development and food security
  – Opportunities for co-benefits
  – Decision-making frameworks including robust decision making

Cross-Cutting Themes: *Socioeconomic dimensions, regional dimensions, temporal dimensions, sustainable development, inequalities (poverty, gender, and governance).*

Finally, a wealth of research topics were identified during this Expert Meeting. Important gaps in knowledge discussed during the meeting include the following:

- Metrics for measuring food security across local and regional contexts, given different drivers of vulnerability
- Climate change interactions with drivers of food demand and dietary patterns
- Climate-agriculture interactions, including effects of climate variability, weeds, pests, and diseases
- Effects of climate change on non-commodity crops
- Effects of climate change on fisheries and interactions with food security and livelihoods
- Effects of climate change on post-harvest components of food systems
- Nutrition and production in a changing climate
- Effectiveness of adaptation options, both incremental and transformational
- Quantification of mitigation potential in the AFOLU and energy sectors, including role of greenhouse gas metric
- Implications of biomass-based mitigation options for potential land and water competition, surface albedo, and non-CO_2 greenhouse gas emissions
- Integrated regional assessments, linking bottom-up and top-down approaches
- Integration of food and land-use trade-offs and co-benefits in integrated assessment modeling
- Characterizing adaptation and mitigation interactions, co-benefits, and trade-offs across scales
- Direct and indirect consequences of policies affecting land use, supply-demand interactions, and international trade.

The meeting highlighted several opportunities where the IPCC and the scientific community can add value to ongoing discussions on one of the most important topics of the 21st century.

2 Plenary Session Discussion Summaries

Plenary Session Discussion Summaries

The Expert Meeting included a series of plenary sessions. Section 3 of this meeting report provides the abstracts for plenary presentations, which were divided into four plenary sessions over the course of the meeting. Brief question and answer exchanges followed each presentation, and each plenary session concluded with a general discussion. Topics raised in these discussions are summarized here.

Plenary Session I: General Overview on Food Security

Discussions around four framing presentations emphasized broad cross-cutting issues and knowledge gaps. Participants noted that the food-water-energy-climate nexus can be seen as falling within a broader nexus of people, progress, and sustainability. In this broad context, there are multiple objectives within food systems. Diverse values shape these objectives across contexts and scales, recognizing that there is also broad agreement on the priority for safe, secure access to sufficient nutritious food. Potential synergies and tradeoffs among objectives and strategies for minimizing risks can be evaluated, recognizing the importance of regional and local perspectives. Such efforts would benefit from further linkages and investigations across disciplines and communities.

There are also many options for quantifying food security, greenhouse gas emissions, and the potential for mitigation in the food sector. For example, beyond food production, yield, and price information, measures of the share of food costs as a fraction of income and of the nutritional content of food were highlighted. The importance of the choice of greenhouse gas metric was noted, especially for foods associated with emissions of methane. There were also calls to strengthen linkages between sectoral research and integrated modeling and to broaden research and assessment on the influence of climate change on crops of importance in specific regions of the world, beyond the major commodity crops like wheat, maize, soy, and rice.

Plenary Session II: Climate-Change Impacts on the Food Sector and Prospects for Adaptation, across Regions

Discussions related to four presentations on changes in climate, impacts on different aspects of the food sector, and prospects for adaptation. Participants again addressed potential research topics, as well as how the IPCC could add value on climate change, food, and agriculture. Research topics included climate-agriculture interactions (e.g., effects of agricultural management on climate extremes); coupled climate-crop modeling; effects of climate change on orphan crops and fisheries; interactions with weeds, pests, and diseases; effects of climate change on post-harvest components of food systems (e.g., storage, distribution); and evaluation of adaptation beyond incremental changes to existing systems. Participants noted feedback during AR5 outreach calling for more in-depth treatment of issues related to climate change, food, and agriculture, suggesting a possible role for the IPCC.

Plenary Session III: Impacts of Mitigation Options on the Food Sector and Prospects for Responses

Discussions in this session on greenhouse gas emissions and mitigation potential, including forestry, bioenergy, and competition for land and water, emphasized a broad characterization of interactions among climate change mitigation, food security, and development, which also intersect with other societal goals such as reducing poverty, improving resilience, achieving healthy diets, and preserving biodiversity. For example, as highlighted in presentations, diet choices will have a large bearing on food sector emissions. In addition, intensification of food production systems (with potential mitigation benefits) can affect their resilience. Improvements in management systems can also lead to more resilient food supply while reducing further land conversion and land-use-change emissions. Building on the discussion of potential future IPCC work in this area, participants noted that there is opportunity for further integration of assessment of food security and mitigation than was possible in the AR5.

Plenary Session IV: Policy Instruments for Land Policies and Food Security

Discussions following the presentation in this session focused on the importance of considering adaptation and mitigation co-benefits and tradeoffs, which can also aid in overcoming social and institutional barriers that may prevent actions that would be economically beneficial. Interactions among mitigation, land value, and land tenure were also highlighted, including the potential for rising land prices to affect small landholders.

3 Plenary Abstracts

I.a: Connecting the Dots – The Food, Water, Energy, Climate Nexus

Christopher B. Field[1]
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This is a stage-setting talk, intended to highlight the rich and potent set of links that connect agriculture, food, and food security with climate, water, and energy. The essence of the system of interactions is that impacts on any component have the potential to ramify through the network along multiple paths, adding to the complexity. The entire food-water-energy-climate system operates in a multi-stressor context where human population, income, behavior, policy, and technology are all influential.

Many of the links involve trade-offs or managing risks. All of the links concern mechanisms where there are opportunities for creative approaches to understanding, managing, and reducing risk. A strong motivation for a system-level perspective is opening paths to solutions that might otherwise remain hidden.

Food-climate links are central to the challenge of climate change. Risks of impacts of a changing climate on food production and food security are identified as a core issue in article 2 of the UNFCCC and have been a primary motivator of research. Impacts of climate changes to date have already impacted the prospects for increasing yield. Future risks are serious. On the other hand, activities associated with food production are major sources of climate forcing, with deforestation, agricultural sources of methane, and agricultural sources of nitrous oxide each generating substantial forcing of climate change. Adjustments to agricultural practices or diets may be profoundly important in either decreasing or increasing climate forcing from the food sector.

Food-water links are equally important. Many of the impacts of climate change unfold as consequences for freshwater quantity or quality, with variability playing a major role. Too much water or water at the wrong time or place can be as damaging as too little water. Improving the reliability of water supplies, especially through irrigation, can be a major contribution to improving food security, but climate change is already complicating the challenge of increasing the reliability of water supplies. Competing demands of water for manufacturing, domestic use, and nature further narrow the option set, while also emphasizing the importance of continued work on increasing the water use efficiency of food production.

Food-energy links have many dimensions. Some involve the energy requirements for food production, especially the energy inputs required to produce nitrogen fertilizer and move water. Food transportation and storage can also be energy-intensive. Other dimensions of food-energy links involve biomass energy and the possibility of competition for land, water, and fertilizer between crops for food and crops for energy. With evidence that some countries and regions have effectively and simultaneously increased production of food, biomass energy, and conservation of natural ecosystems, it is clear that competition is not unavoidable. But in other regions, it is clear that changes in the size of the human population, in dietary preferences (especially demand for meat), commitments to energy from biomass, and climate change are generating ever increasing pressure on the food system.

Food, water, energy, and climate interact across a wide range of scales of space and time, through a large range of mechanisms. Most of the interactions have important two-way connections, and indirect mechanisms can be as important as direct mechanisms. Some of the interactions operate through the physics of the climate system. Others operate through markets and policy. The nexus of interactions has no obvious starting point or ending point, and it has no single framing that is more correct than several of the alternatives.

Increasing food production has been one of the major triumphs of the human enterprise over the last century. Progress on food production underlies a world that meets the food requirements for more than 6 billion people. But nearly a billion people are still dangerously food insecure. Reducing that number to zero is a central mission of sustainable development. Understanding the food-water-energy-climate nexus is a key enabler in accomplishing that mission.

I.b: Food Production and Food Security

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State of Knowledge

Food production and food security was the subject of one chapter in AR5 WGII (Porter *et al.*, 2014). Models and observations present findings on the linkages between climate parameters and production levels. Top line findings from the chapter are dominated by *medium confidence* statements.[a] Reflecting the literature, the greatest emphasis is placed on production in the context of a changing climate. In general the low latitudes are particularly sensitive, because of large negative sensitivity of crop yields to extreme daytime temperatures around 30°C (*high confidence*). Production levels of major crops such as wheat, maize, and rice are projected to decline from 2050 (with disagreement on what will happen before mid-century). Temperatures are the most important determinants of climate change impacts at large (sub-continental to global) scale. Since AR4 there has been more evidence of the stimulatory effect of carbon dioxide and damaging effect of elevated ozone on plant growth; and their role may affect nutritional quality of crops, and weed distribution and disease intensity respectively. The greatest risks are likely in sub-Saharan Africa (Niang *et al.*, 2014) and the rice-growing areas of southeast Asia (Hijioka *et al.*, 2014); whilst Central and South America also considers food production and quality among its key risks (Magrin *et al*., 2014). At local level, declines in food production will directly affect subsistence-based livelihoods, which predominate among the poor. This may lead to tipping points being reached with dryland-based pastoral livelihoods, and cause shifts from transient to chronic poverty (Olsson *et al.*, 2014). However, whilst negative links are more common, there is the potential for positive trends in some high latitudes, and a greater likelihood of success of adaptation; and some non-tropical areas may become more favorable for aquatic food production.

Emerging and Future Research Directions

Whilst traditionally a lot of emphasis has been placed on production, the availability aspect of food security, the elements of accessibility and stability, are under increasing scrutiny. An emerging research agenda exists for those people who procure their food through the market as opposed to producing it themselves (which began with an urban focus, but also occurs in rural areas for people dependent on wage labor) (Revi *et al.*, 2014; Dasgupta *et al.*, 2014; Olsson *et al.*, 2014). It has also been suggested that poor households in urban and rural areas are particularly at risk when they are almost exclusively net buyers (Ruel *et al.*, 2010). Food prices are therefore important in food security, and are projected to increase throughout the 21st century in response to changing production and increasing demand. Recent food price hikes have been linked to climate extremes, but other factors play a role, including market forces, trade regulations (including tariff and import restrictions), and competing demand for resources (e.g., land and water). Attributing causality is thus challenging, and further research is required on the complex pathways between production and food prices, since it risks not only food security but also livelihood and socio-political security, with implications for economic growth and wellbeing (Adger *et al.*, 2014).

Evolving approaches to food security and investigating the nuances of the relationship between availability, accessibility, stability, and utilization have been enabled through an emphasis on food systems. Food systems are defined in the IPCC glossary as "the suite of activities and actors in the food chain (i.e., producing, processing and packaging, storing and transporting, trading and retailing, and preparing and consuming food); and the outcome of these activities relating to the three components underpinning food security (i.e., access to food, utilization of food, and food availability). However, there have been varying levels of attention paid to the different aspects of food systems, and this is one further research direction. In particular there is a gap of scale between macro-level approaches to adaptation (e.g., the extent to which adaptation can reduce potential negative impacts on production) and more local level, where emphasis has been on actual farmer responses and mechanisms through which that adaptation takes place (including climate-smart agriculture). Bringing climate change and agricultural research closer will likely support this. There is also scope for additional adaptation possibilities in the broader elements of the food system, e.g., food processing, packaging, transport, and storage (Porter *et al.*, 2014).

As the lens for analysis of food systems widens, the embeddedness and interlinkages between the components of food security and other aspects of concern become apparent. Within rights-based debates, these include the livelihood and socio-political aspects of human security (Adger *et al.*, 2014), ensuring equitable rights to food based on social factors such as gender, religion, ethnicity, and caste (Barnett *et al.*, 2014; Olsson *et al.*, 2014); and food sovereignty (Agarwal, 2014). On a broader political economic scale this highlights the relevance of food production and food security in trade patterns and policy, and also competing demands for land and water resources and the way in which emerging conflicts are mediated (Dasgupta *et al.*, 2014; Besada and Werner, 2015), and the food-water-energy-climate nexus.

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[a] Confidence is an evaluation of the level of evidence and degree of agreement of findings within that evidence. *Medium confidence*, therefore, may mean there is *limited evidence* with *high agreement*, or *medium evidence* with *medium agreement*, or *robust evidence* with *limited agreement* (Mastrandrea *et al.*, 2011).

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I.c: Future Demand for Food – Relevance of Land Use and Lifestyles and Relationship with Nutrition

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Growing attention has been paid to the potential of dietary change in mitigating GHG emissions from food production – relevant to the AFOLU sector – as discussed by Pete Smith in this meeting (Ray *et al.*, 2013; Bajželj *et al.*, 2014); and from post farm gate activities such as transport, storage, and retailing (relevant to the electricity, buildings, transport, and industry sectors (Garnett, 2011)). There is particular interest in the scope for achieving food-related GHG mitigation in ways that support other food-related objectives, specifically nutritional goals. A burgeoning academic literature compares the environmental and nutritional impacts of different diets, with changes in the animal product content of those diets a key variable. In general the approaches adopted fall into the following categories.

One approach is to model the environmental and nutritional implications of current diets and compare them with defined alternatives that differ in their animal product content. Alternative diets may be those that meet official guidelines, quasi-official diets such as the 'Mediterranean,' New Nordic, or 'Harvard Healthy Eating Plan,' or idealized vegetarian and vegan diets. Pulses and soy tend to be specified as substitutes for the meat. Generally GHGs are considered; sometimes land and water use too. Since diets are idealized, ensuing health benefits are assumed (Vanham *et al.*, 2013; Stehfest *et al.*, 2009; Pairotti *et al.*, 2014; Sax, 2014) but may be modelled (Tilman and Clarke, 2014). A variant is to quantify not just GHG and other environmental impacts but also the macro or micronutrient content of modelled diets (Van Kernebeek *et al.*, 2014; Van Dooren and Kramer, 2012; Röös *et al.*, 2015). Sometimes a linear optimization approach is used to model ways of achieving nutritionally adequate diets that achieve specified cuts in GHGs (Macdiarmid, 2013; Green *et al.*, 2015).

All these studies find that diets with a reduced animal product content (meat, eggs, dairy) are less GHG or land use intensive than, and represent a nutritional improvement on, current average diets; the lower the meat content, the lower the environmental impacts. In descending order the GHG intensity of diets are: no red meat, no meat (vegetarian), no animal products (vegan) (Hallström *et al.*, 2015).

Vieux *et al.* (2013) are distinctive in examining a range of real, as opposed to idealized, diets. They find that high nutritional quality diets have higher GHG impacts than poorer diets. This has little to do with differences in their meat content but because high quality diets contain more fruit and vegetables which substitute for low GHG, high food-energy foods (e.g., sugary foods) found in poor diets. Also examining real diets, this time of meat-eaters, fish-eaters, vegetarians, and vegans, Scarborough *et al.* (2014) find that the lower the animal product content, the lower the GHG impact.

On the basis of these findings governments in the Netherlands, Scandinavia, Brazil, and potentially the US are producing guidelines for diets that achieve both health and environmental sustainability. However there remain at least five areas of uncertainty where more research is needed:

1) **Production-consumption interactions**. Analysis of 'sustainable diets' needs to take account of not only what we eat, but how these foods are produced. The production method will determine how much food can be produced for a given level of environmental cost and it also potentially influences a food's nutritional and other health properties.
2) **Rebounds and leakages**. Shifts in diets in one country may not lead to overall reductions in GHG emissions if foods not consumed are simply exported. Alternatively reductions in livestock farming in one country may, without corresponding dietary change, simply lead to increases in imports.
3) **Sustainability metrics that go beyond GHGs**. The metrics used to assess sustainability tend to be GHG emissions, land and sometimes water use. Less attention is paid to the impacts of different diets on biodiversity on- and off-farm. Critically, we know far less about the complex relationship between environmental and wider social and economic goals, nor about how trade offs are to be managed.
4) **More focus on low and middle income countries**. Most of the research on sustainable healthy diets centers on developed country contexts. Yet most of the growth in food-related environmental impacts from meat and dairy consumption, and most of the rise in obesity and chronic diseases, are taking place in developing countries, particularly in the rapidly industrializing economies of South and South East Asia, and South America. At the same time, while obesity and chronic diseases are on the rise in these regions, the problems of hunger, malnutrition and food insecurity continue. The challenge is to consider how sustainable diets might interface with broader developmental and societal objectives so as to orient development along lower impact, more nutritious pathways.
5) **Interventions to achieve change**. At present insufficient research attention has been paid to investigating how shifts in diet are to be achieved – i.e., through what mix of policy and market based interventions (Garnett *et al.*, forthcoming). This is an area that requires further work.

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I.d: Potential Impacts of Mitigation Scenarios on Bio-Energy Deployment, Land Use, and Food Security

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Today, land-use and land-use change are responsible for approximately a quarter of global greenhouse gas emissions, largely from tropical deforestation, methane emissions from livestock and rice cultivation, and nitrous oxide emissions from livestock and fertilized soils. But, the land system is also seen to contribute much to climate change mitigation in the future by providing biomass for bioenergy, improving agricultural management, and conserving or even enhancing carbon stocks of ecosystems (Smith *et al.*, 2014). Especially the use of large land areas for afforestation or dedicated feedstocks for bioenergy could affect food prices and compromise food security if land normally used for food production is either restricted for agricultural expansion or converted to bioenergy and forests. The degree of these effects is uncertain and depends on a variety of sector-specific details regarding intensification of land use, dietary changes, global market interactions, cultural and institutional changes, and interaction with other sectors such as bioenergy demand for energy supply and transport (Popp *et al.*, 2014). Scenario analysis has been established as a tool to explore and evaluate such extensive uncertainties associated with possible future developments.

This presentation will first of all provide an overview on the state of knowledge on impacts of mitigation scenarios on land use and food security, summarizing the assessment in the IPCC Fifth Assessment Report (AR5). Moreover, a new scenario framework will be presented that is organized around two important dimensions: The five radiative forcing levels consist of four representative concentration pathways (RCPs) which determine the amount of climate change (van Vuuren *et al.*, 2014). The possible future socio-economic conditions (including possible trends in agriculture and land use) that could correspond under climate policies to individual forcing levels are then described in the shared socio-economic pathways (SSPs) (O'Neill *et al*., 2015). Based on a study applying the scenario matrix approach combining climate forcing and socio-economic dimensions for so-called integrated assessment models (IAMs) with dedicated land use modules, the presentation will focus on potential future consequences on the land system and food prices.

Finally, the presentation will end with an outlook on how the SSP scenario framework could help to assess consequences of climate change and climate change mitigation on food prices / security in a consistent way.

