Joint Programming Initiative
Connecting Climate Change Knowledge for Europe
(JPI Climate)

Strategic Research Agenda

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VISION

Preamble

Europe aspires to be the most competitive and dynamic knowledge-based economy in the world, capable of sustainable economic development with more and better jobs and greater social cohesion. Climate change alters the conditions under which these ambitions are to be realized. This generates new challenges, including the need to transform energy systems away from a dependence on fossil fuels and the need to protect European citizens, business and nature from climate risks. Research, knowledge dissemination and innovation are crucial in helping to confront these challenges and generate new opportunities for sustainable development. Climate change is a complex reality, which affects European society at large. Understanding and responding to climate change requires coordinated and large-scale European efforts, in research, innovation and governance.

The JPI Climate provides the platform where these objectives can be met, aligning national research priorities according to a jointly agreed Strategic Research Agenda (SRA) with the aim of complementing and supporting initiatives at the European level (ERANETs, FP8, Climate KIC, ESFRI Projects). JPI Climate facilitates the coordination, collaboration and exploitation of synergies while working against fragmentation and duplication of efforts. Coordination of the research base secured through national resources will help underpin European efforts to confront climate change. JPI Climate aims to respond to the needs of policy and decision makers and the European society at large for knowledge-based information and services to address climate change.

The main objective of this programme is to provide integrated climate knowledge and decision support services for societal innovation. The JPI Climate is built upon four modules: improving climate projections, climate services, societal transformation, and decision-support tools. It is innovative in its interdisciplinary approach in connecting natural- with socio-economic sciences and it is guided, coordinated and managed through a flexible collaborative governance mechanism.

This Vision Paper aims to inform the national and international research and policy community about this initiative as a new opportunity to enhance policy-relevant climate change research in Europe in support of a climate-resilient and sustainable development of our society.

Helsinki, May 2011

MEETING EUROPE'S DEVELOPMENT OBJECTIVES UNDER A CHANGING CLIMATE

Europe aspires to be the most competitive and dynamic knowledge-based economy in the world, capable of sustainable economic development with more and better jobs and greater social cohesion. Because it is projected to impact on the economy and the quality of life of European citizens, climate change fundamentally changes the conditions under which these ambitions are to be realized. Research, knowledge dissemination and innovation can help meet this challenge and generate new opportunities for sustainable development. In the last two decades, substantial progress has been made in understanding the functioning of the earth and climate systems and the human role in these systems. New knowledge is now required to support effective response actions that simultaneously reduce the vulnerability of regions and economic sectors, grasp new opportunities and achieve sustainable economic growth and greater social cohesion in line with Europe's ambitions.

Europe and its member states have set ambitious goals for both mitigation and adaptation. Effective integration of climate issues into existing policy, planning, and governance in different sectors is a critical challenge. In many European countries and at the EU level, research is underway to generate new knowledge to assess and communicate risks and challenges, and to evaluate the costs and benefits of response actions. However, new knowledge and research efforts are still fragmented and often not responsive to the needs of policy and decision-making processes by governments, businesses, citizens and non-governmental organisations at different levels. JPI Climate is a joint programming initiative that integrates European climate change science and connects it to efforts in Europe to be both climate-friendly (through mitigation) and climate-proof (through adaptation).

Connecting Climate Knowledge for Europe (JPI Climate) has been developed by six European countries and is supported by nine additional countries. By connecting science and decision making processes, JPI Climate will help to meet the challenge of making European development both climate-friendly and climate-proof.

Synthesizing knowledge for a climate-friendly and climate-proof Europe

The way Europe's ambitions can be realised under a changing climate raises many questions for policy and societal decision makers. Currently, the fragmentation of national and European climate research hampers an appropriate scientific response. To contribute to knowledge-based policy development and decision making, JPI Climate focuses on the connection between research priority areas, by synthesizing new scientific findings into policy-relevant information, and by translating results to practical societal use. JPI Climate brings together European centres of excellence, integrating climate knowledge in support of sectoral and regional policy and decision-making by different stakeholders at different levels. How the integrated decision support will be put in practice will be decided by participating countries according to their own priorities and context, in support of sectoral and regional planning processes and investment decisions that are both climate-friendly and climate-proof.

For example, for mitigation, JPI Climate will stimulate integrated analyses of and scenario development for concrete sectoral and national mitigation strategies in line with EU climate, energy and other sectoral policy goals, in the context of broader technological, economic and cultural transformation processes. Although closely related to the topic of climate change, JPI Climate will not include research on the technological aspects of climate mitigation (e.g. energy efficiency, smart grids) which are largely driven by the energy research agenda.

For adaptation, new research is needed to improve climate projections, and make them available as part of an integrated climate service mechanism, that will contribute to climate-resilient regional, (cross-) sectoral planning and policy development. JPI Climate will pay particular attention to innovative solutions for vulnerable areas (like cities, mountain regions, deltas and other coastal zones, and agricultural and natural habitats from the Mediterranean to the Arctic); and respond to specific needs of sectors (like agriculture, infrastructure and networks, transport, tourism, energy supply, fresh water supply, health or construction). It will focus on the distribution and dynamics of both risks and opportunities across Europe and on potentials for social and technological innovation.

Specific climate research and policy questions in vulnerable regions and sectors in Europe will determine how JPI Climate will develop common research strategies, coordinate national activities and synthesize available research findings generated by the programme itself with knowledge produced by national and European research programmes.

