AGRICULTURE, FOOD SECURITY AND CLIMATE CHANGE

JOINT PROGRAMMING INITIATIVE (FACCE JPI)

SCIENTIFIC REASEARCH AGENDA

SCOPE, COMMON VISION AND PRIORITY ACTIONS

Scientific Advisory Board, December 2010

Preamble

The Scientific Advisory Board (SAB) of the Agriculture, Food Security and Climate Change Joint Programming Initiative (FACCE JPI) has been elected by the Governing Board (GB) to elaborate a common scientific vision for the JPI, in line with clear global priorities and based on the proposal and on conclusions of Governing Board meetings. The SAB was also asked to provide by the end of 2010 a list of priority actions and advice on the scientific governance for JP implementation.

This document stems from three SAB meetings on June 10, September 16 and December 1, 2010. It is based on contributions of SAB members[1] and on comments on earlier versions by the GB. This scientific research agenda has been approved by the Governing Board of the FACCE JPI on December 17, 2010. It will be revised periodically, every two years.

[1] SAB Members in 2010: Kenneth Cassman, Elias Fereres, Stephen P. Long , Frits Mohren, Bernd Müller-Röber, Pirjo Peltonen-Sainio, John R. Porter , Johan Rockström, Thomas Rosswall, Jean-François Soussana (Chair), Henning Steinfeld, Joachim von Braun.

Executive Summary

Four complementary and interactive goals are defined for research within the Agriculture, Food Security and Climate Change (FACCE) Joint Programming Initiative:

i) Provide new approaches for the environmentally sustainable growth and intensification of agriculture in Europe and increase the resilience of food systems to deliver European food security, feed, fuel, fibre as well as other ecosystem services under current and future climate and resource availability;

ii) Provide an integrated impact assessment of climate change throughout the whole food chain, including market repercussions;

iii) Contribute to direct reductions of GHG emissions through carbon sequestration, fossil fuel energy substitution and mitigation of N_2O and CH_4 emissions by the agriculture and forestry sector, while reducing GHG emissions per unit area and per unit product associated with land use change;

iv) Sharply reduce trade-offs between food production and the preservation of biodiversity, ecosystem functions and services.

Five core research themes have been adopted to meet these goals:

1. Sustainable food security under climate change, based on an integrated food systems perspective: modelling, benchmarking and policy research perspective.

2. Environmentally sustainable growth and intensification of agricultural systems under current and future climate and resource availability;

3. Assessing and reducing trade-offs between food production, biodiversity and ecosystem services;

4. Adaptation to climate change throughout the whole food chain, including market repercussions;

5. Greenhouse gas mitigation: N_2O and CH_4 mitigation in the agriculture and forestry sector, carbon sequestration, fossil fuel substitution and mitigating GHG emissions induced by indirect land use change.

The JPI will need to bring together: core themes 2 and 3; core themes 4 and 5; core theme one across all. Priority actions have been defined within each of these core themes.

We first address the scope of the FACCE JPI, then express a common vision and finally provide a list of core themes and of early priority actions.

1. Scope of the FACCE JPI

While recognizing that priorities are needed, a broad scope is first presented here, before addressing in the next section our common vision of the FACCE JPI.

1.1 Agriculture. Agriculture can be defined in a broad sense as the production of food, feed, fuel and fibre by land based systems. Thus, the sector includes annual and perennial crops, grasslands, livestock and forestry, rural landscapes, land use, biodiversity and ecosystem services. Freshwater and marine aquaculture are also included because feed production is required as input to these systems. Marine fisheries are not considered within the scope, since these will be addressed by the 'Healthy and productive seas and oceans' JPI. Competition for land will grow and it is important to focus on the sustainable intensification of production and, at the same time, consider ecosystem services that agriculture can offer, as well as linkages with the broader bioeconomy[2]. Bioenergy, biofuels and biomaterials are included as they will become even more important as prices of fossil-based energy and raw-materials rise and as the environmental and security risks associated with dependence on fossil fuels are recognized.

1.2 Food security. Agricultural production is not the only component determining people's food security. The UN-FAO World Food Summit 1996 created a definition, which is used in the context of the JPI: 'Food Security exists when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life'. The JPI will highlight supply and utilisation of food with less research on processing, packaging, distribution, retail and economic access. The JPI will also embrace the safety aspects of food security, as defined above, and the agricultural and food policies that impact on food safety and nutrition. Further, the JPI will map and monitor emerging technologies that impact on agriculture and food security. However, the FACCE JPI will <u>not</u> include issues covered by the 'Healthy food for healthy life' JPI, such as: the determinants of diet and physical activity; eating habits and diet advice and diet-related chronic diseases.

1.3 Climate change. The future of agriculture and of food security will take place under climate change and under other global environmental changes[3]. The JPI, while considering climate change in a global and regional context, must develop scientific understanding to assist European Union farmers in adapting locally to climate variability and climate change, and to ensure that EU farming and food systems contribute to reducing greenhouse gas emissions. The link between the global, European and local farm levels necessitates that scaling issues are addressed early on in the programme. Collaborations with the climate research community[4] need to be organised. Since many mitigation efforts can also assist in adaptation it is important to integrate the two, taking into account regional variation across Europe. Links will be made to the Climate Change JPI as well as the Global Research Alliance on Agricultural Greenhouse Gases to avoid overlaps and provide complementarity.