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II.a: Past and Projected Changes in Temperature, Precipitation, and Climate Variability Relevant to Crop Production

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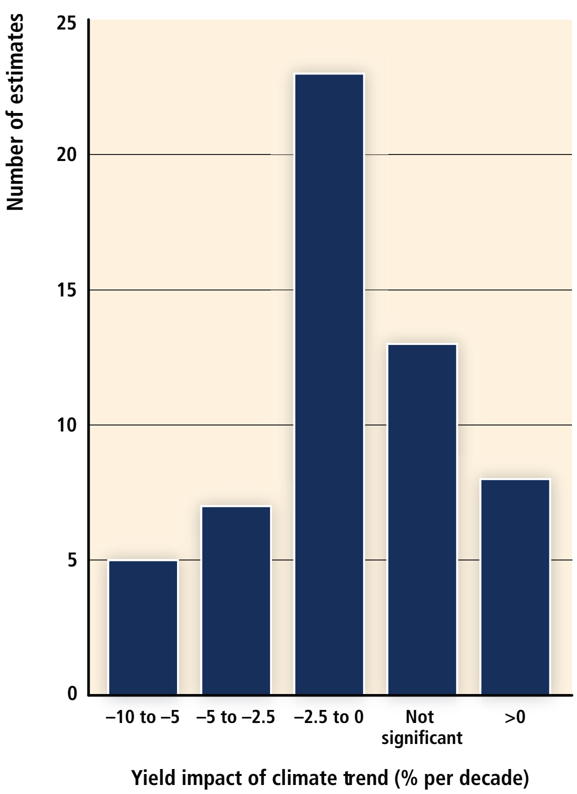
This presentation provides an overview on past and projected changes in mean temperature and precipitation, as well as extremes of relevance to food production, including droughts and hot temperature extremes. In particular, the evidence summarized in the IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX; IPCC, 2012) and the Fifth Assessment Report (AR5) of IPCC Working Group I (IPCC, 2013) is presented, based on Chapter 3 (Seneviratne *et al*., 2012) of the IPCC SREX report, and Chapters 2 (Hartmann *et al.*, 2013), 10 (Bindoff *et al*., 2013), 11 (Kirtman *et al*., 2013), and 12 (Collins *et al.*, 2013) of the IPCC AR5 WGI report. Impacts of climate change on crop production have been assessed in the IPCC AR5 WGII report (Porter *et al.*, 2014). There has also been some new post-AR5 evidence on past and projected changes in extremes, their impacts on agriculture and virtual water trades, as well as two-way interactions between changes in agricultural management and climate change, as discussed below.

Impacts of increasing greenhouse gases on agricultural production can be both positive and negative, although negative effects are assessed to dominate (Porter *et al*., 2014; see Figure 1). Positive effects include the extension of crop production in regions in which it was limited by temperature, decreasing of freezing impacts, and CO_2 fertilization effects on crops. Negative effects have been mostly related to increasing drought (lack of precipitation, soil moisture drought), hot extremes (daytime temperatures and nighttime temperatures, as well as increased vapor pressure deficits), and heavy precipitation events (Porter *et al*., 2014; see also, e.g., Rosenzweig *et al.*, 2002, 2014, and Lobell *et al.*, 2014). It is also important to note that the sensitivity of yield to climate variability may change over time (e.g., Lobell *et al*., 2014; Nicholls, in preparation).



The AR5 WGI report (IPCC, 2013) provided an assessment of past, attributed, and projected changes in extremes. Table 1 includes the assessments for the most relevant extremes from the side of crop production (see above). With respect to projections the assessments were based for the largest part on Sillmann *et al*. (2013), while the IPCC SREX (Seneviratne *et al*., 2012) was used as basis for many assessments of observed changes, with some exceptions (Hartmann *et al*., 2013).

In general post-AR5 evidence agrees with the assessments provided in Table 1 for temperature extremes and heavy precipitation events. Furthermore, in some cases, e.g., the attribution of changes in temperature extremes and heavy precipitation (Sun *et al*. 2014; Christidis *et al*., 2015; Fischer and Knutti, 2015), the evidence has even been strengthened since then. It has additionally been shown that temperature extremes on land display a continuous increase in recent years, even during the so-called hiatus period, and are thus possibly more sensitive to radiative forcing than global mean temperature, at least during this latter period (Seneviratne *et al.*, 2014).

Figure 1. Summary of estimates of the impact of recent climate trends on yields for four major crops (wheat, soy, rice, maize). Studies were taken from the peer-reviewed literature and used different methods (i.e., physiological process-based crop models or statistical models), spatial scales (stations, provinces, countries, or global), and time periods (median length of 29 years). Adapted from Porter *et al*., 2014.

Table 1. Global-scale assessment of recent observed changes, human contribution to the changes, and projected further changes for the early (2016-2035) and late (2081-2100) 21st century. Bold indicates where the AR5 (black) provides a revised* global-scale assessment from the SREX (blue) or AR4 (red). Projections for early 21st century were not provided in previous assessment reports. Projections in the AR5 are relative to the reference period of 1986-2005, and use the new Representative Concentration Pathway (RCP) scenarios unless otherwise specified. Adapted from IPCC, 2013, Table SPM.1.

Phenomenon and direction of trend	Assessment that changes occurred (typically since 1950 unless otherwise indicated)	Assessment of a human contribution to observed changes	Likelihood of further changes	
			Early 21st century	Late 21st century
Warmer and/or fewer cold days and nights over most land areas	*Very likely* {2.6}	***Very likely*** {10.6}	*Likely* {11.3}	*Virtually certain* {12.4}
	Very likely *Very likely*	*Likely* *Likely*		*Virtually certain* *Virtually certain*
Warmer and/or more frequent hot days and nights over most land areas	*Very likely* {2.6}	***Very likely*** {10.6}	*Likely* {11.3}	*Virtually certain* {12.4}
	Very likely *Very likely*	*Likely* *Likely* (nights only)		*Virtually certain* *Virtually certain*
Warm spells/heat waves. Frequency and/or duration increases over most land areas	***Medium confidence*** on a global scale *Likely* in large parts of Europe, Asia and Australia {2.6}	***Likely***[a] {10.6}	Not formally assessed[b] {11.3}	*Very likely* {12.4}
	Medium confidence in many (but not all) regions *Likely*	Not formally assessed *More likely than not*		*Very likely* *Very likely*
Heavy precipitation events. Increase in the frequency, intensity, and/or amount of heavy precipitation	*Likely* more land areas with increases than decreases[c] {2.6}	***Medium confidence*** {7.6, 10.6}	*Likely* over many land areas {11.3}	***Very likely*** over most of the mid-latitude land masses and over wet tropical regions {12.4}
	Likely more land areas with increases than decreases *Likely* over most land areas	*Medium confidence* *More likely than not*		*Likely* over many areas *Very likely* over most land areas
Increases in intensity and/or duration of drought	***Low confidence*** on a global scale *Likely* changes in some regions[d] {2.6}	***Low confidence*** {10.6}	*Low confidence*[g] {11.3}	***Likely*** *(medium confidence)* on a regional to global scale[h] {12.4}
	Medium confidence in some regions *Likely* in many regions, since 1970[e]	*Medium confidence*[f] *More likely than not*		*Medium confidence* in some regions *Likely*[e]

* The direct comparison of assessment findings between reports is difficult. For some climate variables, different aspects have been assessed, and the revised guidance note on uncertainties has been used for the SREX and AR5. The availability of new information, improved scientific understanding, continued analyses of data and models, and specific differences in methodologies applied in the assessed studies, all contribute to revised assessment findings.

Notes:

[a] Attribution is based on available case studies. It is *likely* that human influence has more than doubled the probability of occurrence of some observed heat waves in some locations.

[b] Models project near-term increases in the duration, intensity and spatial extent of heat waves and warm spells.

[c] In most continents, *confidence* in trends is not higher than *medium* except in North America and Europe where there have been *likely* increases in either the frequency or intensity of heavy precipitation with some seasonal and/or regional variation. It is *very likely* that there have been increases in central North America.

[d] The frequency and intensity of drought has *likely* increased in the Mediterranean and West Africa, and *likely* decreased in central North America and north-west Australia.

[e] AR4 assessed the area affected by drought.

[f] SREX assessed *medium confidence* that anthropogenic influence had contributed to some changes in the drought patterns observed in the second half of the 20th century, based on its attributed impact on precipitation and temperature changes. SREX assessed *low confidence* in the attribution of changes in droughts at the level of single regions.

[g] There is *low confidence* in projected changes in soil moisture.

[h] Regional to global-scale projected decreases in soil moisture and increased agricultural drought are *likely (medium confidence)* in presently dry regions by the end of this century under the RCP8.5 scenario. Soil moisture drying in the Mediterranean, Southwest US and southern African regions is consistent with projected changes in Hadley circulation and increased surface temperatures, so there is *high confidence* in *likely* surface drying in these regions by the end of this century under the RCP8.5 scenario.

On the other hand, post-AR5 literature has brought new evidence regarding past and projected drought changes, which implies in part revisions of the AR5 assessment. New evidence (either published close to the AR5 WGI cut-off date or later) confirms that there is *low confidence* with respect to past drought changes on global scale, but that regional changes can be nonetheless identified (Sheffield *et al*., 2012; Greve *et al*., 2014; Trenberth *et al.*, 2014). However, beside evidence on uncertainties associated with the representation of potential evaporation, which was available at the time of the WGI AR5 report (Sheffield *et al*., 2012), more recent investigations have additionally highlighted uncertainties due to the choice of observational precipitation products (Trenberth *et al*., 2014) and actual evapotranspiration estimates (independently of potential evaporation; Greve *et al*., 2014). The regions with identified increasing or decreasing dryness highlighted in the AR5 are confirmed in the multi-product analysis of Greve *et al*. (2014) in the case of three regions (increasing dryness in Mediterranean region and West Africa, decreasing dryness in North America), but not in North-West Australia (no discernible trend in Greve *et al.*, 2014, while the AR5 reported a *likely* decrease in that region, IPCC, 2013). In addition, it should be noted that these observed regional changes are only consistent with projections in the Mediterranean region.

There is evidence suggesting that the assessment of *likely* increase in drought trends on regional and global scale provided by the AR5 (see Table 1) should be partly revised. Table SPM.1 of the WGI AR5 report (IPCC, 2013) highlighted that decreasing soil moisture was projected in presently "dry regions". But recent published and submitted evidence does not suggest a validity of the commonly stated "dry gets drier, wet gets wetter" paradigm over continents, either for historical changes or projections (Greve *et al*., 2014; Roderick *et al*., 2014; Greve and Seneviratne, submitted; see, e.g., Figure 2). The commonly highlighted amplification of regional water cycle features (Held and Soden, 2006) is indeed mostly an oceanic characteristic, and does not generally apply over land, where it would be relevant for agriculture. In projections, the dominant feature is a lack of signal in many continental regions, including dry regions (Greve and Seneviratne, submitted). More generally, recent investigations have in particular highlighted the model-based uncertainty of drought projections, both in Global Climate Models as well as in Global Hydrological Models (Orlowsky and Seneviratne, 2013; Prudhomme *et al.*, 2014; Schewe *et al*., 2014). As an example, the assessed sustainability of present-day virtual water trades under projected changes in water availability depends very much on GCM choice (Orlowsky *et al*., 2014). Despite these model uncertainties, several regions are consistently projected to become drier, including the Mediterranean region, Central North America, and Southern Africa (Orlowsky and Seneviratne, 2013, Schewe *et al*., 2014; note that these are characterized as "transitional" rather than "dry" regions). Because these "hot spots" of drying include important agricultural regions, these signals are of high relevance for crop production.

Finally, recent – including post-AR5 – evidence has more strongly emphasized the importance of two-way coupling between agricultural management and climate change. While it is long recognized that agricultural management affects CO_2 emissions (e.g., Smith *et al*.,

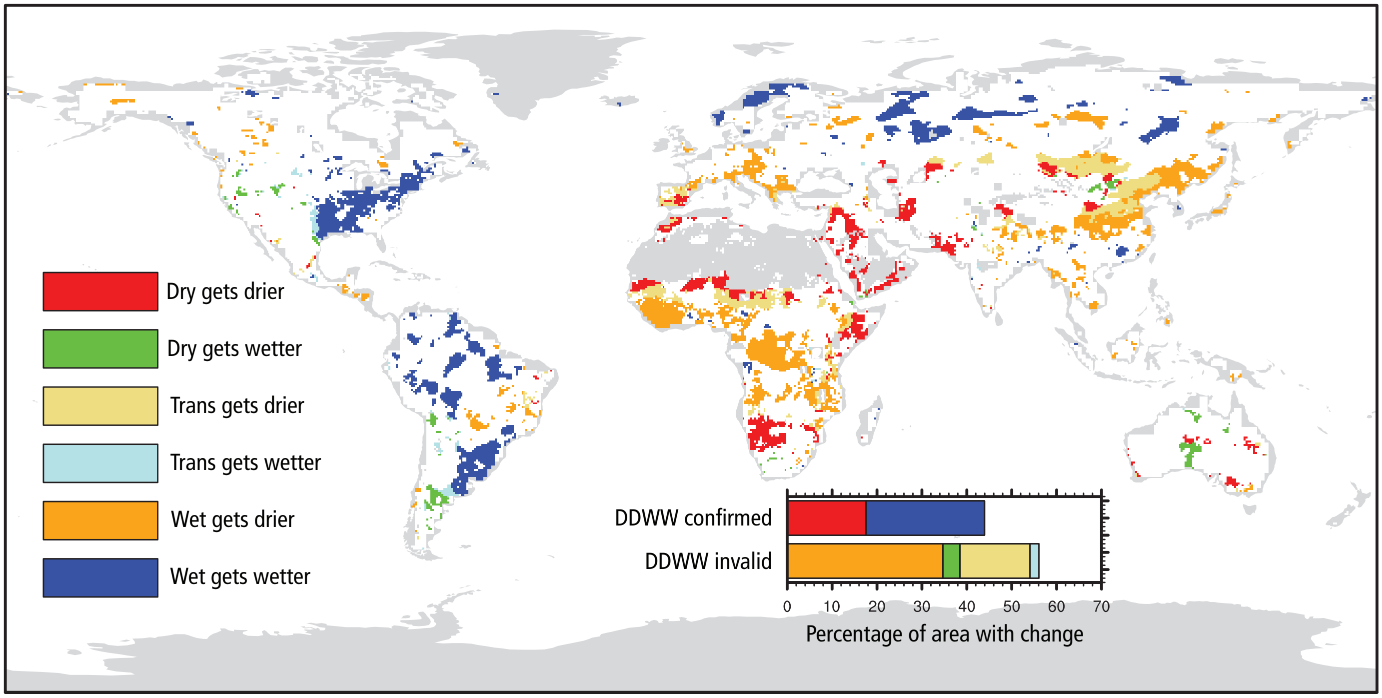


Figure 2. Assessment of robust historical dryness trends (1985-2005 vs. 1948-1968) based on a range of observation-based data sets. This analysis does not confirm the commonly held "dry gets drier, wet gets wetter" paradigm over land. Some wet regions (e.g., tropical Africa) have become drier and the Mediterranean region is a transitional rather than dry land region. Adapted from Greve *et al*., 2014.

2007), more recent publications have also highlighted that biogeophysical feedbacks that could affect projected changes in mean climate and climate extremes. This is for instance the case with irrigation (e.g., Cook *et al*., 2011; Wei *et al*., 2013), changes in albedo associated with no-till farming (Davin *et al*., 2014), and double cropping (Jeong *et al*., 2014). Such effects should be considered in the optimization of land resources under climate change (e.g., Foley *et al*., 2011), for instance in the development of so-called "climate-smart" (Lipper *et al*., 2014) agricultural management.

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II.b: Climate-Change Impacts/Adaptation/Vulnerability for Crops

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The potential challenges from environmental change to our food systems are substantial. The key potential impacts of climate change on crop *production* are increasingly well-documented and have been synthesized in the recent AR5 Working Group II report. In brief, in most site-by-crop combinations, yields are reduced with increasing climate changes, but there are some site-by-crop combinations that show increased yield but the frequency of these decreases with progressive climate change (Figure 1). Yield impacts are more negative in tropical *vs* temperate regions and they vary substantially between crops. Yield variability is likely to increase over the forthcoming decades. Subsequent publications of climate change impacts on crop yield have supported the AR5 analyses, emphasizing the substantial uncertainty in projected crop yield changes and the implications of these on food prices arising through variations in crop, economic, and climate model results.

AR5 however also identified a substantial gap in the literature on how climate change may affect the *food system* beyond production, affecting potential impacts on food availability, quality, and food stability. A small part of this gap is starting to be filled via subsequent studies (for example post-harvest aspects addressed by Jen Burney at this meeting). Additionally, it identified a range of potential crop adaptation measures and the substantial value of these in reducing negative climate impacts on yield but acknowledged the substantial limitations in adequately representing adaptations beyond incremental agronomic practice change.

AR5 also identified a lack of progress in developing implementation pathways for adaptation: in essence noting the need to move from assessment to adaptation action. The fundamental proposition behind adaptation is essentially common-sense: that failure to respond to emerging changes results in either underperformance or increased risk. Hence, there is both an inherent private interest in being well-adapted to change as well as a broader public interest through enhancing food availability and stability. However, this proposition contrasts with the apparent implementation challenge noted above.

We suggest that our existing agronomic, crop production focus will not allow the full contribution that science can make to resolving the food availability and stability challenge under climate change and that there is an increasing need for greater diversity of types of research in this domain. Specific areas of research that need to be addressed include analyses of climate change impacts on:

- Whole food systems, including input supply chains and product value chains inclusive of processing, distribution, storage, and consumption and of adaptation options across these

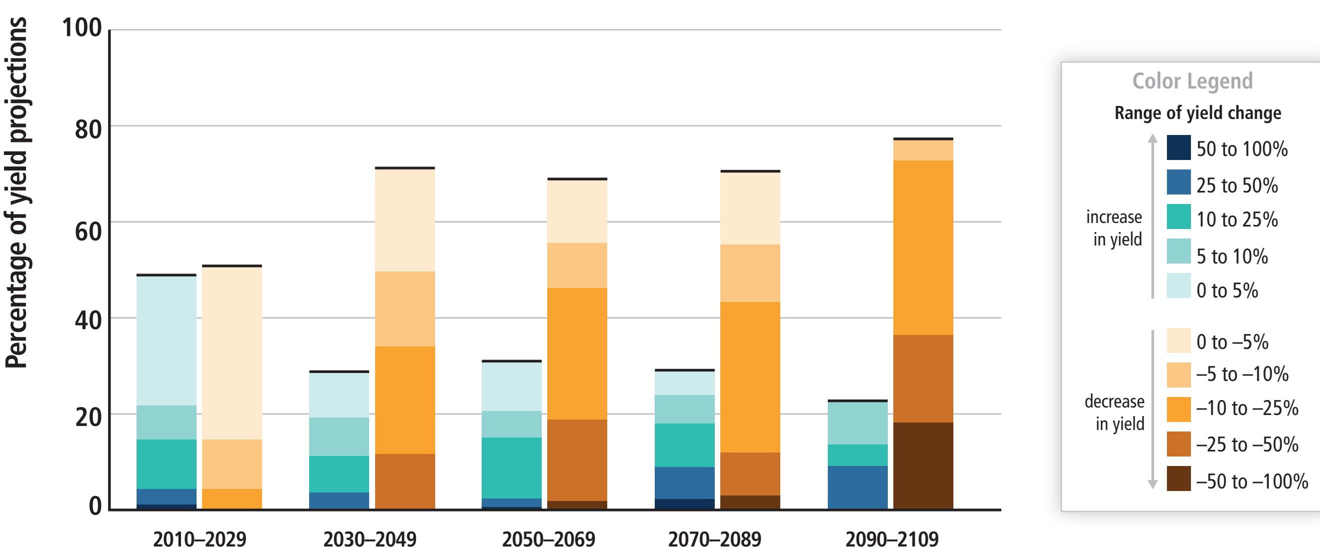

Figure 1. Summary of projected changes in crop yields, due to climate change over the 21st century. The figure includes projections for different emission scenarios, for tropical and temperate regions, and for adaptation and no-adaptation cases combined. Relatively few studies have considered impacts on cropping systems for scenarios where global mean temperatures increase by 4°C or more. For five timeframes in the near term and long term, data (n=1090) are plotted in the 20-year period on the horizontal axis that includes the midpoint of each future projection period. Changes in crop yields are relative to late-20th-century levels. Data for each timeframe sum to 100%. For the latter part of the century positive projections only occur in temperate sites. From Porter *et al*., 2014.