COLLABORATION INCREASES QUALITY AND COST EFFECTIVENESS

Climate change is a key challenge for future development. The collaborative prioritization of climate change research can help meet this challenge, to the benefit of people, environment and economy. JPI Climate proposes a robust and innovative European initiative adding value by integrating and expanding climate change research in concert in a truly transnational, coordinated effort. It will overcome fragmentation in climate change research while maintaining creative diversity. Synchronizing, aligning and combining research efforts in participating countries have at least five advantages that can inspire climate science and policy:

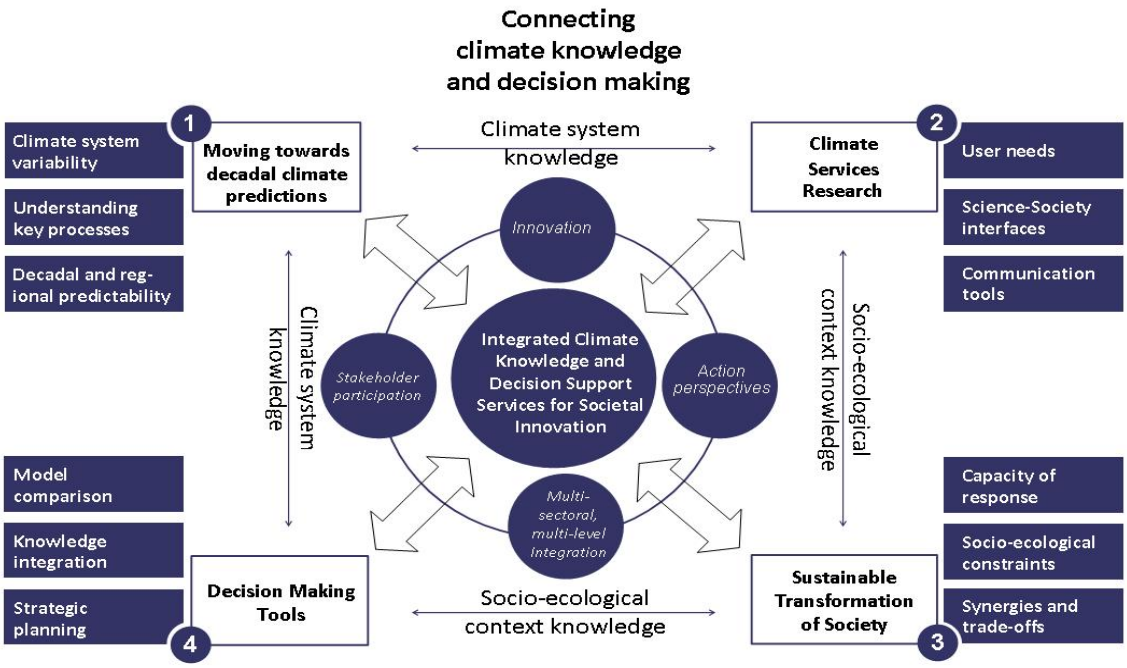
1. ***Enhanced societal relevance.*** The JPI Climate´s interdisciplinary and participatory nature will consolidate, strengthen and amplify current climate research, delivering usable knowledge for decision-making at different levels.
2. ***Higher scientific quality.*** Intensified cooperation between top researchers from different countries with different scientific traditions and perspectives enhances innovation and scientific quality.
3. ***Long-term continuity.*** An international collaborative programme can transcend the limitations of short-term research programmes and projects, and provide more stability and continuity in research collaboration.
4. ***Higher cost effectiveness.*** Transnational research collaboration avoids fragmentation and duplication of research and can use resources more effectively by sharing and jointly developing new data from observational networks and modelling, tools, methods and research infrastructure.
5. ***Stronger global position.*** A well-coordinated JPI Climate can provide a competitive edge in the global climate change science arena. By providing strong science support, it can also foster Europe's role in international climate policy development.

JPI Climate connects climate science to policy and decision-making, enhances coordination, quality and continuity in climate research programming, increases efficiency by avoiding fragmentation and duplication, and enhances Europe's competitive position in science.

FOCUS ON FOUR ISSUES OF THE GREATEST RELEVANCE

The JPI Climate´s Strategic Research Agenda will be a dynamic agenda, which will initially focus on four interconnected modules. Together these modules are designed to generate topical knowledge that will support the development of a climate-friendly and climate-proof European society (see figure below). They do not intend to capture all aspects of the climate problem, but reflect the initial priorities of the participating countries as to salient climate knowledge. The modules are complementary to and connect other areas of research covered by national and international programmes.

Each module can only fully develop its added value in relation and exchange with the overall objective of JPI Climate: to provide integrated climate knowledge and decision support services for societal innovation. This overall objective is the core of JPI Climate (see most inner circle in figure below). It is from this core where interaction between the modules takes place and is consciously stimulated. Thus, all four modules contribute to core activities. Vice versa, the insights and developments in the core will have effect on the modules. The four modules thus engage in a joint learning process and new insights and approaches will be inspired throughout this process.



With the term ‘societal innovation’ we refer to all strategies, efforts and interventions that could lead to a successful climate-friendly (through mitigation) and climate-proof (through adaptation) development of the European society and at the same time could open up new and promising social and economic pathways. Governmental organisations, business, NGOs and citizens are important actors in this development process. These actors operate on various administrative levels and can be considered as the main stakeholders and addressees of this joint research programme. Vice versa, these stakeholders will influence the development and refinement of the JPI Climate research agenda over time.

The core of JPI Climate will be a dynamic and open space of communication across pre-existing boundaries between separate research communities and between research and policy. This is where research questions are articulated and tailored in interaction with stakeholders, and where knowledge is aggregated, integrated and communicated. The science modules provide supporting research perspectives.

The main added value of the JPI Climate is to enhance the connectivity between the currently fragmented climate research, learning and innovation. Greater integration will be secured in three domains:

Society: connecting scientific insights with the demands of policy makers, decision makers and other stakeholders from local to international levels, leading to more effective policies;

Science: connecting different disciplinary approaches in natural and social sciences leading to interdisciplinary research efforts of higher quality and relevance;

Europe: connecting top researchers and research groups from different European countries, leading to high quality and efficient research efforts, long term collaborations and a stronger global position.