1.4 Water. Special attention should be paid by the FACCE JPI to water management in agriculture, since about 70% of the global freshwater pre-empted by human use is allocated to agriculture. Adaptive water management in the context of climate change, increasing

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[2] The usual definition of bioeconomy includes biorefinery as part of agricultural processes which can be included in the FACCE JPI. However, the corresponding industrial processes are not within the scope.
[3] Rate of biodiversity loss, saturation of the nitrogen and phosphorus cycles, stratospheric ozone depletion, global freshwater use, change in land use, atmospheric aerosol loading and chemical pollution (Rockström et al., Nature, 2009)
[4] World Climate Research Programme (WCRP) of the World Meteorological Organization (WMO), International Council for Science (ICSU) and the Intergovernmental Oceanographic Commission (IOC) of UNESCO, 'Connected Climate Knowledge for Europe' JPI.

demands from non-agricultural sectors and limited water supply needs to be developed by research targeting water use efficiency in both rain-fed and irrigated agriculture and reduction of yield loss from water deficits. Links will be made to the water JPI to avoid overlaps and provide complementarity.

1.5 Land use. Today, approximately 12% of the Earth's land area is under intensive crop production and close to 20% is pasture and rangeland used for livestock production. Future land-use on Earth must accommodate multiple competing demands for food and fibre, energy, services, infrastructure and conservation by some 9 billion people – on a non-expandable global surface. There is a need for integrative, systems-level research approaches by the JPI to address changes in land use both in Europe and at a global scale, in links with climate change and with food security.

1.6 Scope of the economic and social approaches. Integration of economic approaches and expertise will be important in developing FACCE-JPI. Economics is of importance for identifying research priorities and innovation opportunities, as are social attitudes, consumer preferences, risk management, international trade, employment and institutional issues, etc, given their direct relevance to climate change and food security. Other social sciences (such as sociology, policy sciences etc…) may also be required. This will necessitate a sound consultative process across disciplines.

1.7 Scenarios of global change and time horizon. Current climate research efforts (Intergovernmental Panel on Climate Change, 5th Assessment Report) start from atmospheric GHG concentration pathways to generate new socio-economic and climate scenarios, which can be used for integrated assessments of impacts, adaptation, mitigation and vulnerability. The proposed Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) will develop biodiversity scenarios beyond those initiated by the Millenium Ecosystem Assessment. For agriculture and food security, important areas include the development of contrasted future agricultural scenarios and storylines, upgrade of models (including biophysical, biological, economics) and ensemble modelling for risk assessment. Most climate modelling considers timescales of 50-100 years, but increasing attention should be given to shorter-term seasonal/decadal predictions. Therefore a JPI time horizon of a few decades is proposed, perhaps until 2050. Time horizons will also dictate the geographical scope needed – for example 2050 would need a global horizon, but shorter timescales over the next 3-5 years could focus on the EU.

1.8 Geographical scope. The focus is on Europe, but Europe is part of a global system of food production and consumption. The research agenda of Europe in the food, agriculture and climate change domains has impacts on the global research capacities and creates potentially important spill-over effects to other regions of the world. Thus, the JPI must consider Europe's role in a global context and how the global context will affect Europe. For FACCE-JPI it is proposed to cover the role of Europe for sustainable resource (land and water) use and for European and global food security. A complementary focus on food security and climate change impacts on surrounding regions (e.g., the Mediterranean Basin) and on outside Europe (e.g., in Sub-Saharan Africa) is recommended and could be carried out through collaborations with other countries and with international programs, such as the Climate Change, Agriculture and Food Security (CCAFS) of the CGIAR. The JPI will greatly advance the study of agriculture in developed countries for global food security and this will complement CGIAR international efforts which are currently centred on developing countries.

2. Common vision and core research themes

The SAB has further elaborated the central theme of the FACCE JPI in the form of a common vision.

2.1 Strategic research

The interactions between agriculture, food security and climate change have been envisioned highlighting the three binary interactions and the single ternary interaction, which are at the heart of the FACCE JPI (Fig. 1). The complex system formed by each of these components and by their interactions is under multiple pressures from external drivers, such as the rising food and fibre demand, globalisation and global environmental changes and is moreover constrained by planetary boundaries such as land and water limits.