- Nutrition security by moving beyond simple quantitative metrics of yield
- Weeds, pests, and diseases, including animal diseases and adaptation options for these
- Marine fish species and communities at sub-regional scales as studies are typically at global or regional scale and include adaptations to only a limited extent
- Integration with non-crop aspects of the food system and adaptation options arising from this
- Mitigation options (noting that this is partly addressed in other presentations).

Underlying climate projections need to incorporate more effectively changes in climate extremes and variability and their impacts on crop-based activities and food systems models need to be evaluated for their capacity to address extremes and variability and to include realistic adaptations to these. This includes analysis of social and institutional limits/facilitation in response to climate factors.

Methodological improvements could include developing consistency in approaches to analysis of impacts and adaptations with the latter separating out best-practice adjustment to existing climate risk from adaptations specifically targeted at climate change. Studies should be inclusive of the broader range of systemic and transformational adaptation options open to agriculture.

Overall, there is a need to develop analyses and meta-analyses that are more relevant to policy and that have a clear pathway to impact.

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II.c: Climate-Change Impacts/Adaptation/Vulnerability for Domestic Animals

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Livestock are the source of 33% of the protein in human diets and, especially in developing countries, provide many other services such as traction, manure, risk management, and regular income. At the same time, 30% of the global land area is used for livestock rearing (Havlik *et al.*, 2014). Livestock agriculture and climate change interact in two domains: livestock emit greenhouse gases (GHGs), and livestock systems will be impacted by climate change and will need to adapt to it. This review focuses on the impact, vulnerability, and adaption of livestock systems to climate change.

Climate-Change Impacts

Climate-change impacts on the livestock sector are multiple, varied, and complex (IPCC, 2014a; Porter *et al.*, 2014), the impact of climate change on livestock agriculture including:

1) **Feed-grain production, availability, and price**. Climate change is already hampering agricultural growth. According to the IPCC Fifth Assessment, climate change affects crop production in several regions of the world, with negative effects more common than positive, and developing countries highly vulnerable to further negative impacts, and global warming is expected to lengthen forage growing season but decrease forage quality (Godber *et al.*, 2014; IPCC, 2014a; Lipper *et al.*, 2014).
2) **Pastures and forage crop production and quality.** There are important indirect interactions for pastures under climate change, such as plant competition, perennial growth habits, seasonal productivity, and plant-animal interactions (IPCC, 2014a). Climate change has caused a marked seasonality in feed quantity and quality on rangelands in Southern Africa. Due to climatic induced factors the vegetation dynamics have changed, which affects grazing capacity. Temperature increases and rainfall decreases due to climatic variability have affected the grasses and legumes species on rangelands promoting especially unpalatable species, reducing livestock productivity (Assan, 2014).
3) **Animal production, health, and reproduction.** Climate change (specifically increased temperature) can cause heat stress in livestock, which will induce behavioral and metabolic changes, including altered heat exchange between animal and environment; feed intake, mortality, growth, reproduction, maintenance, and production are all affected, potentially. The imposed heat stress has resulted in decreasing milk yield, fat, and protein percentages, and increasing somatic cell. A THI≥65 was found as the threshold that marks a significant steep decline in those parameters and increase in somatic cell score (Silanikove and Koluman, 2015).
4) **Disease and pest distribution.** Climate change will affect the distribution, reproduction, maturation, and survival rate of parasites, their vectors, and their intermediate hosts. As a result of climate change, animals will tend to suffer increasingly high levels of infections (Cooper *et al.*, 2014). A general model simulation using historical and predicted future climatic data for a temperate region reveals the potential for an increase in annual infection pressure of GINs in small ruminants (Rose *et al.*, 2014, 2015).
5) **Water scarcity and quality.** Climate change will affect the water resources available for livestock via impacts on rainfall, runoff, and groundwater, which also determines the quantity and quality of grassland and rangeland productivity (Assan, 2014); provision of water for livestock production could also become more difficult under climate change. Problems of water supply for increasing livestock populations will be exacerbated by climate change in many places in sub-Saharan Africa and South Asia (IPCC, 2014b).
6) **Biodiversity, loss of genetic and cultural diversity.** Much attention has been paid to the effects of climate change on species' range reductions and extinctions. There is however surprisingly little information on how climate change-driven threat may impact the tree of life and result in loss of phylogenetic diversity (PD). PD losses are not significantly higher under predicted extinction than under random extinction simulations. Focusing resources on climate-threatened species alone may not result in disproportionate benefits for the preservation of evolutionary history (Pio *et al.*, 2014).

Adaptation to Climate Change

Adaptation to climate change is unlikely to be achieved with a single strategy. An integrated, evidence-based, and transformative approach (including animals housing, reproduction, nutrition, health care, and genetic changes) to address livestock adaption to climate change is required:

1) **Integrated grazing management.** Matching stocking rates with pasture production. Adjusting herd and watering point management to altered seasonal and spatial patterns of forage production. Managing diet quality by using diet supplements, legumes, choice of introduced pasture species, and pasture fertility management.
2) **Raise regional appropriate animals.** The lure of high productivity has led to ill-advised schemes to import livestock to places where they are genetically unsuited. However, indigenous livestock species represent a genetic resource that is resilient to climate variability and should not only be conserved for future use but also utilized as a potential tool to mitigate against climate change effects. More can and must be done to encourage farmers to realize the advantages of livestock adapted to local areas (Assan, 2014; Eisler *et al.*, 2014).

3) **Application of best practice and measures.** Adaption of the extensive production system to intensive or industrial production system by using cross-breeding with heat- and disease-tolerant breed, and cooling systems in livestock housing. Increased shade provision through trees or cost-effective structures can substantially reduce the incidence of high heat stress days. Enhance monitoring and managing to avoid the spread of diseases.

Suggestions for Further Research

Addressing climate change is a never-ending process. The IPCC Fifth Assessment clearly states that the different intersections of climate change with livestock systems, despite being crucial, are still relatively under-studied research areas (IPCC, 2014a):

1) **Impact of climate change on different livestock production system.** The influence of water stress and disease resistance as predicted in the context of climate change should be studied, and future livestock research focus should have an element of testing livestock in stressful heat environments.
2) **Genetic selection for adaption.** Significant research commitment and genomics will play a role in the genetic measures taken for adaptation of livestock to climate change, including collection of information on animal genetic resources (AnGR) and its environment, optimization of indigenous AnGR potential according to genetic selection objectives and strategies for adaption, and development of tools for genetics of adaptations (Boettcher *et al.*, 2015).
3) **Cost-effective adaptation measures on different livestock production system.** Research prioritization should be guided by demands from livestock farmers to curb the negative effects of climate change to sustain animal production and maximize livestock productivity (Assan, 2014).

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II.d: Climate-Change Impacts/Adaptation/Vulnerability for Fisheries and Aquaculture

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Oceans cover more than 70% of the planet and their biota provide an array of natural resources and services to humankind. Oceans provide 17% of the global population's intake of animal protein; 4.3 billion people get more than 15% of their total protein from seafood (FAO, 2014). Climate change causes oceans to warm and stratify, sea level to rise, and Arctic summer sea ice to shrink. Warming causes oceans to lose oxygen overall and hypoxic water layers to expand. Concomitantly, the accumulation of anthropogenic CO_2 in ocean surface waters disturbs water chemistry and causes acidification. Ocean warming, deoxygenation, and acidification alter ocean ecosystems and the services they provide. They frequently relocate and reduce marine biological resources on which human societies depend, affecting economic benefits, livelihoods, nutrients availability, and public health particularly for coastal communities.

The recent IPCC assessment report (AR5) as well as the Structured Expert Dialogue have comprehensively considered impacts, vulnerability, adaptation options, and projected climate risks for the oceans and their services to humankind (www.ipcc.ch), and their key findings are further supported by a literature review after AR5 (Weatherdon *et al*., 2015). Ocean warming has caused geographical shifts in the distribution of marine species, resulting in changes in the species composition and function of ecosystems. Species are constrained to limited thermal ranges of performances that define species fitness, including their capacity to interact with each other. Recent meta-analyses indicate that ambient temperature and hypoxia extremes in some regions are already close to tolerance limits of marine organisms and their limits to evolutionary adaptation. Empirical observations of species' geographical movement together with such mechanistic knowledge of organism and ecosystem vulnerabilities permit detection of climate impacts in the field and their attribution to climate change as well as the effect of individual climate drivers.

Projected shifts in species distribution, declines in body size, and alteration of ocean productivity due to warming are projected to result in the redistribution of exploited species (Jones and Cheung, 2015) and fisheries catch potential (Barange *et al*., 2014), especially at lower latitudes where potential catches are expected to decrease. In contrast, fisheries at high latitudes may benefit from increased abundance and diversity of commercially valuable species, although anthropogenic ocean acidification poses a major uncertainty to such potential benefits (Lam *et al*., in press). Evidence is increasing that ocean acidification is affecting organisms, ecosystems, and associated human interests (particularly bivalve fisheries and aquaculture) in areas with and without a natural background of elevated CO_2 concentrations. Hypoxic areas that exclude active pelagic fishes such as tuna and their fisheries are expanding. Impacts thus go beyond those of simply warming and include effects of acidification and deoxygenation. These combined effects of the three climate drivers will lead organisms to reach long-term tolerance limits earlier than with temperature changing alone, enhancing sensitivity through dynamic shifts of thermal limits. For example, recent modeling emphasizes that combined warming and oxygen loss constrain metabolic scope of key exploited species and thereby habitat and biogeographical distribution across wider ocean areas than previously thought (Deutsch *et al.,* in press).

Through effects on performance in reproduction, behavior, and growth, marine life forms including those that are economically relevant are thus threatened by climate drivers changing individually and even more so by their additive or synergistic impacts. Together with shifts in ocean circulation and productivity the resulting dynamic changes in thermal windows have major implications for the ranges of geographical distribution of marine species, their competitive and trophic interactions, population dynamics, and community compositions. These insights should be included further in modeled projections of ecosystem change, which will inform social-ecological models projecting effects on fisheries and aquaculture.

Attempts to quantify ecosystem service losses due to ocean warming, deoxygenation, and acidification have used primarily future scenarios or risk assessments. Acidification overlaid with warming has been a main focus of this work, and studies have generally concluded that human communities with the greatest dependence on natural resources often have the lowest capacity to adapt to losses in resources and the services they provide. For example, artisanal fishermen are less able to increase their ranges to pursue migrating fish populations than industrial fishing fleets (Sumaila *et al*., 2011), and low-latitude coastal populations tend to be heavily dependent on seafood for protein, with few protein alternatives and little economic resources to purchase or import foods (Cooley *et al.*, 2012). Substantial challenges remain to anticipate the ecosystem-wide impacts of the combined drivers of warming, deoxygenation, and acidification, and the ensuing alterations of ecosystem services for human communities. Factors like the existence of formal and informal markets, cultural beliefs, and other social influences substantially influence whether lost services can be replaced or substituted adequately, and these are generally not included in ecosystem service models at all at this time.

Projections of climate change impacts (including sea-level rise) on natural resources in the oceans and along coasts need to be considered when setting long-term global goals of climate change mitigation. At the same time, the associated risks to human communities and the human and marine biological scopes for adaptation also must be considered to identify robust, long-lasting solutions that fully respond to and mitigate climate change.

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II.e: Climate-Change Impacts/Adaptation/Vulnerability for Post-Harvest Components of Food Systems

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Using the Availability-Access-Utilization-Stability framework, IPCC AR5 broadened the discussion of climate and food security from climate impacts on food production to a more complete picture of the interactions between climate and food systems (Porter *et al*., 2014). However, in so doing, AR5 revealed a notable evidence gap in the literature: We have learned more (and with greater confidence) about the biophysical impact of climate changes on food production – crop yields, fisheries, and livestock – but we know comparatively little about how climate change will affect the post-harvest components of global and regional food systems. AR5 noted that climate change is expected to impact all four pillars of food security post-harvest. However, since global food production is the aggregate result of hundreds of millions of farming households responding to heterogeneous economic incentives and environmental expectations, estimating the longer run dynamic implications of these impacts remains difficult. A key insight of AR5 is that economic and trade models (and their assumptions about growth and adaptation) matter as much as, if not more than, the climate and biophysical impact models.

Availability

Climate change may have key impacts on overall food availability (food supply) post-harvest, through alterations in basic processing effectiveness, shifts in pest and pathogen landscapes, and climate-related changes in product shelf life. Grain drying and storage needs will change with precipitation and humidity patterns. Changes in pest life cycles and habitability zones may result in the need for new storage techniques to avoid storage losses; this may be particularly important for farmers trying to arbitrage prices through storage or for poor autarkic households needing to stretch their stores through the hungry season to the next harvest. There is strong agreement that increased mycotoxin contamination is a significant food safety/food loss risk of climate change (Paterson and Lima 2010; Vermuelen *et al*., 2010; Chakraborty and Newton, 2011; Magan et al 2011). Finally, for non-grain products (fruits, vegetables, meat, dairy), increased temperatures are expected to reduce shelf life; as an example, the rule of thumb is that shelf life of fruits and vegetables is extended 2-3 times per 10°C reduction in pulp temperature (Moretti *et al*., 2010). Adaptation to higher temperatures will require better cold storage and cold chains and their concomitant energy and emissions.

Access

The main impact of climate change on food access (economic) is via prices. Of particular concern from a food security perspective is the reality that hundreds of millions of people worldwide are chronically hungry, very poor, and highly responsive to changes in food prices. Significant work in the past decade linking trade models to climate and production models has helped illuminate different patterns of vulnerability to production and prices across spatial scales (Porter *et al*., 2014). This research has made important distinctions between autarkic, net consumer, and net producer households, and has revealed that net buyers of food across scales (from households to countries) are the most vulnerable to changes in food prices. Most of the linked climate-trade-economic work has focused on how climate-induced changes in food production will impact the world's poor and food-insecure communities. There is general agreement that higher food prices hurt the world's poor (even those that are net sellers of food), but there is less understanding about the impact of higher price volatility (and price volatility of different time scales) on food security.

In addition to production-related impacts on prices, climate impacts on post-harvest processes may also contribute to increased food prices, or changes in food price volatility. These channels include increased costs for processing, storage, and transport (particularly where cold chains or humidity control is involved) that are passed on to consumers. In addition, recent literature has shown direct negative impacts of environmental factors (heat, pollution) on agricultural worker productivity (e.g., Graff Zivin and Neidell, 2012). There is no understanding as yet of impacts on quality control (which would impact overall availability), but productivity rates are lower, which could raise labor costs and final prices, in addition to dynamic feedback impacts to producers.

Utilization

AR5 highlighted changes in nutritional quality of agricultural products (e.g., decreased protein content in cereals) anticipated under future climate. Again, post-harvest climate impacts have important implications for utilization and nutrition. Increased mycotoxin production and ingestion is a significant worry. In a similar vein, ingestion of food under storage conditions rendered inadequate by changing climate could pose significant food safety concerns. If increased processing, storage, and transport costs are passed on to price-sensitive consumers, they may shift diets away from protein and micronutrient sources towards lower cost starchy staples.

Interactions with vector-borne diseases like malaria and water-borne diarrheal illnesses have important consequences for food utilization, as outlined by other abstracts here. In addition to the shifting disease landscape, recent work has illuminated the importance of the pre-natal environment and the role that climate-related shocks to pregnant mothers – drought, pollution, floods, heat – have on long-run outcomes for children.

Stability

AR5 highlighted some key pathways of impact for climate on stability of food systems across spatial scales and highlighted important knowledge gaps. In particular the authors underscored the uncertainty surrounding the role of both yield and price variability on food security and the lack of relevant data across scales. They also pointed to the growing literature on climate-related violence, some of which may be due to climate-related income shocks to agriculture, and price-related changes that lead to riots.

Climate related impacts on post-harvest availability, access, and utilization have important consequences as well for stability. For example, the climate impacts on storage and pests and pathogens will also necessarily apply to seeds and seed storage, with important consequences for stability. A better understanding of how farmers in different contexts consider and respond to post-harvest risks will be critical both for future projections and for identifying potential policy interventions. More broadly, the biggest knowledge gap lies in understanding current adaptive capacity of food systems across scales, and how climate-related changes to the risk profiles and adaptive capacities of the various actors might lead to tipping points and dramatic changes in the food security landscape.

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III.a: GHG Emissions and Emission Reductions, and Increasing Yields in the Food Sector

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The Agriculture, Forestry, and Other Land Use (AFOLU) sector is responsible for just under a quarter (~24%) of anthropogenic GHG emissions, mainly from deforestation and agricultural emissions from livestock, soil, and nutrient management. AFOLU is the only sector in which emissions during the decade 2000-2010 decreased relative to previous decades, which is due to a reduction in net emissions from deforestation, largely due to reduced deforestation rates in South America (Smith *et al.*, 2014).