The four modules form the backbone of the Strategic Research Agenda of JPI Climate:

- *Moving towards decadal climate predictions.* Existing climate projections already provide useful information for planning in government, business and society. However, there remains a clear challenge for research to deliver tailored climate information, including the uncertainties, at time and space scales more relevant to decision makers for adaptation and mitigation policies. Strong improvements in climate models are required, based on better understanding of key climate processes including feedbacks, as well as of climate phenomena such as extreme events and possible nonlinear responses for past, present and future conditions. The extent to which climate prediction is possible on decadal timescale also needs to be further explored. As a platform for coordinating science on climate predictions and observations across Europe, the JPI Climate offers an important progression from the current and mainly national activities.

- *.Research for climate service development.* Climate services produce science-based client-oriented information about projected regional climatic changes and regional and sectoral impacts. They should be based on a good understanding of the stakeholder needs, and provide easy access to up-to-date information and expertise regarding specific policy or research questions. Strengths, limitations and uncertainties about current knowledge should be adequately communicated, in support of robust decision-making. JPI Climate will bring interaction between the emerging national and climate services European initiatives. The definition and alignment of an climate impact research agenda is beyond the scope of JPI Climate at this stage. However, the climate services module will include climate change impact research at the level of aggregating and integrating the results from existing national and European research efforts and making them accessible in support of the core objective.

- *Understanding sustainable transformations of societies under climate change.* It is widely recognized in Europe that responding effectively to the long-term challenge of climate change will require fundamental transformations of our production and consumption patterns, as well as the way we deal with climate change related risks in spatial and sectoral planning. Understanding of societal transformation processes is needed to stimulate and govern the innovations that are needed to achieve a climate-friendly and climate-proof Europe. JPI Climate will bring together the disparate European social and economic research efforts on sustainable societal transformations.

- *Improving models and scenario-based tools for decision-making under climate change.* Connecting complex scientific knowledge to decision-making requires practice-oriented methods. These include scenarios in support of policy development, integrated assessment models, guidance tools, methods for evaluating response options, or tools for spatial assessment. Such tools will be further developed, compared and applied in close interaction and dialogue between researchers and stakeholders at different levels. The JPI Climate provides a forum within which tools from across Europe can be brought together and strengthened.

The JPI Climate initially focuses on four connected priority areas of research, identified by the participating and supporting countries as the most urgent and relevant for a trans-national *collaborative effort in support of climate change decision-making. They are complementary to and connect national and international research programmes.*

Implementation and governance through a flexible collaborative mechanism

Variable geometry is the guiding principle of collaboration and management in JPI Climate. This principle ensures that member states participate within the remits of their own research and research funding capabilities. It allows individual partner countries to focus on those elements of the overall framework that best match national preferences. The large number of participating and interested countries allows building long-lasting, sustainable partnerships to tackle the major societal challenge of climate change.

The governance of the JPI Climate is built on lean and effective structures. It consists of the Governing Board, an Executive (Management) Committee, several Working Groups and a Central Secretariat. These bodies are responsible for the strategic orientation, effective implementation and management of the initiative. The role and responsibilities of participating funding and research management institutions in the governance structure will depend on the level of financial and substantive commitment. An overall Advisory Board, consisting of national and international members from academia and from relevant stakeholder groups, will advise the Governing Board on specific issues on request. This overall Advisory Board is an important instrument to involve relevant stakeholder groups.

JPI Climate will be linked, where appropriate, to other research programmes, networks and initiatives at member state or European level. In the initial phase, JPI Climate will collaborate with CIRCLE-2, the network of European research programmes in the area of impacts, vulnerability and adaptation, inter alia on the articulation of user needs.

A wide range of mechanisms will be employed to implement the JPI Climate. They encompass joint strategic planning (aligned research agendas), joint approaches towards related networks and programmes at national and European level (ESFRI, ERA Nets, national research networks), and joint knowledge sharing activities (exchange of researchers, summer schools, workshops, conferences, information platforms). Joint research funding is considered one out of a number of beneficial ways of which the partner countries are willing to engage into to implement the JPI Climate.

The JPI Climate framework will be open and flexible, allowing periodic adjustments in research focus and composition of the governance structure. A wide variety of mechanisms *will be applied to reach its goals, with joint research funding as one of several beneficial ways of collaborating, but also series of workshops, academic courses, and policy support actions. Collaboration will be pursued with other research programmes, networks and initiatives at member state or European level.*

ADDED VALUES

Module 1

This module requires a range of expertise on both observations and modelling from across the European Research Area (ERA).

In terms of modelling, the JPI Climate will combine forces to tackle the challenge of developing decadal prediction systems for Europe. It will foster coordination of model developments as well as of consistent experiments and diagnostics aimed at optimising the prediction capacity and representation of relevant processes and feedbacks. It will stimulate the use of multi-model and ensemble approaches for decadal prediction and projections with both global and regional models, which arerecognised to outperform the capability of any system based on a single model. Developing the European climate modelling infrastructure will provide distinct added values: it will enhance the perceptibility of Europe's climate modelling research at international level, improve the quality of climate understanding and climate change studies by providing easier access to different climate models and boost critical mass for model advancements by sharing developments, standards and good practice.

Cooperation within the JPI Climate will enable the synergetic use of observation systems and maximise the benefits and usability of European infrastructures (monitoring systems, field campaigns and databases). It will consolidate a critical mass of scientists to carry out the tasks in a cost-efficient manner. A clear benefit of the work is eased access to data and multiple uses of observational data in Earth system research and modelling. The JPI Climate will also ease the coordination of empirical and experimental research, which requires a broad range of expertise as well as a range of research infrastructures, such as vessels, research planes and distributed monitoring platforms.

Through coordinated modelling and observations, the JPI Climate will provide scientific evidence and advice to European governments and society coordinated at EU-level.

Module 2

The added value of trans-national research collaboration as compared to separate national research efforts encompasses several aspects. It has the potential to decrease fragmentation and duplication and increase consistency in critical areas of climate impact research, while maintaining sufficient variety across the European Research Area to promote discussion and gain different insights, e.g. on how to quantify uncertainty.