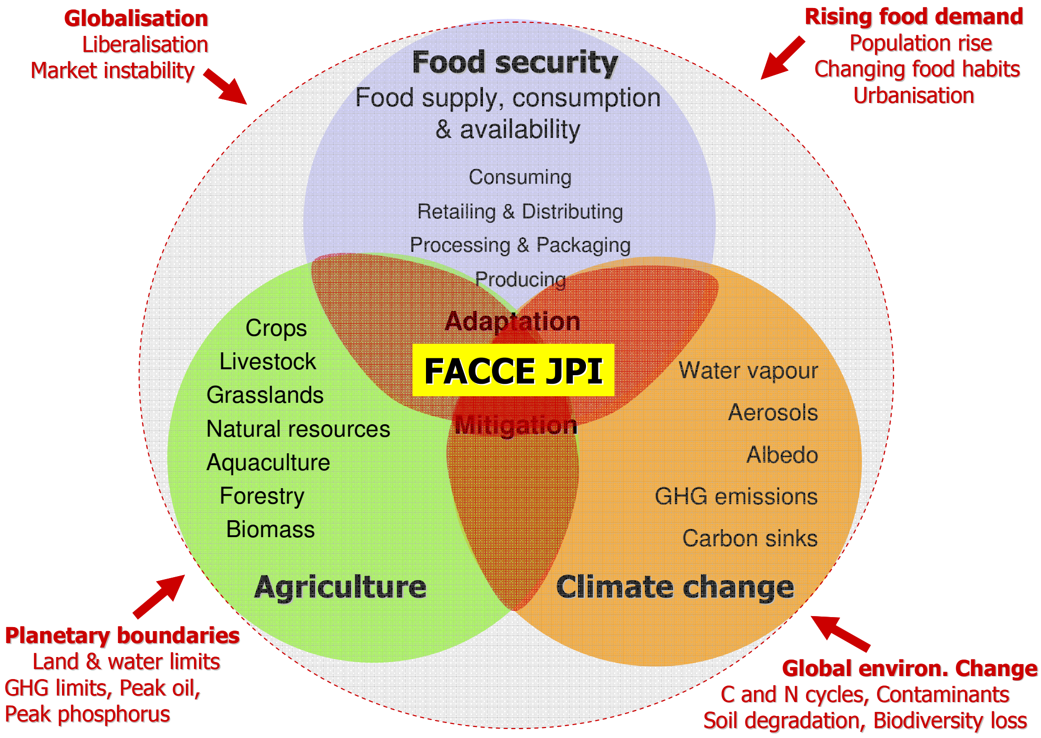

Fig. 1. A vision of research areas in the FACCE JPI showing drivers (in red) and highlighting interactions between agriculture, food security and climate change.

To answer these challenges, research undertaken should be mission oriented, with four complementary and interactive goals:

i) Provide new approaches for the environmentally sustainable growth and intensification of agriculture in Europe and increase the resilience of food systems to deliver European food security, feed, fuel, fibre as well as other ecosystem services under current and future climate and resource availability;

ii) Provide an integrated impact assessment of climate change throughout the whole food chain, including market repercussions;

iii) Contribute to direct reductions of GHG emissions through carbon sequestration, fossil fuel energy substitution and mitigation of N_2O and CH_4 emissions by the agriculture and forestry sector, while reducing GHG emissions per unit area and per unit product associated with land use change;

iv) Sharply reduce trade-offs between food production and the preservation of biodiversity, ecosystem functions and services.

2.2 An integrated research agenda

To reach these goals, research should be integrated on a large scale:

- A systemic understanding should be gained, by developing and integrating a large range of disciplines from climatology, to ecology, agronomy, forestry and socio-economy, through plant, soil, microbial and animal sciences, that must be strongly connected to a foundation of agro-ecological and socio-economic modelling.
- Key European infrastructures need to be assembled in order to integrate scenarios, observations, experiments and models in order to develop and inter-compare agro-ecological and socio-economic projections while assessing their uncertainties.
- Economics of short- and long-term adaptation/mitigation strategies should be analysed also aiming at improving current food security while taking into account: i) uncertainties in the projections of climate change and impacts, ii) the valuation of ecosystem functions and services and their resilience.
- Developing and implementing specific solutions at the ecosystems and policy levels based on detailed information on regional impacts and meaningful assessment of the adaptive options and their feasibility at local and farm levels. Workable adaptation options will be developed in close collaboration with decision-makers and stakeholders involved in the research and development process.
- A roadmap of breakthrough technologies in the areas of crop, livestock, fuel and fibre production, of land, water and genetic resources management and of biodiversity conservation and use will be developed. When mature, these innovations will be considered for integration in production systems and in policy measures.

Such an integrated research agenda has been envisioned to deliver key outputs for Europe by contributing: i) to raising the biological efficiency of European agriculture, ii) to responding to a globally increased food demand, iii) to operating agriculture within greenhouse gas, energy, biodiversity and contaminant limits and iv) to building resilience in agricultural and food systems (Fig. 2).

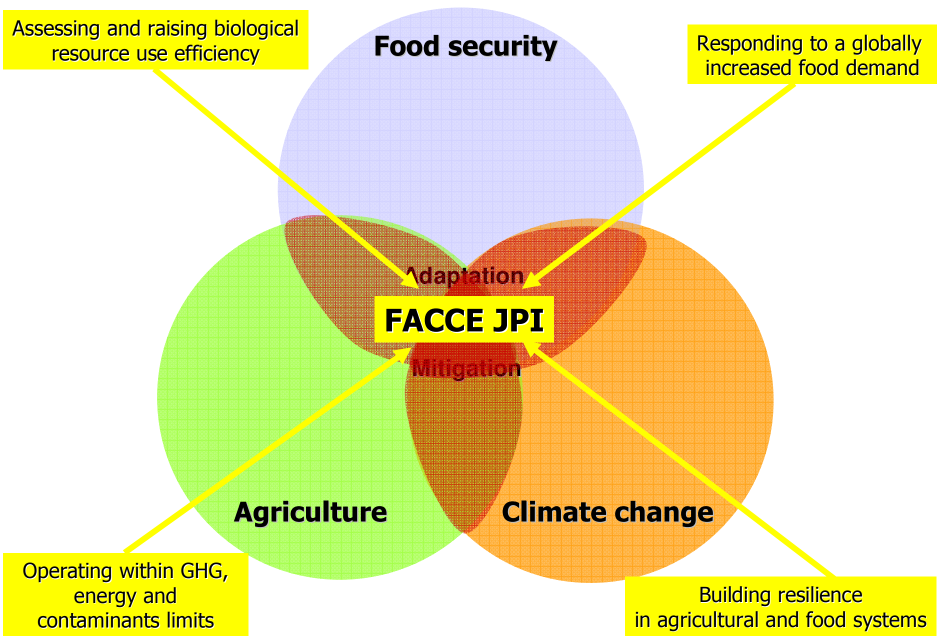

Fig. 2. A vision of key outputs (underlined in yellow) of FACCE JPI for Europe.

2.3 Core research themes

2..3.1 Criteria for core research themes

A set of criteria has been developed in order to select the core research themes of the FACCE JPI. According to these criteria, core themes should:

- Be evidence based,
- Be groundbreaking at European level,
- Have high expected returns,
- Be of urgency for Europe and/or regions of Europe,
- Reinforce Europe‘s contribution to global public goods,
- Be interdisciplinary,
- Provide guidance for developing the research agenda,
- Be complementary, with clear links and synergies within and across themes.