Opportunities for mitigation include supply-side and demand-side options. On the supply side, emissions from land-use change (LUC), land management, and livestock management can be reduced, terrestrial carbon stocks can be increased by sequestration in soils and biomass, and emissions from energy production can be saved through the substitution of fossil fuels by biomass. Bioenergy will be discussed further by Omar Masera and afforestation, reducing deforestation, and REDD+ will be discussed further by N.H. Ravindranath later in this session, so are not discussed further here. On the demand side, GHG emissions could be mitigated by reducing losses and wastes of food, changes in diet, though quantitative estimates of the potential are few and highly uncertain. Supply-side options depend on the efficacy of land and livestock management. Considering demand-side options, changes in human diet can have a significant impact on GHG emissions from the food production lifecycle. There are considerably different challenges involved in delivering demand-side and supply-side options, which also have very different synergies and tradeoffs. A comparison of supply-side, economic potentials published between IPCC AR4 and AR5 and estimates of technical demand-side potentials are shown in Figure 1.

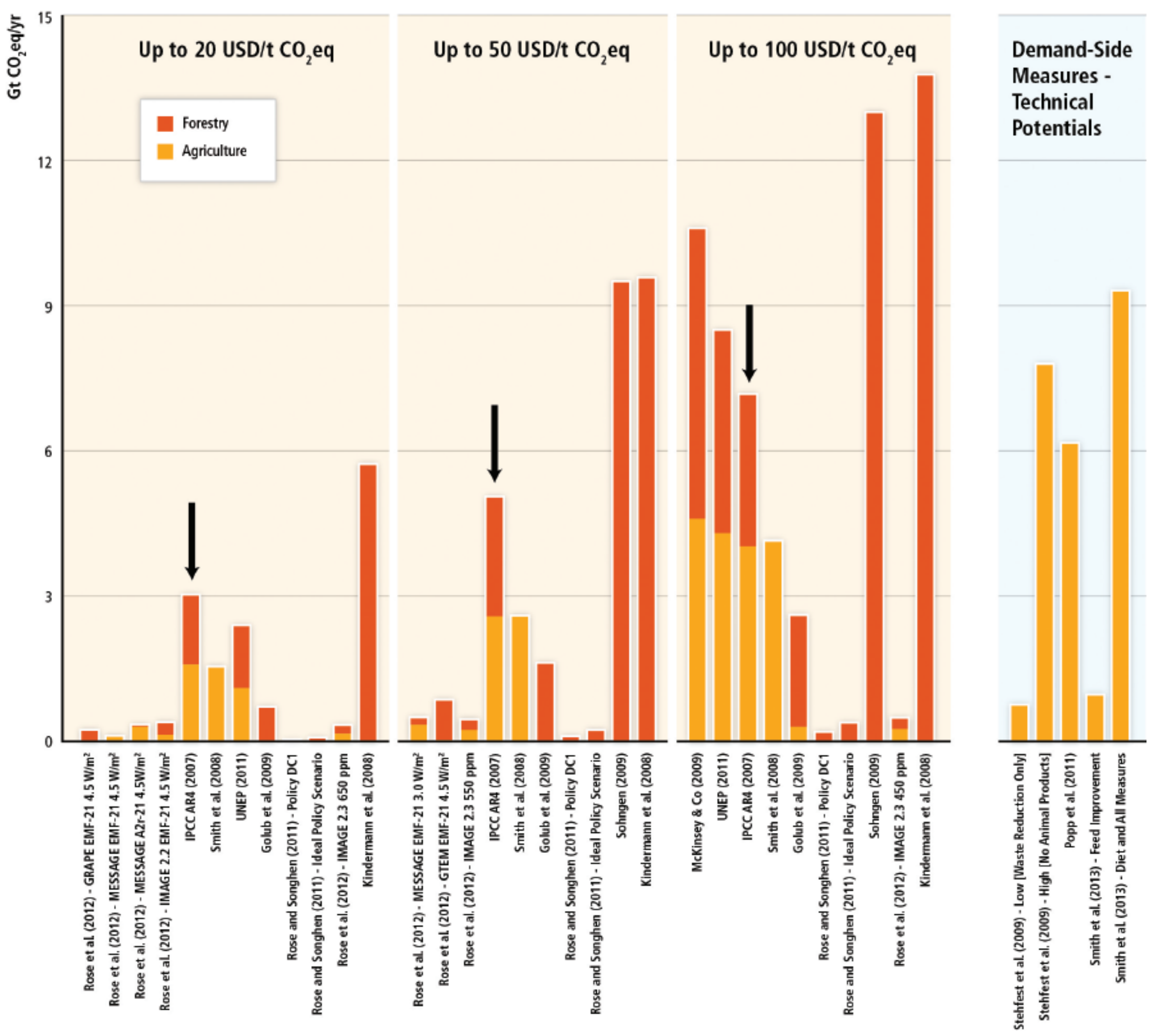

Figure 1. Estimates of economic mitigation potentials in the AFOLU sector published between AR4 and AR5 (AR4 estimates denoted by black arrows). Supply-side mitigation potentials are estimated for around 2030 and are collated for those reporting potentials at up to ~20, ~50 ~100 USD/tCO_2eq. Demand-side options (shown on the right-hand side of the figure) are for ~2050 and are not assessed at a specific carbon price, and should be regarded as technical potentials. Further details are given in Smith *et al*. (2014).

Increasing production without a commensurate increase in emissions reduces emission intensity, i.e., the GHG emissions per unit of product, which could be delivered through sustainable intensification. Emissions intensity of food products have decreased since 1960, and this emissions decoupling may continue into the future, though there are still order-of-magnitude differences in GHG intensity of different food products, whether expressed on a mass, energy, or macro- or micro-nutrients basis (Ripple *et al.*, 2014).

Economic mitigation potential of supply-side measures in the AFOLU sector is estimated to be 7.18 to 10.60 (full range: 0.49–10.60) $GtCO_2eq/yr$ at carbon prices up to 100 USD/tCO_2eq, about a third of which can be achieved at <20 USD/tCO_2eq (Smith *et al.*, 2014). These estimates are based on studies that cover both forestry and agriculture and that include agricultural soil carbon sequestration. Estimates from agricultural sector-only studies range from 0.3 to 4.6 $GtCO_2eq/yr$ at prices up to 100 USD/tCO_2eq (Smith *et al.*, 2014). The large range in the estimates arises due to widely different collections of options considered in each study, and because not all GHGs are considered in all of the studies. The composition of the agricultural mitigation portfolio varies with the carbon price, with the restoration of organic soils having the greatest potential at higher carbon prices (100 USD/tCO_2eq) and cropland and grazing land management at lower (20 USD/tCO_2eq; Smith *et al.*, 2014).

Among demand-side measures, which are under-researched compared to supply-side measures, changes in diet and reductions of losses in the food supply chain can have a significant impact on GHG emissions from food production (0.76–8.55 $GtCO_2eq/yr$ by 2050), with the range being determined by assumptions about how the freed land is used. More research into demand-side mitigation options is merited. There are significant regional differences in terms of mitigation potential, costs, and applicability (Smith *et al.*, 2014).

Since IPCC AR5, new studies have been published on supply-side measures, but none fundamentally changes the estimates of mitigation potential from the agriculture sector. There has however been new emphasis on demand-side measures, with a number of studies examining the potential for synergies between food security, climate mitigation, human health, and the delivery of other ecosystem services from land (Smith *et al.*, 2013; Bajželj *et al.*, 2014; Tilman and Clark, 2014). These will be discussed briefly, and will be dealt with in more detail by Tara Garnett during this meeting.

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III.b: Afforestation, Reducing Deforestation, and REDD+: Implications for Food Production

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Forest Sector Mitigation - IPCC AR5

IPCC AR5 (2014) provided a comprehensive assessment of GHG emissions and mitigation potential for the land use sectors. IPCC AR5 (2014) showed that the AFOLU sector is contributing to under a quarter (10-12 $GtCO_2eq$/year) of anthropogenic GHG emissions, mainly from deforestation and agricultural activities. Most recent estimates indicate declining AFOLU CO_2 fluxes, largely due to decreasing deforestation and increasing afforestation rates. According to FAO (2010) the annual forest loss during 2000-2010 was estimated to be 13 Mha (compared to 16 Mha during the previous decade), largely due to conversion of forest land to agriculture and plantation crops. The net loss in forest area during 2000-2010 declined to 5.2 Mha, mainly due to large scale afforestation. Further, CO_2 emissions from the sector are projected to decline, with net emission potentially less than half of 2010 level by 2050.

According to IPCC (2014) the most cost-effective mitigation options in forestry are afforestation, sustainable forest management, and reducing deforestation, with large differences in their relative importance across regions. About a third of mitigation potential in forestry can be achieved at a cost <20 USD/tCO_2eq. In addition, bioenergy can play a critical role in mitigation of climate change, if conversion of high carbon density forest ecosystems and peat-lands is avoided and best-practice land management is implemented. All the forestry mitigation options including bioenergy could potentially have positive or negative implications for food production, which needs to be assessed.

REDD+ Status, Potential, and Implications

There is an increasing interest in the REDD+ mechanism of UNFCCC. REDD+ includes: reducing emissions from deforestation and forest degradation, forest conservation, sustainable management of forests, and enhancement of forest carbon stocks. This mechanism is likely to play a critical role in transformation pathways aimed at stabilization of GHG concentrations at around 450 ppm. The REDD+ mechanism under UNFCCC has led to large interest among countries in developing and implementing policies aimed at reducing deforestation and increasing the carbon sink in the forest sector. A study by Baucher *et al.* (2014) has highlighted several REDD success stories in relation to deforestation from Brazil, Guyana, Madagascar, Kenya, and India. The study analyzes how policies and programs aimed at forest conservation and afforestation have contributed to reducing deforestation. Brazil has achieved the most successful reduction in deforestation-related CO_2 emissions (Wolosin, 2014). In Brazil GHG emissions have increased for all the sectors steadily during 1990-2012, except for land-use sector. Trends in reduction of CO_2 emissions from the land-use sector, in particular deforestation, can be observed in Figure 1.

Similarly in Vietnam after decades of continuous decline in area under forest (1940s to 1990s), the area under natural forest stabilized and area under forest plantations increased from 2005 (Pham *et al.*, 2012). India also has succeeded in reversing the high rates of deforestation by stabilizing forest cover and increased area under plantation through afforestation (Baucher *et al.*, 2014) and in fact the forest sector is a net sink in India (Government of India, 2012).

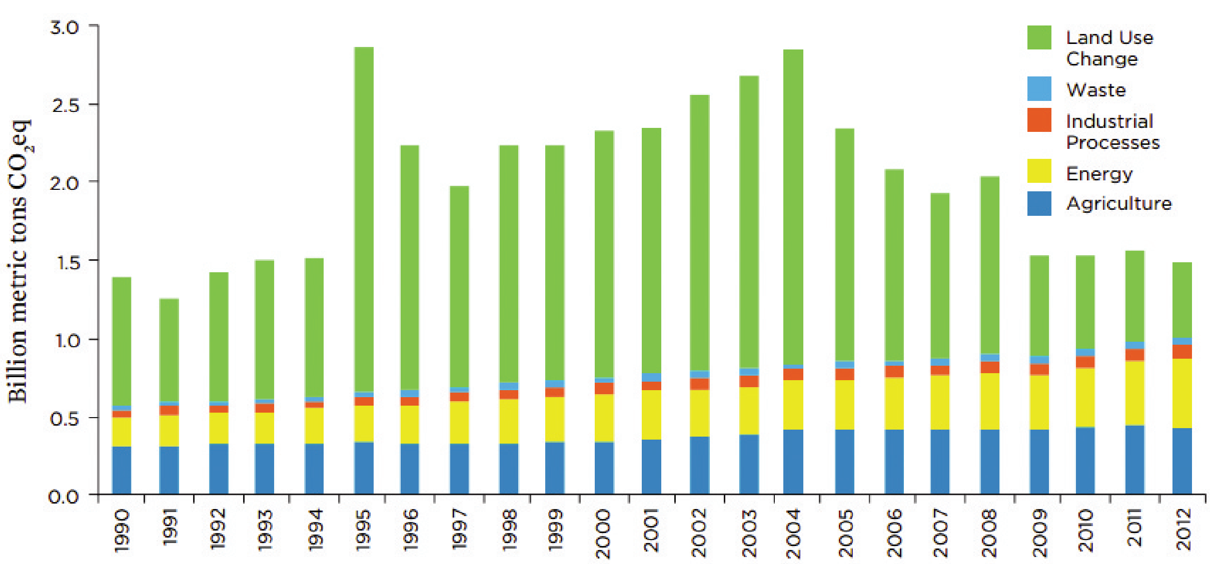

Figure 1. Trends in GHG emissions from different sectors in Brazil during 1990 – 2012. From Wolosin and Springer, 2014.

Thus many countries have successfully formulated and implemented policies and programs aimed at reducing deforestation and reducing CO_2 emissions from forest sector. There is a need for policy analysis to understand the drivers of deforestation in different countries and also to understand the policies and programs that have successfully contributed to reducing CO_2 emissions from deforestation in several countries. In this context understanding the role of emerging REDD+ mechanism under UNFCCC in driving forest policies in the past 10 years is necessary, to assist policymakers at the national and international level in devising forest and land-use policies to reduce deforestation and related CO_2 emissions. The implications of continued deforestation and aggressive implementation of REDD+ mechanism on food production at regional level should be analyzed to assist policymakers in decisionmaking. Finally, climate change itself could impact the mitigation potential of forest sector in the coming decades, requiring a good understanding of the implications of rising CO_2 concentration, nitrogen deposition, and climate change on the carbon stocks and CO_2 sequestration rates.

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III.c: Bioenergy

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A future large-scale deployment of bioenergy systems is associated with a wide range of technical, environmental, social, and economic aspects that may affect its net outcome in terms of climate change mitigation as well as its potential conflicts with food production. The consequences of bioenergy implementation depend on (i) the technology used; (ii) the location, scales, and pace of implementation; (iii) the land category used (forest, grassland, marginal lands, and crop lands); (iv) the type of feedstock used, i.e., if is it a by-product of other activities (i.e., forest residues) or if it involves additional lands specifically dedicated to produce bioenergy crops; (v) the governance systems; and (vi) the business models and practices adopted, including how these integrate with or displace the existing land use.

Based on the comprehensive review conducted for the IPCC AR5 report (Smith *et al.*, 2014; Creutzig *et al.*, 2014) it has been concluded that cellulosic feedstocks, increased end-use efficiency, improved land carbon-stock management and residue use, and, when fully developed, BECCS appear as the most promising options, depending on development costs, implementation, learning, and risk management. Combined heat and power, efficient biomass cookstoves, and small-scale power generation for rural areas can help to promote energy access and sustainable development, along with reduced emissions. Adequately implemented, the integration of bioenergy systems into diverse and multi-functional agriculture and forest landscapes can improve land and water use efficiency and help address concerns about environmental impacts.

The sustainable technical bioenergy potential was estimated as up to 100 EJ (*high agreement*), 100-300 EJ (*medium agreement*), and above 300 EJ (*low agreement*). Stabilization scenarios indicate that bioenergy may supply from 10 to 245 EJ/yr to global primary energy supply by 2050. Models indicate that, if technological and governance preconditions are met, large-scale deployment (>200 EJ), together with BECCS, could help to keep global warming below 2° degrees of preindustrial levels; but such high deployment of land-intensive bioenergy feedstocks could also lead to detrimental climate effects, negatively impacting ecosystems, biodiversity, food security, and livelihoods.

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IV.a: Adaptation and Mitigation – Land-based Policies and Food Security

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Agriculture, forestry, and other land use (AFOLU) contribute up to one quarter of global anthropogenic GHG emissions, with most of this coming from deforestation, the production of livestock, as well as soil and nutrient management. Chapter 11 of WGIII AR5 discusses the role which land-based mitigation policies can play in a transition to climate stabilization. Under 'perfect implementation', such policies can deliver a disproportionate share of abatement at modest carbon prices. The largest portion of AFOLU abatement is expected to come from forestry, with slowing deforestation dominating in the tropics, whereas forest management is relatively more important in temperate regions. In agriculture, cropland and manure management are key contributors at low carbon prices. Experience with such policies is extremely limited and many have become discouraged about the potential for REDD+ and other land-based policies to contribute to permanent, meaningful climate change mitigation. However, the recent slowdown in deforestation of the Amazon offers an example of how quickly and significantly such abatement can occur, given the right combination of policies (Nepstad *et al.*, 2014).

Chapter 11 also includes, for the first time, extensive discussion of 'demand-side' options – mainly the potential benefits from changing human diets. However, there is little discussion of how such outcomes might be attained, and also little attention to the vast literature on the behavioral determinants of food consumption behavior. AR5 also recognizes the potential impacts on food prices of mitigation efforts which induce competition for land that would otherwise be used for agricultural production. The resulting trade-off between food and environmental security must be given attention before large-scale, land-based mitigation efforts are put in place. Rising food prices are particularly burdensome for the poor and will increase the incidence of malnutrition in the absence of compensatory policies. Ultimately attaining food security is a question of having sufficient income, and for this reason, poverty is a more robust metric of household well-being than indices based on food availability or food prices. The poverty impacts of mitigation policies depend critically on changes in household earnings, including unskilled wages, as well as returns to land and other assets controlled by the household. This is not considered in AR5. A recent study suggests that large scale land-based mitigation policies are likely to be poverty increasing in many countries due to the fact that the main earnings side effect of land-based mitigation is to boost land rents and low income households typically control little land (Hussein *et al.*, 2013). What land is controlled is often communal, yet most REDD+ contracts are undertaken on privately held land, as the per unit cost of such contracts is half of that on communal land (Peters-Stanley *et al.*, 2012).

Sustainable intensification is amongst the mitigation options discussed in AR5. Boosting crop and livestock productivity on existing agricultural land offers one avenue for lessening pressure to convert additional forest land to farming. Indeed, there is evidence that intensification of crop production has played an important role in permitting Brazil to continue to expand soybean production, even as deforestation rates have fallen (Nepstad *et al.*, 2014). However, agricultural productivity gains need not be 'land-sparing' in all circumstances. When the gains occur in regions (e.g., Africa) with relatively low emissions efficiency (low yields relative to carbon released from land conversion), productivity gains can be detrimental to the environment (Hertel *et al.*, 2014). In such cases, productivity inducing investments must be accompanied by increased protection of environmentally sensitive lands as has been done in Brazil.

An important development since AR5 is the collapse of oil prices following the boom in U.S. shale gas and oil production. This, coupled with environmental concerns, has greatly altered the landscape for biofuels – which featured prominently in AR5. While an aggressive climate policy could once again bring biofuels to the forefront of developments in the global land economy, the near-term prospects suggest more of a niche role. Few investors are willing to make the huge up-front investments in second generation biofuel plants when facing massive oil price and policy uncertainty. Absent such investments, future costs are unlikely to come down quickly.