It broadens the existing knowledge base (e.g. creating common data bases, but also in terms of the method and impact of communication, guidelines pertaining to the use and processing of climate data, etc.) and increases its practical value by facilitating and improving its societal application and thereby improving future decision making under climate change.

Through promotion of consistency in trans-boundary information on the impacts of climate change (currently, for example, different climate models register different discharges into the River Rhine) this research area contributes to the development of a systemic approach that exceeds the research capacities of individual member states.

While enabling countries with specific climate knowledge requirements that may not be covered adequately by EU-wide programmes to jointly perform focused high-quality research, joint activities in the field of climate services broadens the knowledge and resource base on which investment decisions at regional, local or company level are based, thereby strengthening the competitiveness of the European economy and enhancing local, regional and national capacities for sustainable development.

Finally, through identification of 'good practices' in terms of successful adaptation of tools, models, instruments and methods to specific sectors and local circumstances it achieves a competitive advantage of the European Research Area in relation to other world areas in climate services research and supports a longer-term vision and stable research collaboration on climate services in Europe.

MODULE 3

Module 3 frames climate change in its social dimensions. It presents a strong European perspective of the social dimensions of climate change and response strategies directed at it. After decades of predominantly natural scientific research into climate change, it has become increasingly apparent that social sciences will also make a vital contribution.

This vital contribution is strengthened by the solid embedding of the four JPI modules within the network, which should be regarded as four interrelated areas of equal importance.

The module 3 approach involves connecting climate change knowledge in an inter- and transdisciplinary manner as opposed to focussing on the improvement of singular elements. It contributes to developing and implementing a joint European vision for transition and a shared understanding of possible pathways. In integrated assessments and model comparisons, module 3 addresses and elaborates the issue of 'sustainable transformations of society' in an area not analysed extensively in the past. This will be a specific European contribution to these research streams.

Module 3 highlights the necessity of addressing the issue of societal transformations (in terms of social learning and change processes) in the IPCC works, where it has not been covered as an explicit thematic area so far, basically due to political reasons. It advocates the use of comparative research in the European context.

Experiences from the most recent climate negotiations (COP 15/16) have disclosed the need for far-reaching innovations in national and international climate governance, given that no single top-down instrument is feasible enough to deal with either adaptation or mitigation.

MODULE 4

A nested system of scenarios and scenario-based decision-making tools and instruments across scales will be essential for ensuring that investments into scientific research, development and innovation bear fruit in terms of improving decision support. The JPI will try to make use of the current dynamics within the scenario and modelling communities to systematically build bridges between academia working on climate change analysis and practitioners taking strategic, political or investment decisions.

In this sense, strengthening of existing, community-based developments for the greater integration of knowledge will structurally increase the community's capacity to become more policy-relevant and deliver results of higher practical value.

The call for defragmentation assures that the JPI will provide a clearer view of the wealth of existing analytical approaches to climate scenario development without compromising creative variety or scientific quality. However, if the consistency and connectivity of approaches can be improved, comparability will also increase and enable a broader range of previously incommensurable development paths to be explored. This may well increase the potential for scenario development to act as a stimulus for innovation and progress and stretch the bounds of possibility.

The coordination of research funding backing up the pertinent developments in this field increases efficiency of the investments of the individual member states by providing strategic guidance and a better grasp of the wider context of funding activities. If it is well-coordinated and strategically placed, there is a high potential for this module to make a large impact with comparatively little investment.

Finally, a coordinated approach in this field of research will ensure the EU is firmly placed in the scientific landscape as regards working towards integrated climate scenarios and scenario-based decision-making tools and instruments.

Helsinki, May 2011

1 MOVING TOWARDS RELIABLE DECADAL CLIMATE PREDICTIONS

1.1 Overview

As it is now evident that climate change is ongoing, there is a strong need to improve our knowledge of future climate changes. Provision of reliable climate information for the coming decades is particularly important in relation to the planning and implementation of adaptation measures. Furthermore, the provision of climate information to decision-makers to support adaptation is required at smaller spatial scales (high-resolution). These objectives are indeed challenging for research. Meeting the climate mitigation challenge, in turn, needs improved science on climate sensitivity and Earth system feedback that operates both on decadal and longer time scales.

Through improved knowledge, the JPI Climate aims to provide enhanced climate information and climate prediction capacities for Europe and regions of key interest for European policy. Underlying these pursuits is an ongoing improvement in our understanding of key climate processes – including feedbacks – and climate phenomena such as extreme events and possible nonlinear responses for past, present and future conditions. These objectives require a long-term strategy for observations, experimental studies and modelling at various spatial and temporal scales. A substantial development of climate models is warranted, which calls for an improved understanding of processes and more comprehensive observation systems. This requires a coordinated and enduring effort on the part of the climate research community to develop integrated interdisciplinary studies and, not least, theoretical frameworks.

Changing paradigms

Until recently, much of the research effort has been devoted to investigating future global climate changes to provide information for mitigation strategies, with a focus on global scale and century timescales. Given the evident advance of climate change, greater emphasis now needs to be placed on shorter timescales spanning the next few decades and on obtaining reliable regional climate information to support adaptation. Extreme events and abrupt changes are of particular interest for society due to their strong potential impacts.

This change of paradigm comes with many challenging issues. Firstly, where anthropogenic forcing is dominant on century timescales, natural internal variability has a strong influence on shorter timescales, enhancing uncertainty and requiring a better understanding and representation of natural decadal variability. Secondly, whereas models agree on the global scale and on some major continental structure of change, there are still significant uncertainties on the regional scale and even at the more local scale. For example, basic climate variables, such as precipitations, are still uncertain in model projections for many areas, e.g. monsoon regions. Thirdly, uncertainties still exist in processes and feedbacks in the climate system.