2.3.2 Five core research themes

Following, these criteria, the following five core research themes have been adopted:

1. Sustainable food security under climate change, based on an integrated food systems perspective: modelling, benchmarking and policy research perspective.
2. Environmentally sustainable growth and intensification of agricultural systems under current and future climate and resource availability;
3. Assessing and reducing trade-offs between food production, biodiversity and ecosystem services;
4. Adaptation to climate change throughout the whole food chain, including market repercussions;
5. Greenhouse gas mitigation: N_2O and CH_4 mitigation in the agriculture and forestry sector, carbon sequestration, fossil fuel substitution and mitigating GHG emissions induced by indirect land use change.

The JPI will need to bring together: core themes 2 and 3; core themes 4 and 5; core theme one across all. This leads to the following scientific structure (Figure 3) of the FACCE JPI.

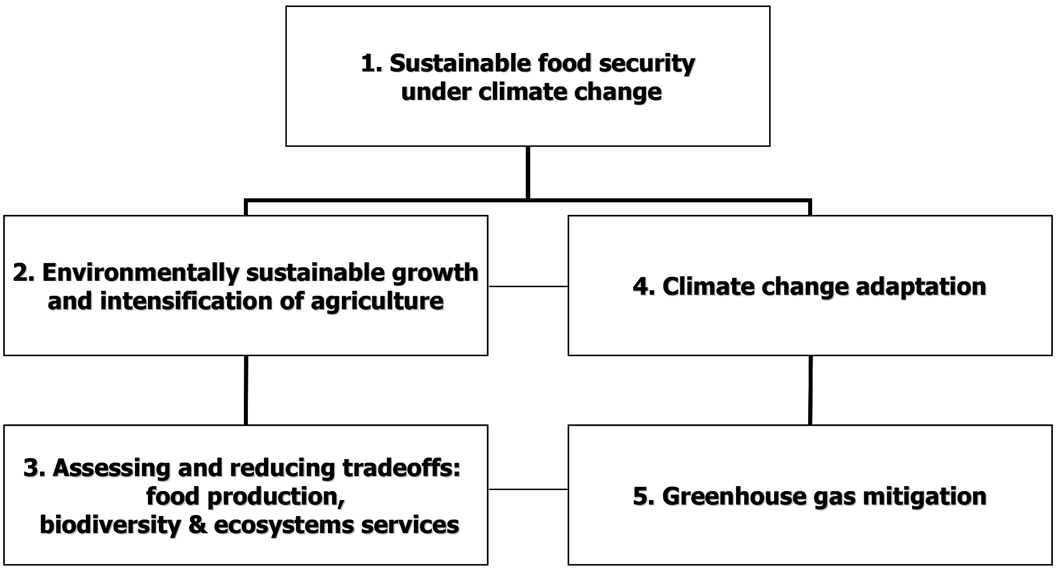

Figure 3. The five core themes forming the FACCE JPI.

<u>Core theme 1: Sustainable food security under climate change</u>

- Integrated food systems perspective, combining biophysical and socio-economic modelling with policy research perspective

- Integrated risk analysis of the European agriculture (and food systems) under climate change: test responses to volatility both from natural and market phenomena

- Global change impact and resilience of food systems (through the value chain and to the consumer)

- Europe's role in international markets, price volatility, global food security impacts

- Develop contrasted scenarios involving perceptions and policy dialog

- Combine observations, experiments and modelling through the development of appropriate European research infrastructures.

<u>Core theme 2: Environmentally sustainable growth and intensification of agriculture</u>

- Provide new approaches for improving farm management and for the sustainable intensification of agricultural systems, but also for low-input high natural value systems in Europe under current and future climate and resource availability;

- Understanding recent yield trends in Europe, taking into account changes in costs and prices and research investments as well as changes in environment, management and genotypes.

- Benchmarking efficiencies of resource use (water, N, energy) according to *Genotype x Environment (including climate) x Management* combinations across Europe

- Assessing and raising biological resource use efficiency of crop and livestock systems; increasing total factor productivity.

- Combining crop, livestock and bioenergy systems for sustainable intensification;

- Low input, higher efficiency seeds and breeds;

- Knowledge based IT innovations in agriculture;

- Improved understanding and control of soil functioning and biotic interactions at field to landscape scales.

<u>Core theme 3: Assessing and reducing tradeoffs between food supply, biodiversity and ecosystem services</u>

- Provide new approaches to the increased use of functional biodiversity in agricultural systems (e.g. intercropping, mixtures, conservation agriculture…)

- Developing methods for assessing and valuing biodiversity and ecosystems goods and services (e.g. carbon sequestration, water storage…) in intensive agricultural systems;

- Develop approaches for optimizing the trade-off between agriculture and ecosystem services in a variable environment (climate change, volatility…) and at farm scale;

- Develop a solid knowledge basis for the provision of public goods by European agriculture, so that ecosystem services are delivered efficiently and effectively.

Core theme 4: Adaptation to climate change

- Adaptation to climate change and increased climatic variability throughout the whole food chain, including market repercussions;

- Tailoring adapted regional production systems under climate change;

- Adapting seeds and breeds through conventional breeding and biotechnology[5] to new combinations of environment and management: e.g. abiotic stresses, elevated CO_2;

- Monitoring pests and diseases and developing climate-informed crop and animal protection;

- Adaptive water management in agriculture, watershed management, flood management, irrigation technologies, water re-use;

- Adapting food processing and retailing, markets and institutions to increased climatic variability and climatic change.