Research on adaptation and mitigation frequently ignores the role of economics. Yet land-based adaptation and mitigation outcomes are the consequence of economic decisions made by hundreds of millions of landowners and farmers. Without factoring in the incentives facing these decisionmakers, policies will rarely be effective. AR5 acknowledges the importance of economics, dividing determinants into 'supply' and 'demand', each of which is separately considered. Discussion of demand-side factors, such as eating less meat, takes place with limited reference to the fundamental drivers of demand, which are prices and incomes. Currently global trends are towards more meat consumption, not less. In addition, the economic framework in AR5 is incomplete, since long run economic equilibrium is actually determined by the *interplay* of supply and demand. Absent adjustment in the demand for food, or production intensification, the removal of land for carbon sequestration will be fully offset by area expansion elsewhere. However, the ensuing rise in land returns will induce an intensification response, thereby boosting yield. In addition, the rise in food prices following land withdrawals will reduce food consumption, thereby also moderating the land expansion, but potentially jeopardizing food security.

Another key limitation in AR5 discussion of land-based mitigation is the limited attention given to the political economy of policies. REDD+ is in its infancy as international institutional innovations go and we need much more experimentation and analysis to forge a successful long run approach. The recent success in slowing deforestation in the Brazilian Amazon is attributable to the confluence of economic and political factors which we must understand if we hope to learn from this important experience (Nepstad *et al.*, 2014). The persistence, or alternatively the erosion, of these underlying conditions will determine whether or not this important success is reversed in the future. Understanding these factors will also allow us to determine whether, and how, similar successes can be achieved elsewhere (Seymour and Busch, forthcoming).

Political economy analysis leads decisionmakers to lead with a 'second-best' policy, such as a moratorium on land conversion, thereafter transitioning to a first-best policy of carbon pricing (Busch *et al.*, 2015). More generally, Seymour and Busch (forthcoming) have used such analysis to recommend removing the "A" from "AFOLU". The authors argue that, while forest carbon policies in the developing world are a natural area for international collaboration, the same cannot be said of policies targeted at the agricultural sector where domestic politics of self-sufficiency and farm support take precedence. Indeed, if there is anything to be learned from the past two decades of international trade negotiations under the auspices of the WTO, it is that interventions and reforms in the domestic agricultural sector typically fail when driven solely by international negotiations.

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4 Breakout Group Sessions

Reports prepared by the listed Chair and Rapporteur

Breakout Group I.1: Climate Change Risks to Food Production

Chair: Cynthia Rosenzweig
Rapporteur: Sithabiso Gandure

This Breakout Group focused on defining the state of the science on climate change and food production, with special attention to progress with model intercomparison activities, the role of extreme events, and the efficacy of technology in improving the resilience of agriculture.

Framing the Discussion

The framework for consideration of food production is the farming system, which consists of physical, biophysical, and socioeconomic components and their interactions (Figure 1). Production components include crops, livestock, agroforestry, and fisheries (both marine and freshwater in both natural settings as well as aquaculture). The framing spans the wide spectrum of types of farming systems from smallholder to large-scale, and links to broader interactions with water, energy, and land use, including the role of agriculture in deforestation and afforestation.

Fisheries State of the Science

There are multiple drivers that affect the functioning of fisheries, key stresses being fishing pressure and climate change, with the key factors being temperature, oxygen, and acidification levels. The regional resolution of nutrient dynamics data (in particular nitrogen and phosphorous) needs to be improved in order to better understand the impacts of climate change on marine fisheries. Integrated modeling

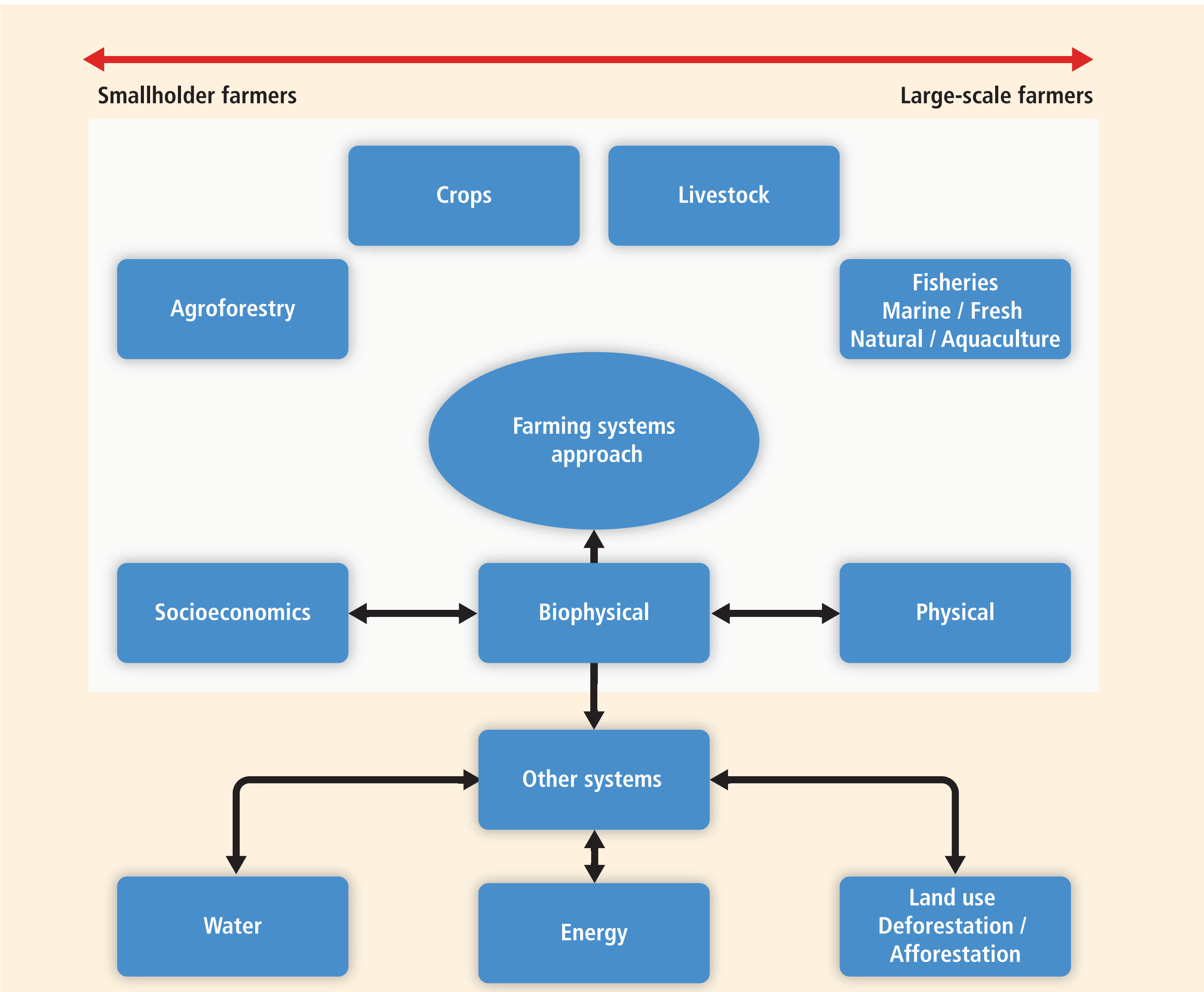

Figure 1. Framing the discussion.

of marine fisheries is now underway, but regional data and scale issues need attention. The degree of climate change and extreme events are critical for the health of many species, fisheries, and marine and freshwater ecosystems. These effects can either be positive or negative, depending on the system. Productivity in high-latitudes has increased with warming temperatures, while coral reef bleaching is an example of a negative impact of temperature. Indicators related to high temperature impacts are important, for example water temperature during spawning. Freshwater fisheries may be more exposed to climate extremes than ocean fisheries. Aquaculture will be exposed to a similar set of stresses as marine and freshwater fisheries with a greater potential for adaptation.

There are also significant interactions with climate change mitigation that need to be emphasized – i.e., fuel reduction in fishing boats, and carbon sequestration in fish. New evidence is showing that fish are an important part of the carbon cycle of the oceans.

Livestock State of the Science

Data on livestock are available through the Food and Agriculture Organization (FAO), while data on soil carbon dynamics and pastures are available through the Global Research Alliance. Modeling the biophysical dynamics of livestock production involves linkage of animal, pasture, and grazing models, of which there are now on the order of 10-15 models available. The Global Research Alliance is conducting a Pasture Model Intercomparison with links to the Agricultural Model Intercomparison and Improvement Project (AgMIP). For the socio-economic aspects of livestock production, the International Institute for Applied Systems Analysis (IIASA) is utilizing Globiom and FAO has a suite of biophysical/economic models. In regard to extreme events, variable weather affects stocking rates, so optimal stocking rate studies are needed. There is also a need to focus on the linked effects of extreme events on pasture, livestock, and livelihoods. A key task to build resilience is to increase pasture productivity, but this may mean bigger food shortages during the dry season. Inclusion of the interactions of livestock production with mitigation is essential.

Crops State of the Science

In regard to data, there is currently a large effort to make agronomic experimental data usable for statistical and dynamic models. Data needs for climate change and crops include observed weather time-series for more locations in agricultural regions, especially in low-income countries; enhanced data on Africa; data on regional crops (beyond the four major grain commodities) with one goal being model development; non-food crops, such as cotton; soil profiles for both local and global scale modeling; management data to be used as inputs to crop and livestock models; more household surveys to enhance regional integrated assessments; and measurement networks/satellite data.

Key interactions and processes that need further study include CO_2 effects and evapotranspiration (ET) and their interactions. The data-crop model process-level intercomparisons being undertaken in AgMIP can help to further this goal.

Linkages are needed between biophysical and economic models at global and regional scales. Over the last 5 years, AgMIP has developed building blocks for coordinated global and regional assessments, including a farming system approach to regional integrated assessment and global gridded crop and livestock models, as well as global economic models focused on agriculture (Figure 2). Further research and

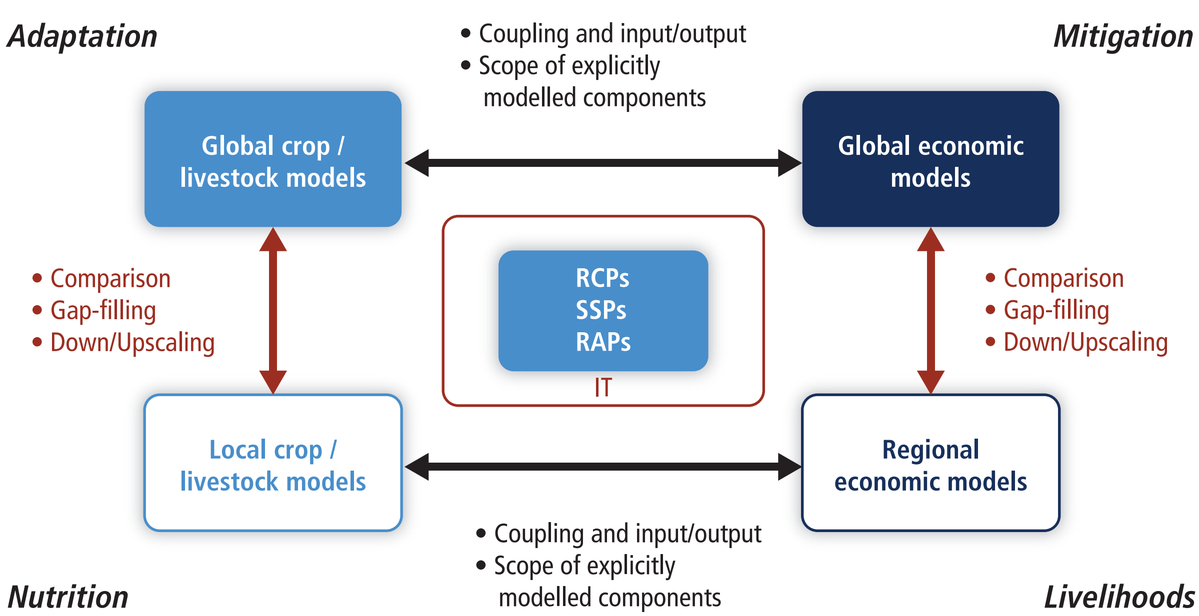

Figure 2. Coordinated global and regional assessments.

assessment activities related to modeling are an intercomparison between econometric and biophysical models, the use of AgMIP results to drive GCM simulations in order to study climate-cropping area feedbacks, and strengthening linkages to land use and land use change. As always, there is a need to verify and validate models.

Key issues with extreme events are intra-seasonal variability effects on crops, and the role of storage and stocks on economic outcomes.

An important coincident, yet understudied driver, particularly in the next several decades, is ozone; interactions of ozone and near-term climate change are an area for multi-factor research and assessment.

There are many management options in cropping systems that offer potential for interactive adaptation and mitigation.

Climate-Impacts Linkages

There are numerous interactions between climate and impacts that are ripe for further research and attention. One key area is related to the development and use of climate information used in impacts studies, with relevance to contributions by and interactions between Working Groups I and II, as well as with WCRP and CORDEX. Questions include how to translate information from WGI to WGII; how to handle uncertainties of climate models, which increase at finer scales; and how changes in land use feed back to climate (e.g., how irrigation may affect regional hydrological cycles). Climate data have two separate uses: one to improve understanding of crop processes and the other to communicate with stakeholders. There is a range of scenario types (e.g., discrete; model-based probabilistic; narratives) for use according to different stakeholder needs. The end-user perspective is important, as are decisionmaking under uncertainty approaches.

Usable outputs are needed from regional climate models (RCMs) and the research community anticipates the use of CORDEX results, but with the appropriate caveats related to the uncertainties of finer-resolution climate projections.

Other questions relate to the lack of representation of small island states in GCMs and how the El Niño-Southern Oscillation (ENSO) and other modes of variability will change.

Climate Variables and Indicators

Key variables for cropping systems include surface radiation, humidity, soil moisture, frost, vapor pressure, and wind. Indicators include extreme temperature for crops during pollination and key growth stages, and temperature extremes during key periods for fisheries and livestock.

The IPCC WGI Workshop on Climate Information in September will be an opportunity for constructive interactions. The new Vulnerability, Impacts, Adaptation, and Climate Services Advisory Board (VIACS) for CMIP6 offers a further continuing opportunity for interactions.

Directions for Further Research

Directions for further research and attention include consequences for food systems of distorting policies (e.g., subsidies, trade limits) compared to magnitude of climate change effects; impacts of and adaptive responses to multiple simultaneous occurrence of regional extreme events; development of food system models; development of Representative Agricultural Pathways (RAPs); attention to closure of yield gaps and adaptation gaps as well as knowledge for implementing climate-smart agriculture; and inclusion of socio-economic processes and linkages, including psychology.

Breakout Group I.2: Consequences of Mitigation for the Food Sector

Chair: Sabine Fuss
Rapporteur: Katherine Calvin

The Breakout Group focused on food security under climate change mitigation and featured participants from all Working Groups (WGs) and a diversity of backgrounds. As a result, the discussion, and this report, represents a broad view of the status quo and gaps in AR5 on the topic. In addition, the participants discussed a number of interesting ideas of how to frame the research questions under this topic for either other IPCC materials, such as a Special Report, or the future AR6. Still, a main message from the discussion was that further collaboration between and integration across the WGs is highly demanded.

There was vast agreement on the need for a multi-functional, multi-objective focus, which would preferably put food security and mitigation in the context of sustainable development. This would on the one hand address tradeoffs (e.g., land needs for cultivating biomass for bioenergy versus ensuring food security for a growing population with increasing living standards), but on the other hand also enable taking advantage of synergies (e.g., in the context of climate finance opportunities). The general feeling was that the picture so far drawn in the debate has been rather dim by focusing on particular negative aspects only and not the full picture of food provision. Calls were made to not just focus on negatives, but to actively identify options that have multiple benefits, such as saving money, increasing food security, and reducing emissions (e.g., through livestock system transitions saving not only CH_4, but also CO_2 by limiting emissions from land-use change (Havlik *et al*., 2014) or through improvements in forestry (Smith *et al*., 2014)). Finally, it is clear that no matter how comprehensive and detailed the research is, there will always be some remaining issues excluded, either intentionally or unintentionally, resulting in uncertainty and/or ambiguity. The group therefore strongly supported a framework for analyzing options under uncertainty, suggesting robust decision making (Lempert and Collins, 2007; Kunreuther *et al*., 2013) as a particular example. In such a framework, the best possible outcome given the worst possible scenario is typically targeted and strategies that minimize "regret" outperform those that optimize expected values. An evaluation within such a framework would minimize the probability of adverse consequences in a variety of dimensions (e.g., ecosystem loss, impacts to most vulnerable). "Red" areas characterized by uncertainty of whether we will cross irreversible thresholds as we move into them would function as guardrails for robust strategies, where mitigation and adaptation would build a portfolio addressing the challenges simultaneously. For example, some climate risks might still be limited, allowing us to keep clear of certain red areas, whereas for others we might be too late and some extent of adaptation will be needed.

Next, the participants in the BOG supported a broadening of the scope of the problem compared to AR5, which has been focused on food production, food prices, and carbon. A call was made for embracing the whole food system as the unit of analysis with more care also for environmental effects beyond carbon (e.g., non-CO_2, albedo (Jones *et al*., 2015; Ward and Mahowald, 2015)). It was recommended to incorporate also other agricultural systems (e.g., perennial crops, multi-functional systems), other mitigation options (e.g., lifestyle changes, consumption shifts (Popp *et al*., 2010)), unknown technologies, and benefits and co-benefits. A separate discussion line also touched on the missing linkage between agriculture and research on oceans in AR5. Finally, the synthesis in AR5 was not perceived to be very outspoken about how change could be incentivized in the future, both in terms of finance and investment, but also in the behavioral dimension at individual and household levels. Climate finance and its opportunities and challenges (e.g., the Green Climate Fund) were not perceived to be well understood and communicated. Additionally, disentangling the destination of financing presents challenges, as money marked for mitigation efforts may be clearly identifiable, but money intended for adaptation is intertwined with development financing in general. As a result, there is an impression that most money goes to mitigation, while only a tiny share goes to adaptation.

The third block of discussion noted that the set of pertinent research questions and the discussion fell into different categories: global scale issues (e.g., global mitigation) and local scale issues (e.g., development). These issues are typically addressed in different modeling frameworks, with global scale issues analyzed in top-down models and local scale issues addressed in bottom-up models. Participants thought that there would be value in linking top-down and bottom-up approaches. Basically, there was an agreement amongst participants that IAMs are useful for some questions, but that they need to be complemented by other models and approaches to comprehensively answer other questions (e.g., Creutzig *et al*., 2012). Some participants suggested coupling these perspectives by adopting a multi-sector, multi-agent approach to mitigation on the land surface. In such an approach, global emissions reductions strategies and the achievement of a climate goal would still require top-down analysis. However, co-delivery of mitigation, adaptation, and co-benefits could be analyzed in a bottom-up way, helping to fill many gaps on this topic that are prevalent in AR5. One participant strongly argued for a focus at local scale in the case of food security, rejecting the notion of prioritizing mitigation, especially in agriculture. No consensus could be reached on this issue in the group.