Providing reliable climate information for society will require a substantial improvement in the way that the international community develops, operates and analyses models over the coming years. It will also require substantial improvement in our understanding of key processes and enhancement of our ways of dealing with uncertainties. By strengthening networking and developing common research strategies on modelling and observations, the JPI Climate can significantly contribute to this overall objective. It will benefit from collaborative work that has been supported by the EC – European Commission – since the First Framework Programme as well as by other international programmes such as the World Climate Research Programme (WCRP) and International Geosphere-Biosphere Programme (IGBP).

1.2 Objectives

1.2.1 Investigate climate predictability onseasonal to decadal timescales

Climate prediction focuses on the time scales between operational weather forecasting and centennial climate change projections. The relevant time scales range from a few months (seasonal) to up to a few decades (decadal). The science of decadal climate prediction is rather new. Initial studies have shown that the climate system may have some degree of predictability on future timescales ranging from 2-3 years up to a decade. If indeed this was achievable, it would be very useful for a range of planning and investment decisions and for taking precautionary measures in many different sectors. However, the issue of whether or not predictability of the near future climate is achievable is still open. In addition to fundamental questions on predictability, the scientific challenges also involve the development of proper, model-based prediction systems and the linking of these to data, as well as research on model initialisation and ensemble techniques. These issues need to be successfully addressed as a prerequisite for creating an operating decadal prediction system. The broad range of research areas involved warrants collaboration at a European level.

Key objectives:

Analysis of seasonal to decadal climate predictability, its uncertainties and limitations in Europe and regions of interest for Europe, including understanding of the physical processes that govern climate variability. Develop methods for initialisation, perturbation and verification of the seasonal to decadal prediction system, including observational data sets of key parts of the climate system (e.g., ocean, soil moisture, sea ice, aerosols).

1.2.2 Provide reliable climate information for the next few decades and up to the centennial scale

If successful, climate prediction information would provide decision support for the next few years and up to a few decades at the most. On and beyond this time scale, climate predictions become more and more dependent on anthropogenic forcing scenarios (greenhouse gas emissions, pollutants/aerosols and land use change) and less and less on initial conditions. Such predictions provide important information on possible future changes in terms of mean conditions, variability and extreme events under different scenarios. The term "projection" is often preferred to prediction. These climate projections are needed both for supporting mitigation and for enabling adaptation in sectors with planning horizons of several decades (e.g. major infrastructures). Uncertainties in this regard need to be continually investigated on global and regional scales to ensure sustained decision support for climate policy and adaptation and mitigation measures. Coordinated research by the JPI Climate will generate more comprehensive and consistent climate information for Europe and regions of interest to Europe.

Key Objectives:

Analysis of climate change and variability over the 21st Century in terms of mean conditions, variability and extreme events (e.g., droughts, heat waves, storms, floods); as well as improving the understanding of the processes involved in their occurrence and persistence through research on past climate observations and climate model simulations.

1.2.3 Improve the observation, understanding and modelling of key processes and mechanisms

The improvement and development of climate models, and subsequently climate predictions and projections underlining decision support on policy, mitigation and adaptation, are conditional on the understanding of physical climate system processes. In many cases, today's understanding is advanced, but there are still fundamental limitations that have a bearing both on our ability to simulate climate variability and confidence in climate change projections. This is due to the poor representation of a number of basic processes (such as precipitation, sea-ice dynamics, aerosol formation...) as well as the need to better understand and model feedback processes that amplify or counteract the direct effect of anthropogenic climate forcing (such as cloud-radiation interaction, coupling of biogeochemical cycles, atmospheric chemistry and climate). Certain limitations are due to model resolution as some processes are only partially resolved; one example being the storms related to tropical and extra-tropical cyclones with their extreme winds and precipitation that cause damage to societies. Many climate-forcing aspects of aerosols, for example indirect aerosol effects such as black carbon (soot) in the Arctic or biogenic secondary organic aerosols, are still poorly quantified. Other important aspects, which still need to be investigated more closely, include ice sheet-ocean interactions, stratosphere-troposphere interactions, permafrost carbon balance, land-vegetation phenology, phytoplankton physiology and carbon-nitrogen cycle ecosystem interactions. Several of these processes are linked to potential instabilities in the Earth system under climate change on decadal time scales. Further advances in these areas require process-oriented studies and consideration of observations, experiments and model development. The JPI Climate can overcome these difficulties by engaging in long-term dedicated research studies involving observation programmes, theoretical studies, model development and process-oriented model evaluation.

Key objectives:

Enhancing the scientific understanding of key processes, mechanisms, feedbacks, system (in)stability, as well as teleconnections and circulation patterns that are significant for climate on decadal timescales and potentially linked to instabilities in the climate system. Improving the representation in process models critical for precipitation and the water cycle, the weather and climate events, climate variability and teleconnections as well as anthropogenic and natural perturbations (such as land use change, atmospheric constituents, volcanoes, aerosols...).

1.2.4 Promote and develop a European climate modelling collaboration environment

Climate models of the Earth system are an essential tool for developing our understanding of climate change and its potential impacts on society both as a result of natural variability and the effects of human activity. Many European countries today have climate modelling facilities. These efforts have expanded even further as new countries have become recently involved in climate modelling. European collaboration between modelling groups has been fostered by EC support since the First Framework Programme. In order to enhance the European capability for climate prediction and subsequent delivery of climate information for adaptation and mitigation strategies, the JPI Climate proposes to further strengthen the European collaboration environment for climate modelling at both global and regional scales. The ultimate goal is to build a European "virtual laboratory" providing the most reliable information on future climate change for science-based support of adaptation and mitigation strategies and action.

Key objectives:

Enable a European collaboration environment for global and regional models in order to foster the development and evaluation of Earth system climate models; organise multi-model ensembles and climate prediction systems; enable the dissemination of model results to the large community of users.