Core theme 5: Mitigation of climate change

- Contribute to direct reductions of GHG emissions through carbon sequestration, substitution of fossil-based energy and products, and mitigation of N_2O and CH_4 emissions by the agriculture and forestry sector, while reducing GHG emissions associated with indirect land use change;

- Develop monitoring and verification methodologies of field, animal and farm scale GHG budgets, including, or not, indirect land use and cradle to grave life cycle;

- Develop verifiable GHG mitigation and carbon sequestration measures in farming systems;

- Develop technologies and methods to substitute fossil-fuel energy through increased use of biomass and other renewable energies in the agriculture sector without jeopardizing food security.

[5] Biotechnology here is used in a broad sense, referring to marker-assisted selection, genomic selection and genetic modification methods.

2.3.3 Main research issues in the five core research themes

In each of the five core themes, there will be a need to address in a highly coordinated way a number of evidence based research issues which are listed in Annex 1. This annex provides further details on how each issue could be addressed within the scope of the FACCE JP and could, hence, contribute to core research themes.

Table 1. Major research issues (a to h, see Annex 1) to be addressed under each of the five core themes (CT)

	a. Scenarios of global change & adaptive strategies	b. Food systems and food security	c. Land use & sustainable management of biodiversity and natural resources	d. Crops: production, health and breeding	e. Livestock: production, health and breeding	f. GHG mitigation and C sequestration by agriculture	g. Bioenergy and biofuels	h. Forestry as related to agriculture and food security
CT1 Food security under climate change	X	X	X					
CT2 Sustainable intensification of agriculture		X	X	X	X	X		
CT3 Assessing tradeoffs between food supply, biodiversity and ecosystem services		X	X	X	X	X	X	X
CT4 Adaptation to climate change	X	X	X	X	X	X	X	
CT5 Mitigation of climate change	X	X	X		X	X	X	X

2.4 Fast track priorities

In order to facilitate the start of early actions by the FACCE JPI, a first list of actions with low hanging fruits has been identified and their relevance to CTs has been earmarked. First illustrative examples of medium and long term actions have also been identified.

Core Theme 1: Sustainable food security under climate change

- Possible pilot action. Detailed climate change risk assessment for European agriculture in a global context: how will climate variability and change affect regional farming systems in near and far future? What are the risks and the opportunities for European food security and agriculture? In collaboration with the international project AgMIP, an ensemble of crop and livestock models will be benchmarked, inter-compared and coupled to both climatic and economic models.
- Medium term: Consequences of changes in food systems (including food habits, processing, wastes, consumption …) on climate change (GHG, footprints, etc) and, conversely, climate change impacts on European food systems.
- Longer term: Modelling the drivers of price volatility and its role on food systems and food security. Use of Representative Concentration Pathways

(RCPs) and development of a range of contrasted scenarios including changes in food habits, processing, etc.

Core Theme 2: Environmentally sustainable growth and intensification of agriculture

- Possible pilot action. Benchmarking at farm gate the current state and historical changes (and their main drivers: economics, Genotype x Environment x Management) in productivity and resource use and institutional innovations and investment needs for sustainable intensification. Assessment of variability in systems by screening a large number of situations, as if taking a meta-analysis approach.
- Medium term. Production of innovative scientific gold standards for agricultural monitoring. Satellite studies where countries could identify key systems with raised productivity and reduced GHG emissions, in which average values of variables can be benchmarked.
- Longer term. Combined development of genomic selection, ecological engineering, precision farming, ecotechnologies and biotechnologies for increased resource use efficiency and productivity in key agricultural systems.

Core theme 3: Assessing and reducing trade-offs between food supply, biodiversity and ecosystem services.

- Possible pilot action: Assessment of ecosystem services in European landscapes and how these link to biodiversity, productivity and resource use efficiency and how they are to be valued by society and economically.
- Medium-term: biodiversity based low-input high productivity multi-component farming systems using e.g. within and between species diversity across trophic levels in combination with genomic selection and conventional breeding.
- Longer term: adaptive management of high natural value agricultural landscapes producing specific products in high demand.

Core theme 4: Adaptation to climate change

- Possible pilot action. Designing management relevant novel ideotypes adapted to climate change and elevated CO_2 and assessing groundbreaking designs for advanced plant and animal phenotyping facilities under climate change.
- Medium term. Understand the adaptive value of diversity, specialization and trade in European agriculture, through appropriate modelling.
- Longer term. Epidemiological models and near real time climate-informed forecasts of pests and diseases. Regional scale strategies for preserving gene resistance against pests, diseases and pathogens in crop and animal species. Drought and heat tolerant productive crop species and thermo-tolerant animal species.

Core theme 5: Mitigation of climate change

- Possible pilot action. Soil carbon sequestration estimation and verification methodologies based on soil surveys, remote sensing, management practices, process modelling, data streams (ICOS, Integrated Carbon Observation System) and novel verification methods (e.g. neutron scattering).

- Mid-term: Assessment of the eco-efficiency of key farming systems within European sub-regions. Technical and economical abatement potential of GHG mitigation measures and policy analysis.
- Longer term: Abatement potential of changes in food systems, including approaches such as economics and sectoral policies, to be linked with adaptation above.

2.5 Issues related to implementation

Several factors in implementation of the FACCE JP will need to be considered by the Governing Board during the development of the action. These include infrastructures, observation and modelling experiments, data and databases, high level synthesis, mobility, innovation and skills.