Further on methodology, the group highlighted the need for alternative ways of evaluating scenarios. Most importantly, the only food security-related metrics examined in the mitigation sections of the AR5 were agricultural commodity prices. However, there was a consensus that other measures are equally if not more important (e.g., household consumption, distributional effects, welfare). It was also noted that by fixing the forcing categories very strictly in the stabilization pathways in AR5 (e.g., the RCPs), a lot of information may have been lost. For example, just slightly exceeding a target might drastically lower the costs without causing significantly more damage. This is due to the possibility of non-linear systems behavior. Relaxing the forcing categories could therefore help to define measures of interest that we are targeting or delineate the "red zones" that we want to avoid and that have been introduced above in the context of robust decision making. Two concrete proposals were made: (1) to define scenarios based on food security goals and evaluate mitigation benefits, rather than the converse, and (2) to systematically analyze the co-delivery of mitigation, adaptation, and co-benefits. Related to the latter, several options were identified that could contribute to mitigation, while enhancing food security. These options include reducing forest and land degradation and deforestation, improving and maintaining soil quality, and reducing N_2O emissions and nitrate flow. In the socio-economic dimension, a point was made (and discussed at length) that upward pressure on prices could also trigger lifestyle changes, for example, which underlines again that – especially in the developed world – the consumption side should be focused on much more in AR6 than it has been in AR5.

Participants also discussed the need for transparency and comprehensiveness in the use of metrics, focusing on how we assess trade-offs across mitigation options (e.g., global warming potential, global temperature potential (Fuglestvedt *et al*., 2003; UNFCCC, 2009)). In this context, it also became clear that there is no agreement on what time horizon to use and this evaluation should be made more transparent in AR6 and other products.

Finally, all participants agreed that while there was a need for integration across Working Groups, there was an even more urgent need for a coordinated communication strategy between the IPCC and the public, especially on targets (e.g., 2°C) and means (e.g., technologies such as bio-energy with carbon capture and storage (BECCS)). It was felt that in the future, the message should be delivered up front. Participants also remarked that long assessment reports might not be the best means of communication with either policymakers or the general public.

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Breakout Group II.1: Food Security

Chair: Cheikh Mbow
Rapporteur: Gerald Nelson

Introduction

This Breakout Group used the framing question, "What are the new frontiers in improving food security under climate change?" to guide its discussions of two key topics: impacts (What are the implications for food systems of the changing social and ecological conditions that we expect with climate change?) and response options (What is needed to improve food security?).

The group discussed briefly the value of IPCC undertaking any new report on climate change and food security. The views expressed were that a Technical Paper based on AR5 would now have little value. A Special Report that draws on new literature would be of substantial value, especially if it went beyond a "pure" climate focus. This could include assessment of how the degree of climate change reduces options for adaptation to meet food security goals, how climate change affects our ability to meet the food-related Millennium Development Goals historically, and how climate change may make the food-related Sustainable Development Goals challenges more difficult.

It was agreed that the widely accepted definition of food security with four components – availability, access, utilization, and stability – was a good organizing framework to pull together the disparate elements of food security. Among other benefits, it allows a holistic perspective. Participants emphasized the importance of both qualitative and quantitative components.

The Four Pillars of Food Security as an Organizing Structure

This report presents highlights from the discussion organized around these four pillars.

Access

Several participants suggested taking access as a starting point for the assessment, discussing the central role of real income (taking into account price effects on cost) in sustainable access to food. At least one participant pointed out that costs may differ by income group, with the poor sometimes facing higher costs, say in the form of limited access to clean water and healthy food, and higher prices.

It was suggested that the assessment could start with a discussion of the need to address poverty and then "add" sustainability, especially the effects from climate change. Participants mentioned the co-benefits to climate change from reducing poverty such as slowing population growth and encouraging changes in unsustainable practices. It will be important to emphasize the two-way direction of effects: from climate change to poverty and from poverty to climate change.

Of course, access is not solely due to income. Food needs to be available for it to be consumed.

Availability

An assessment of availability must include a discussion of production and its determinants. These include the availability of the necessary resources (e.g., soil, water, and genetic material) and their productivity. But local, regional, and international trade are also fundamental elements of availability. One participant pointed out that today Philippine demand moved the world rice market. Self-sufficiency could not possibly work. A partnership with other major rice-consuming regions has helped to manage the effects of world market fluctuations. Other participants pointed out that in local markets, bad roads resulted in large losses at the farm level and lower income for farmers.

It was pointed out that climate change would affect not only farm-level productivity but other elements in the value chain to consumers – for example, its effects on cold chains.

An assessment of the effects of climate change would need to include its effects both on physical infrastructure such as roads, irrigation systems, etc., and the kinds of institutional infrastructure to deal with its effects (e.g., regional partnerships, changes in standards, and efforts to reduce corruption).

Some discussion emphasized the importance of including fish in an assessment, both marine capture fisheries and aquaculture. An assessment should capture the need for land-based inputs (fish feed), similar conceptually to livestock systems.

A brief discussion of whether GMOs can improve resilience to climate change raised issues of what effects they could address – i.e., heat stress, drought, the changing prevalence of pests and diseases, and nutritional components.

Utilization

Participants pointed out that research on utilization has traditionally had a focus on access to food quantity. It has emphasized the link from poverty and the resulting lack of access to education and health care to undernutrition. It has stressed the importance of increasing the availability of staple foods.

As incomes rise, consumers demand improved food quality (a relationship called Bennett's Law). They purchase a more diverse diet. It was pointed out that whether a more diverse diet was healthy depends on preferences and the relative costs of healthy and unhealthy foods. If healthy choices are too expensive, consumption will move to unhealthy choices, and potentially result in obesity and other health problems associated with overconsumption.

Several participants pointed out that preferences are important and asked whether they are immutable. Information sharing, marketing, and advertising were given as examples of ways to change preferences.

Some participants pointed out that price differences are due in part to subsidies and research expenditures targeted to staples rather than healthy dietary choices.

Finally an important point for a future assessment is to address the qualitative observation that climate change will affect nutrient composition of plants and animals, a special problem for the poor for whom supplementation might be difficult to obtain and expensive.

Stability

A new assessment must address the fact that climate change will almost certainly bring more weather-induced variability in food supplies. Farmers have had to manage in the face of variability forever, but climate change will likely change the magnitude and the nature of the variability. It will affect farmers' own production and the markets into which they sell. These changes could be quite local, suggesting the importance of regional and even finer grained analyses, a point discussed in more detail below.

Several participants emphasized the importance of assessing the role(s) of various buffers – i.e., local, regional, and global storage; changes in market access; and varietal changes.

Other Points

Scale: Global to local and local to global

Several participants emphasized the need for an assessment to go beyond global results, pointing out that national policymakers needed national results. The challenge for the assessment is how to deal with links from local to regional to global and back. And to look at the links between regions. There are both analytical and presentational challenges. There was widespread agreement with the need to assess our knowledge of how the four pillars of food security play out at the local level, looking at differences across the regions.

The continuing need for scenarios

All participants recognized that going beyond pure climate change analysis increased the complexity of an assessment and raised the question of where to draw the boundaries of the analysis. A number of participants pointed out that well-designed scenarios make it possible to sort out a multiplicity of interactions.

Breakout Group II.2: Adaptation and Mitigation Interactions in the Context of Food Security

Chair: Sonja Vermeulen
Rapporteur: Max Auffhammer

The point of departure for this Breakout Group was a description by the Chair, which stated that:

- Actions in adaptation can have implications for mitigation, or vice versa.
- Few studies have combined metrics on adaptation, mitigation, and food security.
- These could be co-benefits or costs.
- They work (mostly) at different scales.

There was general consensus in the Breakout Group that, while there is clearly potential for adaptation and mitigation synergies in agriculture and food systems, a better framing of the issues involved was needed. Several IPCC authors from AR4 and AR5 noted that the regional chapters were asked to look at the adaptation and mitigation interactions and found almost no literature whatsoever. This was true for both food security and food production. Some Breakout Group members noted that a better framing with respect to the spatial and time scales involved was important. Others pointed out that it is important to recall that all of these processes play out against a backdrop of development processes.

Concrete steps forward suggested were:

- Generation and review of existing lists of (technological) options
- Qualitative and quantitative evaluation of mitigation and adaptation benefits and costs which could be regionally specific
- Examination of sectors currently largely unexplored (e.g., fisheries)
- Improved understanding of local knowledge base and institutional settings for technological options
- Improved metrics for measuring outcomes from farming and food systems, particularly for adaptation and resilience
- Exploration of the magnitude and impact of productivity gains and stability – good or bad? How good or bad?
- Exploration of trade-offs with land use to inform forestry sector
- Improved understanding of spatial and temporal displacement effects, including previously under-studied interactions, for example between deforestation and ocean quality
- Investigation of ozone (and other pollutant) mitigation benefits to food security
- Evaluation of the potential of GMOs and other emerging technologies, for example in animal science
- Generation of evidence for finance sector, for example possible beneficial impacts to smallholder financiers from increased resilience of farmers they insure or lend to
- Improved linkage of global to regional scale and between top-down modeling approaches and bottom-up empirical field studies, informed by experience in WGI
- Review of experience on implementation of current adaptation and mitigation policies and programs for the agriculture and food sectors across a range of countries
- Framing of mitigation and adaptation options within the water-energy-food security nexus, for example by investigating of how demographic shifts towards cities impact water supply for the farming sector.

As far as data opportunities were mentioned, they focused on paying more attention to new sources of micro and survey data from the World Bank and other organizations like it. Also, some participants pushed for focusing on hotspots instead of the entire globe.

Several participants also urged for the engagement of other organizations like Future Earth and the Global Land Project in the effort.

Overall, the impression of the Rapporteur was that neither the issue nor the topic is well defined and understood. IPCC could play a key role in help framing the research agenda on this topic going forward.

Breakout Group III.1: Future IPCC Products and Partnership for IPCC for Future Work in the Area of Climate Change, Food, and Agriculture

Chair: Ramon Pichs-Madruga
Rapporteur: Gian-Kasper Plattner

Introduction

The Breakout Group was mandated by the Scientific Steering Committee of the Expert Meeting to discuss both potential future IPCC products as well as possible partners for IPCC for its future assessment work in the area of climate change, food, and agriculture. In addition, the Breakout Group was asked to consider key research and assessment questions in the area of climate change, food, and agriculture that could guide the preparation of future IPCC products. The Breakout Group comprehensively covered all these aspects in a lively, engaged, and respectful discussion, integrating many of the discussions from the previous 2 days of the Expert Meeting. This Breakout Group report will thus need to be read in context with the entire report of the Expert Meeting, including the parallel Breakout Group (BOG III.2) report, charged with the exact same tasks.

Summary of Potential Products and Key Research and Assessment Questions

After a short introduction by the Chair and the Rapporteur of the Breakout Group, the group started with discussing potential future IPCC products and, closely related to future products, key research and/or assessment questions.

In the discussions, the Breakout Group comprehensively covered prospects for future IPCC work in the area of climate change, food, and agriculture, including (at the informal end) journal papers or perspectives written by people who participated in the Expert Meeting, an IPCC Technical Paper from the IPCC AR5, or (at the formal end) an IPCC Special Report as part of the IPCC AR6. Discussions covered the amount and nature of new scientific information required, the status of ongoing or planned assessments from other organizations, and the likely impact of various kinds of IPCC-related products.

After thorough discussions and many good and valid arguments laying out the pros and cons of different IPCC-related products, there was no consensus in the group as to the value of preparing an IPCC Technical Paper – which could only include information from the AR5 – or an IPCC Special Report as part of the AR6 cycle. In contrast, there was unanimous agreement that the scoping process for the AR6 needs to be well informed on the topic of climate change, food, and agriculture. One option to facilitate this that received wide support was to prepare a perspective paper for a high-impact/high-visibility journal in order to activate the community early in the IPCC AR6 cycle.

The participants also highlighted the importance of having a comprehensive Expert Meeting report that reflects the relevance of the discussions carried out during the meeting as well as references to the emerging literature in this field. This would serve as very valuable supporting material for the preparations of the IPCC AR6.

The discussions on key research and assessment questions emphasized, among other topics, the need to further enhance and improve the integration among the IPCC Working Groups overall, but in particular in the area of climate change, food, and agriculture, as well as the need for more focus on the linkages across spatial (global, regional, sub-regional) and temporal scales.

The following list provides a bullet-point summary of the discussions as presented to all Expert Meeting participants following the Breakout Group – with minor editorial changes, copyedits, corrections, and a disclaimer added.

Potential Products: IPCC and Others

IPCC Products

Expert Meeting report – group consensus
- Mandatory
- Structure TBD
- Supporting material for AR6 scoping and assessment
- Can be important vehicle to highlight the importance of the topic and lay out research gaps, issues, and a potential future way forward

Technical Paper – no group consensus
- Could be valuable integration of AR5 assessment in single, targeted product
- No inclusion of new, post-AR5 science, i.e., all information would be from 2013 or earlier; would take at least 10-month production time, if not much more, once agreed by the Panel
- Unclear if there is enough information in AR5 to support Technical Paper

- Late in the AR5 process, too late for COP-21; window of opportunity may already be closed
- Impact unclear; experience from past Technical Papers not always encouraging
- Author and/or TSU resources might not be available

Special Report – no group consensus

- Could be valuable focused assessment as part of AR6, integrating latest information from across all WGs into a single, targeted product
- Opportunity to focus on specific policy-relevant question
- Timing: 2-3 years from Panel decision; could provide IPCC input before end of AR6 cycle
- Will there be enough new science available compared to AR5?
- Resources (IPCC and scientific community) required
- Potential competition with other SR proposals

IPCC and Other Products

Input to AR6 scoping – group consensus

- Timely delivery of products essential; products include meeting report and scientific publications

Possibility for new products as part of AR6 cycle?

- Electronic, others (e.g., U.S. National Climate Assessment)

Scientific publications – supported, group consensus

- Commentary/perspective
- Review paper

Key Research and Assessment Questions

Questions guiding the preparation of products, integrating discussions at this meeting. [NOTE: This is not intended to be a comprehensive list, and the sequence of listings should not be interpreted in terms of importance of a topic. This is merely a reflection of the Breakout Group discussions at the Expert Meeting.]

General

- Stocktaking needed on climate change and food security
- Need to integrate WGII/III perspective on adaptation/mitigation
- How to link food production assessments with food security assessments?
- How to improve local and regional climate information for assessments? How to better link global to regional/local assessments? Is there convergence?
- Uncertainties/errors in impacts assessments when not accounting for climate change feedbacks

Specific

- Identifying key metrics (food production, GHG emissions)
- Mitigation potential of agriculture
- Impacts on pastoral communities and mobile peoples
- Building resilience in food systems
- Land competition, land management, integrated approach
- Political economy of land-based policies
- Climate smart agriculture
- Ecosystem perspective on indicators for forest systems
- Assessment of orphan crops, crops not covered by models
- Supply-demand interactions

Summary of Possible Partners for IPCC for its Future Assessment Work

The Breakout Group then moved on to discuss possible partners for IPCC for its future assessment work. The Breakout Group was mandated by the Scientific Steering Committee to evaluate the full range of actors relevant to future work on scientific assessments of climate change and food. The goal was to consider scientific capacity, operating principles, susceptibility to political influence, and historical accomplishments in evaluating ongoing projects, prospects for future projects, and prospects for future interactions with the IPCC. However, the Breakout Group participants felt that these aspects had widely been covered during the previous discussions at the Expert Meeting and would thus not need to be repeated given the limited time available for Breakout Group discussions. The Breakout

Group Chair therefore invited participants to freely propose possible partners, including regional and global institutions working in this field, which would be added to a non-exclusive, non-comprehensive list as the output from the Breakout Group. The Breakout Group therefore did not go beyond an initial listing of possible partners proposed by participants in the Breakout Group.

Options for partnerships include IPCC co-sponsored meetings, joint workshops/EMs, partners for IPCC Special Reports, etc. Hereafter the list of possible partners as presented to all Expert Meeting participants following the Breakout Group is given.

Potential Partners for IPCC in Future Work

- Food and Agriculture Organization of the United Nations (FAO; climate change, agriculture, and food security; pastoralist communities and mobile peoples)
- Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES; food production, ecosystem services)
- World Climate Research Programme (WCRP), including the Global Energy and Water Cycle Exchanges Project (GEWEX; feedbacks, climate effects from land use, etc.)
- Consultative Group for International Agricultural Research (CGIAR) Research Program on Climate Change, Agriculture and Food Security (CCAFS; climate change, agriculture, and food security)
- Future Earth and related global change projects, including Global Land Project (GLP)
- Global Climate Observing System (GCOS; data)
- Global Framework for Climate Services (GFCS)
- GEOSHARE (Geospatial data for Sustainability Analysis)
- Global Trade Analysis Project (GTAP; trade analysis related to climate change)
- International Union on Forest Research Organizations (IUFRO), Collaborative Partnership on Forests (CPF), United Nations Forum on Forests (UNFF) (Forestry and climate change)
- United Nations Environment Programme (bush meat, regional seas conventions), UN-Habitat (demographics)
- Organisation of Economic Co-operation and Development (OECD) Joint Working Party on Agriculture and Environment (JWPAE)
- African Climate Policy Centre (ACPC)

BOG III.2: Future IPCC Products and Partnership for IPCC for Future Work in the Area of Climate Change, Food, and Agriculture

Chair: Ladislaus Chang'a
Rapporteur: Michael Mastrandrea

This Breakout Group considered prospects for future IPCC products and scientific publications related to this Expert Meeting. It also considered key research and assessment topics related to climate change, food, and agriculture, and potential partners to consider in future IPCC work on these topics.

Future Products

The Breakout Group considered a range of potential IPCC products related to climate change, food, and agriculture, beyond the proceedings of this Expert Meeting to be prepared in accordance with IPCC procedures. Considered options included a Technical Paper based on material assessed in the IPCC Fifth Assessment Report (AR5), a Special Report to be undertaken early in the IPCC Sixth Assessment Report (AR6) cycle, and input to the AR6 scoping process regarding treatment of these issues across Working Group contributions.

There was support for a Special Report on climate change, food, and agriculture to be prepared jointly by the three IPCC Working Groups. This topic touches deeply on the scope of all three Working Groups, and new literature continues to emerge on many aspects since the publication of the AR5. The integration of this material in a single product would be new and valuable, and would provide important information supporting the UNFCCC process. Such a Special Report could be considered at the next session of the Panel, recognizing that consideration would be predicated on preparation of a Special Report proposal by member governments.

In contrast, the window of opportunity for a Technical Paper based on the AR5 was seen to be closed, as it would inevitably be based on dated material. Input to the AR6 scoping process could build from a Special Report.

Regarding non-IPCC products, there was interest in preparation of a short commentary or perspective piece for publication in the scientific literature that would outline key research topics such as those listed below, synthesizing ideas raised during the Expert Meeting.