1.2.5 Promote and develop a European collaboration environment for long-term monitoring and analysis of the Earth system

Long-term observation networks play a key role in monitoring climate change and understanding the role of the different components of the climate system. The World Meteorological Organisation Global Climate Observation System (WMO - GCOS) has broadly coordinated and covered some of the key variables and components of the Earth system over many years, while monitoring of other parts of the system (such as aerosols, biogeochemistry in terrestrial systems and ocean) has only recently begun. Moreover, most of these monitoring activities are run by academia with short-term project funding. In recent years, the ESFRI – European Strategic Forum on Research Infrastructures (RI) – process has helped the environmental science community to start establishing more solid and integrated observation infrastructures in Europe. The JPI Climate aims to promote the development of coherent European strategies on long-term observation networks (including proxy and historical data) important for the understanding of the Earth system climate.

Key objectives:

Develop improved European monitoring networks and observation infrastructures; and enable coordinated interoperability of datasets and databases, important resources for improving Earth system analysis as a whole.

1.3 Research directions

Key research directions in the short-term (3-5 years) and long-term (5-10 years) are described in the following for each subtopic.

1.3.1 Investigate climate predictability on seasonal to decadal timescales

The potential benefits of climate prediction still need to be investigated. In the short-term, the internationally coordinated experiments in IPCC - Intergovernmental Panel on Climate Change, Fifth Assessment Report, CMIP5 - Coupled Model Intercomparison Project Phase 5 (see http://cmip-pcmdi.llnl.gov/cmip5/), will provide an unprecedented set of decadal prediction simulations performed by a number of European and non-European modelling groups using different coupled global models and model initialisation techniques. Their analyses in terms of prediction performance, dependency on initialisation and limits of prediction are short-term research priorities.

Short-term research priorities

Investigate the potential of climate prediction

Analyses of the very extensive CMIP5 decadal prediction simulation database will provide valuable information on the potential of climate prediction, strengths and weaknesses of different techniques and will also define priority research areas. In order to accomplish this, the appropriate diagnostics and diagnostic tools need to be devised for both processes (e.g., the strength of Atlantic Meridional Overturning Circulation) and specific regions (e.g., time series of surface temperatures in Western Europe). Experiences gained on idealised models can complement the study of potential predictability associated with specific aspects of climate system internal variability across different regions.

Improved initialisation procedures

Anthropogenic climate forcing is a factor that needs to be accounted for in climate prediction. Up to the decadal scale, however, internal climate system variability is more influential, or at least very comparable with foreseen forced changes. Due to its large heat capacity and the multi-decadal adjustment timescale of the Atlantic Meridional Overturning Circulation (MOC), the ocean is the primary long-term memory of the climate system. Thus, a realistic estimate of the initial state of the ocean is of primary importance in developing a decadal prediction system. Research priorities in this respect include: reanalyses of observed data (atmosphere and ocean); data assimilation (especially ocean data); sensitivity studies looking into the dependency of decadal prediction skill upon assimilated data coverage, data amount and typology; and use of "full values" versus "anomalies" in the initialisation procedure.

The limits of climate prediction

The utility of climate prediction is fundamentally dependent on the degree of predictability in the climate system. Research is needed on what decadal predictions theoretically can and cannot provide. Even if deterministic predictions beyond a few years may remain beyond reach, there could still be exploitable predictability for some aspects, e.g. decadal trends, conditional extremes, and interdecadal variability. Likewise, greater skill is required in relation to climate indices and other specific areas. Mapping decadal predictability skill at regional levels will also need to be investigated.

Long-term research priorities

A systematic exploration of the main drivers of decadal predictability

Apart from the global oceans and anthropogenic forcing, decadal predictability may be influenced by other effects/phenomena/drivers. These include, for example, sea ice distribution, soil moisture and vegetation status, but perhaps also issues such as changes in solar activity, volcanic eruptions and – via the anthropogenic drivers – socio-economic trends in land use change and aerosol emissions. These drivers should be adequately examined and, if need be, incorporated into the models used for decadal predictions. Furthermore, and within this context, multi-model and other ensemble modelling techniques are also required to map the role and effect of the various drivers.

Practical climate prediction

Provided that basic research reveals that there is exploitable climate predictability, a number of issues of a technical nature need to be addressed in order to enable climate prediction in practice (i.e. the creation and routine exploitation of a multi-model-based decadal climate prediction system). Refinement of the research models, design of optimal data collection and provision of ensemble techniques need to be supported with basic and, not least, targeted applied-science efforts. A very important aspect in this respect concerns translating decadal predictions into information for decision-makers. An extensive tailoring tool needs to be developed to accommodate information needs for adaptation policies.

Broadening the use of climate prediction

The design of experiments based on coupled model ensembles that differ in spatial resolution, parameterisations and architecture, increases our confidence in the results and helps to quantify the associated uncertainties. Applying the multi-model approach to the investigation of climate predictability would similarly strengthen the reliability of predictions based on seasonal and decadal timescales.

Additionally exploring climate predictability in the context of more complex climate models, including biogeochemical processes (Earth System Models), may widen our understanding of the processes that may harbour long-term memory in the climate system. In particular, gaining insight into the role played by coupled physical-chemical-biological interactions within the limits of climate system predictability would constitute real added value for this novel branch of predictability studies.

A comprehensive European climate modelling and analysis system for seasonal and decadal timescales (as well as centennial scales) should be “seamlessly” extended to applications in domains other than climate change, such as food security, water resources availability, biodiversity or sustainable energy.

1.3.2 PROVIDE RELIABLE CLIMATE INFORMATION FOR THE NEXT FEW DECADES UP TO THE CENTENNIAL SCALE

The international effort within CMIP5 will provide a large range of simulations to investigate future climate changes. They include not only climate prediction type experiments (M1.1), but also a set of climate projections under different representative concentration pathway scenarios. For the first time, coordinated experiments will also be available at a regional scale for many regions of the world, including Europe and the Mediterranean, that are consistent with CMIP5 experiments within CORDEX - COordinated Regional climate Downscaling Experiment (see http://wcrp.ipsl.jussieu.fr/RCD_CORDEX.html). All of these simulations will provide a significant basis for many climate impact studies targeting both near-term and longer-term time scales. The JPI Climate will coordinate research on topics relevant for society, such as the occurrence of extreme events, abrupt nonlinear responses and sources of uncertainties.