ANNEX 1. Evidence based research issues

In this annex, we provide further details on research issues which are relevant for the FACCE JPI, by briefly setting the scene for an issue and then by discussing what should be done about it and how it is to be done.

a. Scenarios of global change and adaptive strategies

Timescale and links with earth and climate sciences. Most climate modelling considers timescales of 50-100 years, but increasing attention is being given to seasonal/decadal predictions. For FACCE-JPI, key issues for evaluating future scenarios include impact assessment of climate change throughout the entire food chain, including market repercussions. Hot spots areas where climate change will have biggest impact need to be identified, within and possibly outside the EU. FACCE-JPI will also help determining which climate data are required to model crop and ecosystem performance under current and changing climate. The EU could gain global advantage by including detailed and robust crop and livestock components in regional climate impact models coupled with socio-economics. A key link would be with the emerging JPI on climate change. Given recent trends of yield stagnation for major cereal crops within the EU and Asia, the FACCE JPI should provide global leadership to understanding the scientific basis for these trends and how they will be affected by climate change.

Improving scenarios. For scenarios it is proposed that important areas are to identify a range of plausible futures for European farming, in relation to socio-economic, environmental and policy issues. Another element is to upgrade current crop, livestock and farming system models (including biophysical, biological, economics) to perform risk assessment and identify hot spots of high returns in terms of adaptation and mitigation. The development of scenarios is also important for the engagement of stakeholders. Europe needs a strong capacity in modelling and scenario building, which will require a tight coupling with observational and experimental data streams.

Risk assessment and vulnerability. To better deal with climate variability and change, it is envisioned that future crop, livestock, fuel and fibre modelling studies will need to use a risk assessment approach by combining an ensemble of GHG emission (or stabilization) scenarios, of regional climate models and of process-oriented impact models, as well as an ensemble of adaptation and mitigation options concerning both management practices and species/cultivars/breeds. This will provide a first step for comparing regional vulnerabilities and adaptation strategies across Europe. Developing this modelling framework will require experimental data concerning: (i) the role of extreme climatic events, (ii) the interactions between abiotic factors and elevated CO_2, (iii) the genetic variability in plant CO_2 and temperature responses, (iv) the interactions with biotic factors, including pests and diseases, (v) the effects on harvest quality, and (vi) the potential for genetic and management improvements to address each of these factors. Moreover, this direct risk assessment for agriculture will need to be extended to account for indirect vulnerabilities resulting from competition for natural resources (e.g. land and water) use and from global market instability and changes.

b. Food systems and food security

Consumer preferences and needs. Consumer preferences and attitudes change and this will have a major impact on the demands from the agricultural sector. This needs to be analysed using the best available social science expertise. Market access, food safety and convenient food (high quality food products and low prices) are needed. Consumers are also reacting to changes in markets, which necessitates economic analyses both at the farm, regional and global levels. The emergence of voluntary certification systems that address social and environmental concerns including fair trade, organic agriculture, sustainable harvests, and carbon footprints should also be studied as it may affect consumer preferences and food systems.

Post-harvest losses and food wastes. Food wastes have reached large levels in most industrialized countries, while post-harvest losses have been reduced. In contrast, in poor developing countries, food wastes are minimal, while post-harvest losses tend to be large. Novel research on how to minimize food wastes during food process, transport and retail is required, while options for recycling and reuse (e.g. composting, bioenergy…) should also be further explored, while considering health issues.

Institutional issues. Institutional issues are also important, especially as mitigation strategies are agreed on at the global and national levels. There is a need to consider and model behavioural and regional institutional constraints and synergies that help and hinder adoption of mitigation and adaptation measures. Such analyses should contribute to and draw on relevant policy options to promote adoption of such measures. Barriers and constraints to be considered relate to associated sector policies (e.g. Water Framework Directive, land degradation, biodiversity conservation…) and local/regional food security objectives. Beyond effectiveness and efficiency, there are equity dimensions of adapting the agriculture sector to mitigation and adaptation challenges. Institutional perspectives are moreover required for addressing vulnerabilities and the possibility to use index-based insurance systems to minimize farmer vulnerabilities under climate variability and change. In the development of the JPI it will be essential to ensure that social science expertise is included from the start in the definition of the programme.

c. Land use and sustainable management of natural resources and biodiversity

Land use. Higher resolution and more consistent land-use, land-cover and agricultural practices data and projections are required both for Europe and on a global scale, in order to match the needs for integrated assessment models covering land use change, agriculture, food security and climate change, and also taking into account direct and indirect land use change from biomaterial, bioenergy and biofuels expansion. Moreover, there is scope for developing research on criteria to be used when assessing future land use patterns in terms of e.g. food, fibre and energy supply, food security, natural resources and biodiversity conservation, as well as climate change adaptation and mitigation.

Soils. Soil management and use should be given special attention since soils are not renewable within a lifetime. Restoring degraded soils, minimizing soil, wind and water erosion, and building-up of soil organic matter is a win-win strategy leading to increases in soil fertility, carbon sequestration (i.e. mitigation) and water holding capacity (i.e. adaptation). Emphasis should be placed on the role of the soil biota for biogeochemical cycles in the context of an environmentally sustainable growth and intensification of agriculture.

Water. Water scarcity in agriculture will increase, demanding new approaches to manage the limited water supplies at different scales from farms to regions. Demonstrating the potential of adapting water use by rainfed and irrigated agriculture, combining knowledge-based innovative technologies, modelling and transfer of technologies and of innovative practices from the Mediterranean region to areas further North in Europe will be needed. Modelling at a range of scales (from field to river basin) can be used to scope innovations that will require a combination of changes in management practices (e.g. conservation agriculture, field scale soil moisture and plant water status forecast; real-time climate-informed irrigation practices; deficit irrigation practices; field-scale drip irrigation technologies; re-use of sewage water), in plant genetics (change from irrigated maize to rainfed sorghum/maize, change in plant ideotypes including control of cycle duration and of plant architecture in major crops) and in near real-time applications (data from sensors and remote sensing can be combined with simulation models for optimizing the characterization of soil moisture contents and vegetation state and adjusting crop management). Agricultural systems need to be adapted to contribute to the restoration of a good ecological status of all waters within river basins by sharply reducing organic pollutants and heavy metals loads.