Key Research and Assessment Topics

Many key research and assessment topics were raised during this Breakout Group, with the group also recognizing that a comprehensive synthesis should integrate across the presentations and discussions throughout the Expert Meeting. Consistent with the support for a Special Report integrating across all three IPCC Working Groups, the topics include many cross-cutting issues.

Specific topics discussed by the group include:

- Climate-agriculture interactions, including effects of climate variability, pests, and diseases
- Opportunities and limits for food supply in a changing climate, including production and nutrition
- Food security across regions and stakeholders, given broad agreement on the priority for safe, secure access to sufficient nutritious food, in the context of different drivers of vulnerability
- Effects on fisheries and interactions with food security and livelihoods
- Climate change interactions with other drivers of food demand
- Quantification of mitigation potential in the Agriculture, Forestry, and Other Land Use (AFOLU) and energy sectors, and potential interactions with climate change, food, and agriculture (e.g., afforestation, BECCS)
- Implications and side effects of mitigation options, including potential competition for land and water and related changes in surface albedo and non-CO_2 greenhouse gas emissions
- Integrated regional assessments, bottom-up/top-down comparisons, adaptation-mitigation interactions
- Effects of solar radiation management on food production

A critical additional question raised by the group was the need to identify and engage with potential users to better understand what information they need and what information scientific research can provide. For example, some participants described the prominence of food security issues for policymakers in their countries, and others highlighted the relevance of many of these issues to the UNFCCC process.

Potential Partners

Finally, the Breakout Group discussed potential partners for future IPCC work on climate change, food, and agriculture. These fell into three categories: (i) those related to the United Nations, (ii) those organizing international research efforts, and (iii) those related to the private sector.

For the first category, the Food and Agriculture Organization of the United Nations (FAO) was identified as a natural partner to consider for future activities. It was also noted that the Subsidiary Body for Scientific and Technological Advice (SBSTA) of the UNFCCC is in the process of producing a series of food products, which would complement IPCC work on this topic. For marine issues, the International Oceanographic Commission (IOC) of UNESCO was noted. Finally, the United Nations Committee on World Food Security and the United Nations Special Rapporteur on the Right to Food were highlighted as contacts who could provide input to scoping future IPCC work.

For the second category, the Agricultural Model Intercomparison and Improvement Project (AgMIP) and the Consultative Group for International Agricultural Research (CGIAR) Research Program on Climate Change, Agriculture, and Food Security (CCAFS) were identified as potential partners. For marine issues, the International Council for the Exploration of the Sea (ICES) and the North Pacific Marine Science Organization (PICES) where highlighted as possible partners, particularly for regional issues. Research programs organized by the World Climate Research Programme (WCRP), including the Global Energy and Water Cycle Exchanges Project (GEWEX), and by Future Earth, including the Global Land Project, were also noted.

For the third category, the importance of involving the private sector in the scoping, development, and outcomes of future work was emphasized in the group discussion. The International Life Sciences Institute was noted as one potential partner.

Annexes

A) Agenda

B) Participants List

C) Poster Session Abstracts

D) Recent Literature

E) Background Information

Annex A. Agenda

IPCC Expert Meeting on Climate Change, Food, and Agriculture
Dublin, Ireland • 27-29 May 2015

WEDNESDAY, 27 MAY 2015

8:00-9:00 ***Registration***

Welcome and Introduction
Chair: Chris Field

9:00-9:25 **Welcome Address**
Local Hosts

9:25-9:45 **Introduction**
Ismail El Gizouli, Youba Sokona, Thomas Stocker

Plenary Session I: General Overview on Food Security
Chair: Katharine Mach

9:45-10:05 **The Food-Water-Energy-Climate Nexus**
Chris Field

10:05-10:25 **Food Production and Food Security**
Katharine Vincent

10:25-10:55 ***Coffee Break***

10:55-11:15 **Future Demand for Food: Relevance of Land Use and Lifestyles**
Tara Garnett

11:15-11:35 **Potential Impacts of Mitigation Scenarios on Bio-Energy Deployment, Land Use, and Food Security**
Alexander Popp

11:35-12:15 **Discussion**

Plenary Session II: Climate-Change Impacts on the Food Sector and Prospects for Adaptation, Across Regions
Chair: Ramon Pichs-Madruga

12:15-12:30 **Projected Changes in Temperature, Precipitation, and Climate Variability**
Sonia Seneviratne

12:30-12:45 **Climate-Change Impacts/Adaptation/Vulnerability for Crops**
Mark Howden

12:45-13:00 **Discussion**

13:00-14:00 ***Lunch***

14:00-14:15 **Climate-Change Impacts/Adaptation/Vulnerability for Domestic Animals**
Hongmin Dong [Presented by Henning Steinfeld]

14:15-14:30 **Climate-Change Impacts/Adaptation/Vulnerability for Fisheries and Aquaculture**
Hans-Otto Pörtner

14:30-14:45 **Climate-Change Impacts/Adaptation/Vulnerability for Post-Harvest Components of Food Systems**
Jen Burney

14:45-15:05 **Discussion of Plenary Session II and Introduction of Breakout Groups I**

15:05-15:30 ***Coffee Break***

Breakout Groups I

15:30-17:30 **BOG I.1: Climate Change Risks to Food Production**
Chair: Cynthia Rosenzweig
Rapporteur: Sithabiso Gandure
This BOG will focus on defining the state of the science on climate change and food security, with special attention to progress with model intercomparison activities, the role of extreme events, and the efficacy of technology in improving the resilience of agriculture.

BOG I.2: Consequences of Mitigation for the Food Sector
Chair: Sabine Fuss
Rapporteur: Katherine Calvin
This BOG will focus on consequences for food production and food security from a wide range of mitigation activities, including BECCS, afforestation/reforestation, and other mitigation activities with the potential to create competition for land or water. It will also ask whether policies to limit methane or nitrous oxide emissions might impact food security.

17:30 **Adjourn**

18:00-18:30 ***Flash Presentations Introducing Poster Session***

18:30-20:00 ***Reception and Poster Session***

THURSDAY, 28 MAY 2015

9:00-10:00 **Breakout Groups I Reports and Plenary Discussion**
Discussion Chair: Eduardo Calvo

Plenary Session III: Impacts of Mitigation Options on the Food Sector and Prospects for Responses
Chair: Thelma Krug

10:00-10:15 **GHG Emissions and Emission Reductions, and Increasing Yields in the Food Sector**
Pete Smith

10:15-10:30 **Forestry: Afforestation, Reducing Deforestation, and REDD+**
N.H. Ravindranath

10:30-10:45 **Bio-Energy**
Omar Masera

10:45-11:05 **Discussion**

11:05-11:35 ***Coffee Break***

Plenary Session IV: Policy Instruments for Land Policies and Food Security
Chair: Youba Sokona

11:35-11:50 **Adaptation and Mitigation Responses**
Tom Hertel

11:50-12:15 **Discussion of Plenary Session IV and Introduction of Breakout Groups II**

12:15-13:30 ***Lunch***

Breakout Groups II

13:30-15:30 **BOG II.1: Food Security**
Chair: Cheikh Mbow
Rapporteur: Gerald Nelson
This BOG will take a big-picture perspective on food security, looking at impacts both within and beyond food production. It will consider the challenges to food security from distribution, transportation, inappropriate appearance standards, and corruption. It will also address food quality, especially in the context of the current obesity epidemic.

BOG II.2: Adaptation and Mitigation Interactions in the Context of Food Security
Chair: Sonja Vermeulen
Rapporteur: Max Auffhammer
This BOG will focus on opportunities for enhancing food security through a wide range of adaptation and mitigation activities, recognizing that the policy landscape may include GMOs, novel crops, innovative management schemes, and activities with the potential to create competition for land or water. It will ask whether there are opportunities to combine adaptation and mitigation to yield significant co-benefits.

BOG II.3: Optional Breakout Group on Emerging Topics

15:30-16:00 ***Coffee Break***

16:00-17:00 **Breakout Group II Reports and Plenary Discussion**
Discussion Chair: Jean-Pascal van Ypersele

17:00 **Adjourn**

18:00-20:00 ***Reception***

FRIDAY, 29 MAY 2015

Breakout Groups III

9:00-11:00 **BOG III.1: Partnerships for IPCC for Future Work**
Chair: Ramon Pichs-Madruga
Rapporteur: Gian-Kasper Plattner
This BOG will evaluate the full range of actors relevant to future work on scientific assessments of climate change and food. The goal is to consider scientific capacity, operating principles, susceptibility to political influence, and historical accomplishments in evaluating ongoing projects, prospects for future projects, and prospects for future interactions with the IPCC.

BOG III.2: Future IPCC Products
Chair: Ladislaus Chang'a
Rapporteur: Michael Mastrandrea
This BOG will consider prospects for future IPCC work in the area of climate change and food. Relevant considerations include the amount and nature of new scientific information, the status of ongoing or planned assessments from other organizations, and the likely impact of various kinds of IPCC-related products, ranging from (at the informal end) journal papers written by people who participate in the expert meeting to (at the formal end) an IPCC Special Report.

11:00-11:30 ***Coffee Break***

11:30-12:30 **Breakout Groups III Reports and Plenary Discussion**
Discussion Chair: Thomas Stocker

12:30-13:30 ***Lunch***

Closing Plenary
Chair: Chris Field

13:30-15:30 **Finalization of Meeting Recommendations**

15:30 **Adjourn**

Annex B. Participants List

IPCC Expert Meeting on Climate Change, Food, and Agriculture
Dublin, Ireland • 27-29 May 2015

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Annex C. Poster Session Abstracts

IPCC Expert Meeting on Climate Change, Food, and Agriculture
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Food Security under Climate Change: A Korean Perspective

Kim Chang-Gil[1], Jeong Hak-Kyun[1], Moon Dong-Hyun[1]
[1]*Korea Rural Economic Institute (KREI), Korea*

We investigate the impacts of climate change on food security in Korea and then suggest directions for sustainable food supply system. In order to analyze the climate change impacts on food security, the Simulation Model for Climate-Agriculture Relations (SIMCAR) was developed and then utilized in combination with the crop growth model (CERES-rice model) and the Korea Rural Economic Institute - Korea Agriculture Simulation Model. The analysis of rice supply simulation model following climate change reveals a production decrease by 27.4%p in 2050 in the RCP 8.5 scenario in comparison with the baseline. Thus, rice self-sufficiency decreases in 2050 by 47.3% which is 27.7%p lower than the baseline to suggest a food security issue. In order to construct a stable food supply system against climate change, it is necessary to develop climate change-tolerant crop varieties, introduce customized cultivation technology, and modernize agricultural infrastructure so as to enhance domestic production capacity. For an increased buffering capacity, it is necessary to enhance resilience and biodiversity, build a risk management system, and increase food storage capacity.

ORACLE: Opportunities and Risks of Agrosystems and Forests in Response to CLimate ChangEs in France

Nathalie de Noblet-Ducoudré[1], Julie Caubel[2,1], Jean-Christophe Calvet[3], Dominique Carrer[3], Iñaki Garcia de Cortazar-Atauri[2], Nabil Laania[3], Marie Launay[2], Anne-Charlotte Vivant[1], Sophie Wieruszeski[1]
[1]*Laboratoire des Sciences du Climat et de l'Environnement, Unité mixte CEA-CNRS-UVSQ, France*
[2]*INRA, France*
[3]*VEGEO section of CNRM-GAME, METEO-FRANCE, France*

The ORACLE project (<oracle.lsce.ipsl.fr>) brings together climatologists, agronomists, economists, hydrologists, and statisticians with a common goal: **systematically explore the potential for risks or benefits for major crops in France, to increase our level of confidence in the projections**. As there is no perfect approach to evaluate the impacts, we have chosen to **use a combination of approaches based on statistical and mechanistic modelling**.

Potential risks or opportunities for cropland have been evaluated via a suite of indicators that are either computed directly from meteorological variables, or from generic biosphere models. *Climatic indicators* provide information on climate only, but with a selection of those that are relevant for a specific managed system. *Eco-climatic and biotechnic indicators* are directly computed from meteorological variables but designed to be ecosystem-specific. Other *eco-climatic and biotechnic indicators* are **derived from simulations using generic vegetation models**, with a prior definition and calibration of the indicators. **Conclusion on whether a specific crop type is either at risk or potentially cultivable** is based on an analysis of the combined changes in all indicators.

MAnaging Global Negative Emissions Technologies – a Research Initiative of the Global Carbon Project

Sabine Fuss[1]
[1]*Mercator Research Institute on Global Commons and Climate Change (MCC), Germany*

The vast majority of AR5 scenarios targeting 2°C feature negative emissions - mostly based on carbon-neutral bioenergy (due to the same amount being sequestered by feedstock growth as being emitted when combusting biomass for energy generation) combined with carbon capture and storage (BECCS), which in addition captures CO_2 during the energy production phase. But also other options are discussed including large-scale afforestation and soil carbon sequestration. Yet, while having long appeared to be an attractive option for climate management, many uncertainties remain—both socio-economically/technologically and on part of the climate science. The Global Carbon Project (GCP) has launched a research initiative entitled MAnaging Global Negative Emissions Technologies (MaGNET). This flash presentation will provide an overview of GCP activities with focus on overlapping research areas and need for collaboration across communities.

Climate Regulation Enhances the Value of Second-Generation Biofuel Technology

Thomas Hertel[1]*, Jevgenijs Steinbuks[2], Wallace Tyner[3]
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To assess the value of second generation biofuels to society, we employ the FABLE model to calculate the globally optimal path for protected natural lands, forests, crop and livestock land use, oil, and biofuels over the period 2005-2105. By running this model twice for each future state of the world – once with 2G biofuels technology available and once without – we measure the contribution of the technology to global welfare. In the base case with no climate policy and rising oil prices, the value of second generation biofuels is US$64 billion. With stringent climate change regulations in place, this valuation doubles.

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**The views expressed in this abstract do not necessarily reflect the views of the World Bank, its Board of Directors, or member states.

Investigation on Tree Ring Width Indicator for Climate Change Impact on Forest Ecosystem, Employing Dendrochronology Method of Old Trees (Case Study in Tehran Province – Iran)

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Forest and natural ecosystems are best indicators for identify the present and estimate the past climate conditions. Temperature and humidity are two main elements which impact on tree growth and as consequences on tree ring width. Trees are good archives for study on climate and environmental changes. This research has investigated climate change impacts in Tehran province, Iran, employing application of dendrochronology method and using borer samples of old trees. Vegetation map has been studied, and then by field visit, five regions were selected. For easy comparison and data analysis, all tree samples have been taken from juniper species (*Juniperus excelsa*). Nearest climatology stations' recorded data have been used for statistical analysis. Different statistical software were used to analyze the collected data. Year 2001 is an indicator year for high temperature in all Tehran province stations. But year 1992, and also 1972 and 1957, have been recorded as low temperature. Year 1996 in near all stations in Tehran provinces have recorded as a high precipitation. But year 1995 as well as 1964 and 1967 showed a low precipitation records.

Climate Change, Food, and Agriculture

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The Met Office Hadley Centre applies cross-disciplinary climate science to aspects of future food security:

- **Carbon Budgets.** Our Earth System models quantify carbon budgets and emissions reductions required to meet climate targets. We assess the role of land-use and bioenergy in achieving low emissions scenarios and the implications for agricultural land.
- **Food Security.** We take into account trade links and climate vulnerability of populations in both market-connected and -disconnected countries. We find increasing risk of hunger and vulnerability to food insecurity under all future scenarios, with higher scenarios causing much bigger increases in vulnerability by the end of the century.

A LiDAR-based Flood Modelling Approach for Mapping Rice Cultivation Areas in Apalit, Pampanga

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Majority of rice cultivation areas in the Philippines are susceptible to excessive flooding brought about by the variability in rainfall events. The study applied LiDAR technology and GIS for flood modelling particularly in classifying appropriate cultivation areas for certain rice varietal types in Apalit, Pampanga. Decrease in yield may be prevented by matching flood-tolerant rice varieties to the flood characteristics of the site. Flood-tolerant varieties and those that are tolerant to stagnant flooding are highly recommended in areas where both depth and duration exceed the threshold values set in this study.

Global Soil Wetness Project Phase 3 (GSWP3) and LS3MIP in CMIP6

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The third phase of Global Soil Wetness Project (GSWP3) is an ongoing intercommunity service to provide long-term land reanalysis. Comprehensive and extensive set of quantities for hydro-energy-eco systems are produced in order to investigate the long-term changes of the components of the energy-water-carbon cycles and their interactions, with appropriate model verifications in ensemble land simulations. Also, by including a wide range of land surface, hydrologic, and ecological models, the impacts of missing/included processes and model uncertainty can be investigated. Recently, it is proposed to contribute to CMIP6 as a part of Land Surface, Snow, Soil moisture MIP (LS3MIP) with GLACE-CMIP and ESM-SnowMIP, which aims to provide a comprehensive assessment of land surface-, snow-, and soil moisture-climate feedbacks, and to diagnose systematic biases in the land modules of current ESMs using constrained land-module only experiments.

Capacity Building for Managing Climate Change in Malawi (CABMACC) Program

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Malawi is among the countries faced with climate change-related challenges. This has resulted in more communities to be vulnerable to food insecurity. To address this challenge, the Government of Malawi – with funding from Norway – is implementing a 5-year program to build the capacity of different key stakeholders. The program is supporting research and technology development projects. The research projects that are being supported are (i) techno-economic feasibility of decentralized production of bio-ethanol using waste from cassava; (ii) livestock value chain, food security, and environmental quality: transforming rural livelihoods through community-based resilience indigenous livestock management practice; (iii) evaluating feeding and breeding technologies for optimal dairy productivity; (iv) developing allometric model and tools for predicting above- and below-ground biomass in miombo and agroforestry farm lands; (v) developing, testing, and adopting clean energy and sustainable fish processing technologies; (vi) scaling-out Integrated Soil Fertility Management (ISFM) approaches for improved crop resilience to climate change (to be implemented in Balaka district); and (vii) enhancing adaptive capacity of female smallholder farmers to climate change.

Climate Change, Food Security, and Development

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Food security is a key ingredient in the inter-linkages "climate change, response strategies, and development", including various relevant nexus that involve other basic dimensions such as water, energy, biodiversity, multidimensional poverty, conflicts, and migration. Several non-climatic factors and multidimensional inequalities increase vulnerability to climate change and affect food security, particularly those related to financial and technological gaps in developing countries, trends in population growth and equity, developing country foreign debt and adjustment programs, short-term oriented transnational business in agriculture, volatility of international food prices, and financial speculation, as well as the underestimation of indigenous and localknowledge.

Climate Change Impact Assessment Results in Cuba and Belize

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Plausible climate change impacts on main staple crops in Cuba (rice and potato) and Belize (dry beans, maize and vegetables) were assessed in two distinct studies with similar techniques. CO_2 fertilization effect was not considered. CARIWIG Project Tools' RCM outputs were used directly as climatic input to the DSSAT suite of biophysical models in Belize case and filtered through Rivero's methods in the Cuban case. All crops were found to be affected with negative trends, especially dry beans, vegetables, and some varieties of potato. Adaptation measures most likely include the possibility to improve management efficiency to achieve actual yields closer to potential yields.