<u>Short-term research priorities</u>

Consistent and comprehensive regional climate information for Europe

Provision of regional scale climate information remains a key research area, with a further challenge being extensions to local scale. Recent developments of regional climate models, coordinated experiments and exploratory performance-based model metrics strongly support further development of regional-scale scenario ensembles. These can provide more robust estimates of regional-scale climate change and variability throughout the 21st Century, in particular on weather extremes, in support of adaptation policies. The priority research areas are: probabilistic analyses of global and regional climate model ensembles, ensemble generation techniques, increasing resolution of global and regional climate models, joint analysis of climate observations and models, and the statistical and stochastic interpretation of model simulations.

Detection and attribution

As society is increasingly aware of climate change and as attention is likely to be heightened by superposition of climate change and natural variability, decision-makers will increasingly be asking detailed questions regarding climate risks. Only recently has it been possible to detect a human contribution to changes in key indicators of the changing climate: zonal mean precipitation, total column water, river flow and salinity changes. It is crucially important to sustain a complex climate monitoring capability and to provide expert, process-based assessment in order to support the attribution of weather and climate events. Detection and attribution methods provide a powerful framework for confronting models with observations and for formulating hypotheses about the controlling processes. These hypotheses must be tested with advanced climate system models, which require both depth and range in terms of expertise and should ideally be carried out in a concerted fashion by the entire European community. Detection and attribution approaches have a central role to play in increasing the reliability of, and trust in, climate predictions and risk assessments.

Extreme events

While society is affected by changes in the mean climate as well as variability, changes in extreme events are particularly crucial in reducing climate-related risks and in guiding climate adaptation. For Europe as a whole, extremes of key importance are wind storms, heavy rains, flooding, drought and heat waves. Within Europe, depending on the particular region, additional categories of extreme events such as extreme snow fall, landslides and storm surges are also of importance.

In many cases, the characteristics of extreme events are not well known due to the sporadic nature of extremes and the limited availability of long time observation series. An increased use of global reanalyses would boost research on past extreme events. Improving climate models in terms of resolution and parameterisations relevant for extreme events and increasing the number of model simulations, would offer better perspectives for addressing the likelihood and magnitudes of extreme events under climate change. Methodological research issues are likewise very important; for example, providing more user-oriented measures of extreme events, such as climate indices that take into account the relevant systems' tolerance thresholds, combined events, etc. The non-stationarity of climate undergoing change is a challenge in itself when it comes to the provision of information on reference levels, return periods and, ultimately, risk assessments.

Investigate major sources and values of uncertainty related to climate and Earth system feedbacks for the next century

Further advances are needed on Earth system feedbacks both on the global and on regional scales to understand and reduce the uncertainty in the models. Earth system feedbacks may either limit the "allowable greenhouse gas emission space" when targeting some specific climate stabilisation target (e.g. clouds and aerosols, carbon feedbacks), or affect the urgency of adaptation when yielding non-linear responses with strong impacts on society (such as ice sheet instabilities and sea level changes). Given the uncertainty on feedbacks, multi-model ensembles are required to better quantify uncertainties and also need to be systematically explored at a regional scale.

Investigate abrupt changes

A systematic classification of processes that could give rise to rapid changes in the climate system is still missing. Changes to the Atlantic Meridional Overturning Circulation, Arctic sea ice, glacier and ice sheet instabilities, widespread exhaustion of regional water reserves, rapid CO2 exchange or CH4 release from peatlands or gas hydrates are examples of nonlinear processes that may yield an abrupt climate change, also named 'tipping points.' ESM simulations, paleoclimate records and theoretical considerations are important tools for preparing tipping point inventories that are of global and European importance, in order to better identify the key processes that may lead to such sudden changes and design diagnostics that can be used as an indicator for upcoming system transitions. In addition to increased understanding, research of such inventories will benefit research strategies in the longer term.

<u>Long-term research priorities</u>

Develop high-resolution global and regional (local) climate models

Global and regional climate model resolutions will continue to improve over time. This will enable utilisation of advances in climate process research (see M1.3), a more detailed modelling of key processes – e.g. atmospheric storms and ocean eddies, feedback mechanisms related to clouds, deep convection and mixing – as well as the study of extremes in more detail. This in turn will lead to improved understanding, better characterisation and attribution of climate changes including the related uncertainties as well as bring the results closer to local scales, which are relevant to many users. Indeed, increasing model resolution and improving process parameterisations must go hand in hand. The pursuit of high-resolution in climate models will entail revisiting the models not only in terms of physical parameterisations (M1.3), but also to adapt to new computing architectures (see M1.4).

Advanced Earth system models

The advancement of climate change and Earth system research requires inclusion in climate models of feedbacks from other components of the climate system such as vegetation, biogeochemical cycles (carbon, sulphur, nitrogen), atmospheric chemistry, ice sheets and ocean biogeochemistry. For example, carbon and nitrogen cycles are coupled and improved estimates of the ecosystem carbon balance require the interactive modelling of nitrogen. Changes in oceanic conditions are coupled to ice sheet dynamics. Ultimately, socio-economic activity can in itself be regarded as an interactive component of climate system evolution, being a driver, but also responding to changes that take place. Numerous efforts are presently being made to meet these ends, e.g. incorporating vegetation. However, given the spectrum of scientific disciplines involved on the modelling side, in addition to broadening the requirement for evaluation data, faster progress requires greater European collaboration.