Ecosystem services and biodiversity. There are clear links between ecosystem degradation and the persistence of rural food insecurity. Benefits derived from ecosystems can be direct or indirect and tangible or intangible, as reflected in the typology used by the Millenium Ecosystem Assessment – which distinguishes provisioning, regulating, cultural and support services. Significant changes in policies, institutions and practices are necessary to make advances for reconciling biodiversity conservation, ecosystem services and food security. Recent developments in trait-based ecology could help adapt and (re-)design agroecosystems to meet both goals of biodiversity conservation and food security. Just as crop genetic erosion undermines food security, biodiversity loss in general undermines the provision of the ecosystem services agriculture itself depends on. Estimating the value of ecosystem services in monetary terms is still a bottleneck for policy support. This economic evaluation is best applied not to an entire ecosystem but to an incremental change and within a specified policy context. This approach clearly requires increased efforts to further reduce uncertainties and develop internationally agreed standards.

d. Crops: agronomy, plant health and breeding

Sustainable increases in yields. Emphasis should be placed on developing crop production systems of increased productivity while reducing the environmental footprint of agriculture per unit product. This will require accurate benchmarking of current agroecosystems and the design, experimentation, and modelling of alternative systems. The central importance of interactions between genotype, environment and management should be emphasized as the basis of production. Primary production, water and nutrient use efficiency, tolerance to abiotic stresses were also seen as important, in order to combine the necessities of sustainability with increases in yield. Increased emphasis should be placed on increasing the yields of legumes, in order to reduce the dependency of Europe in terms of soybean imports and to substitute mineral fertilizers by biological N_2 fixation. Increasing crop yields will need the involvement of public plant breeders and geneticists due to the long time frame to develop new varieties. The combination of management and genetic diversity is a key way forward for the applied development of cropping systems and cultivars to answer FACCE-JPI challenges. New integrated approaches are needed for molecular, cellular and whole-plant phenotyping technologies under laboratory, greenhouse and field conditions to identify useful genotypes and to use biodiversity more effectively in selection and breeding. New modelling approaches will also need to be developed to interpret "omics" data for plant breeding. A critical component of climate change modelling and agriculture's impact on GHG emissions is the rate at which crop yields will vary on existing farm land.

Plant health. The impact of climate change on rate of change in evolution of pests to current genetic resistances of crops is becoming a critical issue. Research is needed to slow evolution of pest's resistance and to reduce use of herbicides, insecticides and fungicides in crop production. Improved understanding of the pest evolution process and innovative models to predict it can help guide research on crop management, breeding and genetics to address this problem. Advances for detecting in advance important future pathogens are required based on understanding the biology of hosts and pathogens or pests and their interactions under climate change. Integrated crop protection strategies are required to reduce pesticide use and this implies far reaching changes in management practices (e.g. crop rotations), that need to be further explored.

Genetic resources and plant breeding. A broader use of species diversity, of species mixtures and of genetic diversity within crop species will be a key for adaptation to climate change. This also implies that there are increased needs for conservation and exploration of plant genetic resources. Alternative crops, multi-components systems (e.g. agroforestry), crop mixtures (e.g legume-based mixtures) and genetic diversity within a crop species are, together with improved conventional breeding and biotechnology, needed to develop new cultivars of current crops and to explore the potential of new crops for adapting to climate change as well as rising atmospheric carbon dioxide and ozone. More effective transfer of knowledge is needed from advances gained using model species into practical application in crops, including plant breeding. There are promising opportunities to increase yields e.g. through altered phenology and improvements in photosynthesis that could lead to transformative, rather than incremental progress.

e. Livestock: production, animal health and breeding

Animal health. It will be important to manage the threat from, and impact of, animal diseases and zoonoses, including both current and newly emerging or exotic diseases, and spread of disease from and to wild animals. Risks of animal disease transmission and spread are increasing with climate change and increased movement of animals and people. Effective surveillance, monitoring, prevention and treatment are all required. Integrated animal health strategies, involving a reduced use of antibiotics in production systems and integrating pain, distress and discomfort reduction issues should also be studied.

Sustainable livestock systems. As with crop systems, the emphasis should be placed on better closing carbon, nitrogen and phosphorus cycles and reducing greenhouse gas emissions in livestock farming systems or integrated crop-livestock systems and thereby increasing production, while reducing environmental footprint per unit product. Waste should be better treated at farm level to recover valuable components (e.g. phosphorus). Emphasis should also be placed on reducing knock-on effects such as the eutrophication of water bodies and increasing the conversion efficiency of water and nutrients, along long supply chains which are typical for animal production systems. Mitigation will be required, combining reduced non-CO_2 emissions (enteric fermentation of ruminants, nitrous oxide emissions from pastures and feed crops), increased carbon sequestration in soils, better assessment of the GHG balance of farming systems through the development of farm-gate assessments and of lifecycle analyses. Moreover, these mitigation strategies will need to be effectively combined with adaptation strategies concerning animal tolerance to high temperatures and to increased parasitic pressures, as well as climate change adaptation of grasslands and of feed crops.

Animal breeding. The potential of genomic selection should be further explored by defining phenotypes and goals for multi-criteria selection. Such goals should include improved environmental footprint, product yield and quality, better health, improved welfare and robustness. Analysis of genetic diversity to explore livestock adaptation to diverse environments and product characteristics is also required.