Climate Change, Land-Use Change, and Food Security in China

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We investigate the changes in climate means and extremes as well as their impacts on crop growth and yields in China in the past decades, based on the long-term trial data and census data at large scales, to gain insights of crop response and adaptations to climate change. We develop the MCWLA family crop models and a super-ensemble-based probabilistic projection system (SuperEPPS) to assess climate change impacts on crop productivity and water use in future in a probabilistic framework, and develop adaptation strategies. We also have integrated assessment on climate change, land use change and food security in China.

Annex D. Recent Literature

IPCC Expert Meeting on Climate Change, Food, and Agriculture
Dublin, Ireland • 27-29 May 2015

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Annex E. Background Information

IPCC Expert Meeting on Climate Change, Food, and Agriculture
Dublin, Ireland • 27-29 May 2015

Request for a Possible Technical Paper or Other Appropriate Action on Climate Change, Food, and Agriculture
IPCC-XL/Doc.14,Corr.1
31 October 2014

At its 39th Session, the Panel had before it a request from the Consultative Group on International Agricultural Research (CGIAR) for a technical report on climate change, food, and agriculture. The Panel discussed three options: preparation of a Technical Paper; organizing an Expert Meeting; and preparation of a Special Report. The IPCC Chair requested the Secretariat to approach CGIAR for more details and clarification and to consult with other UN organizations, including United Nations Environment Programme (UNEP), Food Agriculture Organization (FAO), World Meteorological Organization (WMO), United Nations Framework Convention on Climate Change (UNFCCC), The World Bank, and the UN Special Rapporteur on the Right to Food, to enable an informed decision by the Panel at its 40th Session.

On 16 April 2014, the Secretariat received a written request from the Deputy Director-General, Coordinator for Natural Resources, of FAO for IPCC to prepare a Technical Report on climate change and agriculture systems as an essential means of achieving food security and in reducing projected emissions growth (see Annex 1).

According to the Principles Governing IPCC Work (section 2 on Definitions), Technical Papers are based on the material already in the Assessment Reports and Special Reports are prepared on topics for which an objective international scientific/technical perspective is deemed essential. Furthermore, a Special Report is an assessment of a specific issue and generally follows the same structure and production methodology than a volume of an Assessment Report. In addition, Section 7 on Workshops and Expert Meetings of the Principles Governing IPCC work establishes that IPCC Workshops and Expert Meetings are those that have been agreed upon in advance by an IPCC Working Group, or by the Panel as useful or necessary for the completion of the work plan of a Working Group, the Task Force on National Greenhouse Gas Inventories or a task of the IPCC.

Following up on the request from the IPCC Chair at the 39th Session of the Panel, the Secretariat undertook informal consultations with other organizations. The outcome of such informal consultations is summarized below:

- The Chief Scientist and Director (ad interim) of the Division of Early Warning and Assessment of UNEP encouraged IPCC to prepare a Technical Paper on climate change and agriculture, with special focus on food security. She indicated that UNEP is keen to collaborate with IPCC in this field (options that may be discussed at a later stage would include co-sponsoring any possible preparatory meeting, supporting the publication of the Technical Paper, and/or co-sponsoring outreach initiatives). She also indicated that it would be particularly useful if such a paper could be ready by summer 2015 as then it would provide a good background for a workshop UNEP wants to organize on this topic, in collaboration with FAO, in the fall of 2015.
- The Chief of the Agricultural Meteorology Division of WMO encouraged IPCC to prepare a Technical Paper on climate change and agriculture, with special focus on food security, as this would provide a good baseline for new publications that WMO would like to promote on this topic in the course of 2015.
- The Manager for Science and Review of the Adaptation Programme at the UNFCCC Secretariat confirmed that agriculture and climate change is a very important topic for the UNFCCC and it is indeed included specifically in the programme of work of the Subsidiary Body for Scientific and Technical Advice (SBSTA).
- The Senior Director for Agriculture at The World Bank expressed great interest and support for the production of an IPCC Technical Paper on climate change and agriculture, with special focus on food security. He said that The World Bank would be very keen to collaborate with IPCC in this field (options that may be discussed at a later stage would include co-sponsoring any possible preparatory meeting, supporting the publication of the Technical Paper, and/or co-sponsoring outreach initiatives).
- The office of the UN Special Rapporteur on the Right to Food expressed support for the production of an IPCC report on agriculture and food security. She also expressed interest of the office in collaborating with IPCC on this topic (options may be discussed at a latter stage).

Taking into account all the above the Co-Chair of Working Group II prepared a paper on the scope of a potential IPCC Technical Paper on Food Security which was submitted to the 47th Session of the IPCC Bureau. Discussions at the Bureau focused mainly on the desirability of a Technical Paper versus a Special Report and on the scope of any of these two alternatives.

The Bureau at its 47th Session (Geneva, 18 September 2014) discussed various options for addressing the matter. Most of the opinions expressed at the Bureau were supportive to produce a Technical Paper and suggested that such a Technical Paper be prepared jointly by Working Groups II and III. Two delegations proposed to expand the scope of the paper to include water security, water technology, and a specific focus on developing countries. Two other delegations proposed that the scope should include the contribution of agriculture to GHG emissions. One more suggested that TFI should also be involved. One delegation expressed support to the development of a Special Report and to broaden the scope to cover issues such as bioenergy and land availability. One delegation raised concerns on the foreseeable workload and one more manifested that at this moment on time the paper should be limited to food security. In addition, four delegations suggested considering the organization of a workshop in preparation of a Technical Paper or a Special Report.

Annex 2 includes a revised version of the scoping paper developed by the Co-Chair of Working Group II which takes into account all the information and feedback received. The Technical Paper team will consist of a coordinating lead author, plus 14 lead authors, plus two review editors, with coordination by the WGII TSU working in close cooperation with WGI TSU, WGIII TSU, and TFI TSU. The coordinating lead author, lead authors, and review editors will be identified from the author pool of the AR5 cycle, including the special reports and the methodology reports.

Preparation of the Technical Paper on Climate Change, Agriculture, and Food Security will require two small authors meetings. The finalization will take place at a Bureau session within current budget. Annex 3 includes a budget proposal for the production of the Technical Paper, including costs for meetings, publication and translation, distribution, and outreach.

The Panel is invited to consider the proposal for the preparation of a Technical Paper, its scope, workplan and budget and take a decision on how to proceed in addressing the matter of climate change, food, and agriculture.

Annex I

منظمة الأغذية والزراعة للأمم المتحدة | 联合国粮食及农业组织 | Food and Agriculture Organization of the United Nations | Organisation des Nations Unies pour l'alimentation et l'agriculture | Продовольственная и сельскохозяйственная организация Объединенных Наций | Organización de las Naciones Unidas para la Alimentación y la Agricultura

Viale delle Terme di Caracalla, 00153 Rome, Italy Fax: +39 0657053152 Tel: +39 0657051 www.fao.org

Our Ref: Your Ref:

16 April 2014

Dear Dr. Christ,

The work of the IPCC's fifth assessment reports from the three working groups constitutes the most comprehensive scientific work on climate change with very important implications for FAO's work. We are pleased to have contributed to these reports and very interested in seeing the results widely disseminated and used to support policy processes.

To this end, FAO believes it would be very useful to extract and summarize the key findings related to agriculture and climate change from the three working group reports (physical science, vulnerability of socioeconomic and natural systems and options for mitigation) and to make these widely available especially for key upcoming UNFCCC meetings.

What is clearly emerging from the IPCC work is the magnitude and urgency of addressing climate change in agricultural systems, as an essential means of achieving food security and in reducing projected emissions growth. Each of the fifth assessment working group reports covers vital issues on agriculture and climate change, and the impact of this work would be greatly enhanced by bringing these results together in one volume. As you know, in December 2015, the parties are expected to conclude a global climate change agreement, and having scientifically sound material about agriculture and climate change available well in advance of the December meeting (or at the latest by June 2015), will be an invaluable tool to support the development of an agreement. Agriculture has been a contentious issue in the negotiations and it is thus all the more important to have the latest and highest quality scientific work on the topic available to negotiators. FAO would appreciate the IPCC giving high priority to this request for a Technical Report on Agriculture and Climate Change.

Best regards,

Maria Helena Semedo
Deputy Director-General
Coordinator for Natural Resources

Dr. Renate Christ
Secretary
Intergovernmental Panel on
Climate Change (IPCC)

Annex 2

Potential IPCC Technical Paper on Climate Change, Food, and Agriculture

Submitted by the Co-Chair of WGII
Revised, 25 September 2014, v2

Background

The IPCC Procedures specify that "IPCC Technical Papers are prepared on topics for which an objective, international scientific/technical perspective is deemed essential." They "are initiated: (i) in response to a formal request from the Conference of the Parties to the UN Framework Convention on Climate Change (UNFCCC) or its Subsidiary Bodies and agreed by the IPCC Bureau; or (ii) as decided by the Panel." Technical Papers provide a mechanism for assembling related material across chapters or working group contributions and organizing it for added value. Because Technical Papers are based on material in existing IPCC Assessment Reports, Special Reports, or Methodology Reports, the writing, review, and approval process is relatively streamlined, though still thorough and robust.

Historically, IPCC Technical Papers have been some of the most widely used IPCC products. As of August 9, 2014, the 2008 Technical Paper on Water had been cited 1924 times, based on Google Scholar.

Food production and agriculture are core issues for the IPCC. Food production is specifically highlighted in Article 2 of the UNFCCC. Every IPCC Assessment Report has included at least one chapter on agriculture. Recent reports have assessed aspects of land use, food production, and food security across several chapters in the contributions from all three working groups, plus the Task Force on Inventories. No issue is more central than food to the long-term sustainability of the human enterprise.

Yet, the availability, price, and security of access to food emerge as a result of a large number of interacting processes, with diverse relationships to climate change and responses to climate change. Direct impacts of climate change on crop and animal physiology play a key role, but so do reliable access to water for irrigation and energy for manufacturing fertilizer. The availability of land and potential competition with other land uses is also important, especially in an era with growing demands on land for carbon storage or the production of biomass energy. Shifts toward more animal-based diets put additional pressure on land resources and dramatically alter emissions of methane and nitrous oxide. Because the availability of food and the breadth of access to food entail harvesting, processing, storage, distribution, and access, as well as production, potential impacts of climate change can occur at many levels. The strong links between food production, human health, and the economic prospects for rural communities mean that these domains need to be understood as an integrated unit.

Food and agriculture are issues not only for the land but also for the coasts, oceans, and freshwater bodies. With fisheries and aquaculture providing employment for over 200 million people and the primary source of protein for more than 2.6 billion people, sustainability of these resources and integration of terrestrial and marine food production systems need to be key topics.

New evidence, assessed in the AR5, indicates the sensitivity of food production to climate variability. New information on extremes in a changing climate provides a starting point for building a deeper understanding of the present and future role of climate variability.

Agriculture plays a major role in the forcing of climate but also in the portfolio of options for mitigation and adaptation. Important climate forcing from agriculture comes not only from greenhouse gas exchange but also from effects of croplands on water balance and reflected sunlight (albedo). Some of the major sources of methane and nitrous oxide are agricultural activities, and clearing of forests to increase land for agriculture can result in large releases of carbon dioxide. On the other hand, appropriate management of agricultural lands can lead to carbon storage. Several countries have been pioneers in developing ways to simultaneously increase agricultural yields, develop biomass energy, and protect forests.

These diverse topics are all discussed in the AR5, SREX, SRREN, and the 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands. They are not, however, assembled in a way that makes the key findings and integrated themes easily accessible. Food security and food production are the focus of chapter 7 of the WGII contribution to the AR5, but issues related to interactions between climate change and agriculture are discussed in most chapters of the WGII contribution, as well as several of the chapters of the WGI and WGIII contributions, SRREN, SREX, and the inventory supplement.

A technical paper on climate change, food, and agriculture can be an efficient mechanism for assembling this critical material into a set of accessible, integrated findings. It can provide a single source for information that currently spans six separate reports. More important, effective organization will facilitate sophisticated, multi-disciplinary approaches to the challenge of sustainable food and agriculture, encouraging effective actions by decision makers and stimulating new research. A technical paper on climate change, food, and agriculture can be a useful resource for governments, UN agencies, development organizations, the scientific community, and a broad range of private-sector entities.

As of September 2014, CGICAR, FAO, UNEP, WMO, The World Bank, and the office of the UN Special Rapporteur on the Right to Food have expressed interest in an IPCC Technical Paper on Food Security.

Key Issues to be Addressed

A technical paper on climate change, food, and agriculture will require approximately 200 pages of text (including figures and references) for full coverage of the material in recent IPCC reports. The material could be organized into 7 mini-chapters:

1) Climate-change impacts and prospects for adaptation in crops, domestic animals, and fisheries [mostly from WGII sectoral and regional chapters]
2) The food-water-energy nexus [material from SRREN, WGI, WGII, and WGIII reports]
3) Agriculture and climate variability [material from SREX, WGI, and WGII sectoral and regional chapters]
4) Climate-change impacts on post-harvest components of food systems [material from WGI, WGII, and WGIII reports]
5) Food security, human health, and human security [mostly from WGII sectoral and regional chapters]
6) Managing competition for land [material from SRREN, WGII, and WGIII]
7) Climate forcing from agriculture [material from SRREN, WGI, WGII, WGIII, and TFI]

Process

The process for writing, reviewing, and accepting an IPCC Technical Paper is described in section 5 of appendix A to the IPCC Principles. The team of authors and review editors would be selected based on IPCC procedures. There will be 2 lead authors for each of the 7 mini-chapters. The draft document will be submitted for simultaneous review by experts and governments. After revision, it will be submitted to governments for a final review, and then revised again in consultation with the IPCC Bureau, as described in the IPCC procedures. A Technical Paper on climate change, food, and agriculture will require coordination through one or more of the existing WG TSUs.

With a decision to proceed in the Autumn of 2014, a Technical Paper on Food Security can be approved and released in the second half of 2015, prior to the COP 21 of the UNFCCC.

Timetable

A possible timetable for completion of a Technical Paper on Climate Change, Food, and Agriculture is:

October 27, 2014	Consideration of proposal by IPCC 40, Copenhagen, Denmark
November 17, 2014	Close of nominations for coordinating lead author, lead authors, and review editors
December 1, 2014	Submission of final list of selected Coordinating lead author, lead authors, and review editors to Bureau for approval
February 2015	Lead Author Meeting #1
March 2015	Draft Technical Paper to experts and governments for 4 week review
May 2015	Lead Author Meeting #2
June 2015	Final draft Technical Paper to governments for 4 week review
August 2015	Finalization of Technical Paper on Food Security, in consultation with the IPCC Bureau

Participants

The Technical Paper team will consist of a coordinating lead author, plus 14 lead authors, plus two review editors, with coordination by one or more of the existing WG TSUs. The coordinating lead author, lead authors, and review editors will be identified from the author pool of the AR5 cycle, including the special reports and the methodology reports.

Financial Resources

Preparation of the Technical Paper on Food Security will require two small author meetings, with 5-7 authors supported by the Trust Fund and 8-10 supported by developed countries. The project will require the support of one or more of the WG TSUs.

Annex 3

Budget

1st meeting authors		
7 journeys	28,000	
Other expenses	4,760	
Subtotal		32,760
2nd meeting authors and review editors		
8 journeys	32,000	
Other expenses	5,440	
Subtotal		37,440
Publication and translation		200,000
Distribution		20,000
Outreach		50,000
TOTAL		***340,200***

Progress Report: Expert Meeting on Climate Change, Food, and Agriculture IPCC-XLI/Doc.23

19 February 2015 [REVISED 3 March 2015 in response to discussion at P-41]

At P-40 [Copenhagen, Denmark • 27-31 October 2014], the panel decided to organize an Expert Meeting on Climate Change, Food, and Agriculture during 2015, with the mandate to consider existing IPCC information on this matter and to recommend to the Panel possible further action, including the options of producing a Technical Paper or a Special Report, or to address the matter otherwise in the forthcoming assessment cycle. Ireland generously offered to host the meeting in Dublin.

The Chair of the IPCC formed a planning committee consisting of Renate Christ, Chris Field (Convener), Hoesung Lee, Carlos Martin-Novella, Youba Sokona, and Thomas Stocker. After considering the topic and the necessary expertise, the planning committee expanded its membership by adding Long Cao (China), Thelma Krug (Brazil), Cheikh Mbow (Senegal), Alexander Popp (Germany), Geert Jan von Oldenborgh (Netherlands), Pete Smith (United Kingdom), and Katharine Vincent (South Africa), with Ellie Farahani (WGIII), Susanne Kadner (WGIII), Katharine Mach (WGII), Michael Mastrandrea (WGII), Jan Minx (WGIII), Gian-Kasper Plattner (WGI), and Melinda Tignor (WGI) providing TSU support.

The planning committee has met four times by conference call, on December 17, 2014, January 7, 2015, and February 10 and 19, 2015. The focus of these calls was finalizing the goals and agenda for the meeting, the list to be submitted to the Acting Chair of IPCC of participants to be invited, and the meeting dates.

The meeting will be held May 27-29, 2015. There will be approximately 50 total participants, including 20 funded by the Trust Fund.

The expert meeting will address the following themes:

1) The food-water-energy-climate nexus
2) Food production and food security
3) Future demand for food: relevance of land use and lifestyles
4) Potential impacts of mitigation scenarios on bio-energy deployment, land use, and food security
5) Projected changes in temperature, precipitation, and climate variability
6) Climate-change impacts/adaptation/vulnerability for crops
7) Climate-change impacts/adaptation/vulnerability for domestic animals
8) Climate-change impacts/adaptation/vulnerability for fisheries and aquaculture
9) Climate-change impacts/adaptation/vulnerability for post-harvest components of food systems
10) GHG emissions and emission reductions, and increasing yields in the food sector
11) Forestry: afforestation, reducing deforestation, and REDD+
12) Bio-energy
13) Adaptation and mitigation responses.

The meeting structure will be approximately 50% presentations and 50% discussions over the first two days of the meeting. The presentations would follow the themes above. Each of the presentations would focus on the overall state of knowledge as reflected in the AR5, as well as the most compelling new opportunities in emerging research. Break-out groups will explore key scientific results and options for future IPCC work on this topic. During the morning of day 3, discussion will focus on developing recommendations for future IPCC work.

The planning committee has agreed on an initial list to be submitted to the Acting Chair of IPCC of participants to be invited, and invitations are to be issued in early March.

This revised progress report includes changes made in response to the discussion of the Expert Meeting at P-41 [Nairobi, Kenya • 24-27 February 2015] on February 27.