Feed resources. Renewed attention to the exploitation of feed resources is needed to evolve systems that are minimally competitive with humans for food by capitalising on the advantages of ruminants for generating high quality products from land that cannot otherwise be cropped, and by maximising the use of by-products and co-products in non-ruminant systems.

Integrated crop-livestock systems. Mixed systems for mitigation and adaptation (e.g. crop-livestock; agro-forestry…) should receive far greater attention for their potential role in food security, in reduction of environmental footprint and in climate change adaptation and mitigation. Such systems have the ability to offer a range of ecosystem services that are not usually available in monocultures.

f. Greenhouse gas mitigation and carbon sequestration by agriculture

Asssessing the radiative forcing of the atmosphere by European agriculture.
On a global scale, the agriculture sector accounted for an estimated emission of 5.1 to 6.1 Gigaton (Gt) CO_2 equivalents per year in 2005 (10% to 12% of total global anthropogenic emissions of greenhouse gases (GHGs) (IPCC, 2007) and for ca. 60% of N_2O emissions and 50% of CH_4 emissions). Nevertheless, while useful for national inventories, this sectoral analysis has several deficiencies. First, it does not account for indirect GHG emissions generated by farm activity through the use of farm inputs (e.g. fertilisers, feed, pesticides), which are covered by sectors such as industry (e.g. for the synthesis and packaging of inorganic N fertilisers and of organic pesticides), transport (e.g. fuel combustion for transport of fertilisers and feed), and buildings (e.g. electricity and fuel). Second, agricultural activities also induce land-use changes – especially deforestation – caused by expansion (or decline) of pastures and arable lands, which are not included in the agriculture sector balance. Third, changes in soil stocks caused by carbon sequestration or loss in arable lands, grasslands and peatlands managed by agriculture are also not directly included in the carbon balance of the agriculture sector. In the same way, indirect effects of agriculture on the nitrogen cascade lead to further greenhouse gas emissions or uptake, which need to be better assessed. Finally, at the Earth system scale, there are further feedbacks of agriculture in terms of radiative forcing of the atmosphere through changes in albedo, water vapour and heat fluxes momentum. Improved methodologies are therefore required to consistently address the radiative forcing which is both directly and indirectly caused by European agriculture, taking into account these various effects.

Estimating and verifying farm scale GHG budgets. Further research combining measurements, process understanding and modelling is needed to reduce current uncertainties in the N_2O and CH_4 emissions from European farming systems and farming practices. Moreover, methods for projecting and verifying changes in soil organic carbon stocks (i.e. C sequestration) at the field and farm scale are required in order to assess the net GHG emissions of farming systems in CO_2 equivalents. This may lead to a change in paradigm with increased emphasis placed on soil C sequestration opportunities in pastures, in arable feeding systems, as well as in the restoration of degraded soils.

Developing GHG mitigation options that are consistent with climate change adaptation. A variety of options need to be further developed for mitigation of greenhouse gas emissions from crop and livestock production systems on the farms, as well as emissions embedded in farm inputs. The technical potential of these options should be better established for a large range of soil, climate and farming systems conditions in Europe. Moreover, the abatement (economic) potential of technically effective measures needs to be identified, also considering social and policy barriers for their implementation.

Developing a policy framework of GHG mitigation in agriculture. As countries put policies in place to curb GHG emissions, the agriculture sector will be especially concerned. If not properly designed, these strategies may be ineffective in reducing emissions while at the same time causing economically, socially and even environmental negative spillovers. Understanding how policy frameworks addressing climate, energy or agriculture will affect the crop-livestock-climate nexus is thus urgent; their social acceptance and cost-effectiveness across crop and animal production systems being central issues. Integrating both mitigation (i.e. reduce the greenhouse gas emissions) and adaptation (i.e. deal with the unavoidable impacts) strategies to climate change is needed and it remains a significant challenge for the scientific community that will require further research.

g. Bioenergy, biofuels and biomaterial

Crop-derived bioenergy and biofuels and, to a lesser extent, non-food crops competing with food crops may not be tenable in the long-run. Arable land resources are limited and expansion of farmland into forest, grassland and woodland areas will result in biodiversity loss and significant carbon emissions, which may negate the primary justification for carbon savings with bioenergy and biofuels. As long as biofuel expansion is based on first-generation food crops, the speed of biofuel increase needs to be balanced by increases in overall agricultural productivity. Use of crop residues for bioenergy and biofuels may also lead to reduction in organic carbon supply to soils and, hence, in lower soil organic carbon stocks. The key challenge for commercial second-generation biofuels is to develop conversion technologies at industrial scale and at competitive prices. These technologies, still at the laboratory experimentation and demonstration stage, require large-scale feedstock supplies and pose logistical and sustainable management challenges. A substantial potential for producing lignocellulosic feedstocks on currently unprotected grassland and woodlands exists worldwide but its exploitation is likely to increase pressures on biodiversity and ecosystems. Integrated studies on land use changes and competition between food and non-food production systems will be required, assessing the consequences of European policies for a range of options concerning biomaterial, bioenergy and biofuels targets. Moreover, integrated systems combining food and energy production will be studied and assessed in terms of climate change adaptation and mitigation and contribution to global food security.

- **h. Forestry as related to agriculture and food security**

Forests and woodland are an important part of land use and land cover, and provide timber and other goods and services. Forests and woodlands may contribute to GHG mitigation, carbon sequestration and fossil fuel substitution. Forests and woodlands, as well as their production of fibers will be considered by the FACCE JPI in as far as this interacts with land use, food security, climate change mitigation, ecosystem services and conservation of biodiversity at the landscape level.