1.3.3 Observing, understanding and modelling key processes/mechanisms

There are still fundamental limitations that have a bearing both on our ability to simulate climate variability and confidence in climate change projections. This is due to the poor representation of some basic processes (e.g. precipitation, sea-ice dynamics and aerosol formation) as well as the need to better understand and model feedback processes that amplify or counteract the direct effect of anthropogenic climate forcing (such as cloud-radiation interaction, coupling of biogeochemical cycles, atmospheric chemistry and climate). Due to the complexity of the climate/Earth system, a combination of various methodologies and approaches is required, such as observations, experiments, models and theories. Through its targeted system research efforts, such as field campaigns, laboratory experiments and long-term observation programmes (including for the past), the JPI Climate aims to improve the understanding of the key processes/mechanisms and evaluate models by process-oriented research.

Short-term research priorities

Integrated research on key processes/mechanisms

Many climate forcing aspects of the short-lived forcing agents (e.g. CH_4, black carbon, biogenic secondary organic aerosols, tropospheric O_3) are still poorly quantified and need further integrated process-oriented research. Given its contribution to the uncertainty of climate change feedback, the role of cloud feedback is also an important area for continued research. A key related scientific question is the simulation of precipitation. Special effort needs to be dedicated to improving the representation of cloud-convection-turbulence and cloud-radiation processes in climate models and their interactions with the general circulation and the land surface (vegetation, subsurface hydrology, snow). The interactions between aerosols and clouds in the climate system are one of the major uncertainties in the estimation of anthropogenic climate forcing and climate sensitivity. The JPI Climate can facilitate and provide a European contribution to international initiatives such as the ACPC (Aerosols, Clouds, Precipitation, Climate) initiative coordinated by iLEAPS (integrated Land Ecosystem); the Atmosphere Process Study and IGAC (International Global Atmospheric Chemistry); and GEWEX (Global Energy and Water Cycle Experiment).

Biogeochemical cycles (carbon, nitrogen, phosphorous) and their interactions and feedbacks need to be investigated much more closely than has so far been the case. Important aspects are, for example, carbon-nitrogen interactions, land cover/use changes, land-vegetation phenology and phytoplankton physiology. The improved knowledge on these processes and their associated climate feedbacks will strengthen the prediction power and reduce uncertainty of the models. The JPI Climate will support European process-oriented research on coupled biogeochemical cycles and the transfer of new knowledge to the models.

As for the ocean, coastal upwelling, small scale eddies and vertical mixing are critical processes for which a dedicated effort is required to improve both the physical and biogeochemical characteristics of climate. In particular, oceanic deep convection is a key process behind the internal variability of the global climate due to its role in the deep water formation process and implied modulation of the meridional transport of mass and heat. Despite its climatic relevance, the physics and phenomenology of this process is far from fully understood: direct observations are scarce and knowledge of the locations where it occurs is similarly poor.

Efforts towards a better understanding and observation of this crucial process would be beneficial to properly constraining the overturning dynamics in the ocean component of global climate models, which may also have impacts on decadal timescales.

Design and support of the coordination of European field campaigns

Field campaigns are important for investigating processes. They generally require assembling different types of expertise and need a critical mass of human resources only achievable at an international level. The JPI Climate offers the opportunity to plan and organise field campaigns that mobilise European expertise to investigate key processes in the specific areas. One such international effort is, for example, HyMeX (HYdrological cycle in the Mediterranean Experiment), which aims to better understand and quantify the hydrological cycle and related processes in the Mediterranean, with an emphasis on high-impact weather events, inter-annual to decadal variability of the Mediterranean coupled system and associated trends in the context of global change. Another example is a Boreal field campaign (in the planning phase) to investigate the overall role of Boreal forests as carbon sinks and an aerosol source in the climate system by studying soil processes, photosynthesis, biosphere – atmosphere interactions and boundary layer processes. The JPI Climate can help European researchers to design and coordinate such extensive field campaigns.

Investigate past natural climate variability on decadal timescales

Characterisation and mechanisms of natural variability on decadal timescales still necessitate further understanding. Not least, this means addressing the role of biosphere-cryosphere-hydrosphere-atmosphere interactions (e.g. interaction between atmosphere and the ocean, sea ice, land surface). Our knowledge of how decadal variability and short-term variability have been coupled in past conditions prompts further investigation. The role of natural forcing on decadal variability, such as volcanic and solar forcing, also requires greater scrutiny. By upgrading the integrated analyses of long-term instrumental records, high-resolution paleo-proxies and modelling, new knowledge can be gained; for example, on how decadal variability is affected by changes in the mean climate and how different Earth system components are affected by the changes.

Model data synthesis efforts based on the assimilation of time series describing the oceanic and atmospheric state over sufficiently long periods of time (~ 20 to 50 years) will be important for understanding climate variability as well as for regional studies of the coupled ocean/atmosphere system and related impacts on ecosystems and biogeochemistry. This will require consolidation of the existing reanalysis capacity in order to include new components such as sea-ice and to properly resolve the whole spectrum of interacting scales from mesoscale eddies to planetary waves.

Process research on European key regions (hot spots)

The Arctic, Mediterranean and Mountain regions have been identified as main hot-spots of climate change. In the case of the Arctic, also simultaneously in terms of warming: the area of Arctic sea-ice has been decreasing in all the seasons, and precipitation and river discharges into the Arctic Ocean have been increasing. These changes have dramatic impacts on Arctic ecology and societies. Interactions between ice sheets, oceans and permafrost processes may have global effects. There is still no consensus on the reasons why the climate changes so fast in the Arctic, or whether the amplified Arctic warming will continue in the future. Model simulations of Arctic clouds are particularly deficient and impede better quantification of the radiative fluxes that are vital for deciphering the snow/ice-albedo feedback. Important, poorly-quantified players in this context are numerous short-lived climate forcers (SLCF), including natural and anthropogenic aerosols, tropospheric ozone and methane.

In the Mediterranean region, a large decrease in mean precipitation and increase in precipitation variability during the dry (warm) season are expected as well as a sizeable increase in temperature. However, there are still major uncertainties regarding the future evolution of climate in the Mediterranean. Progress has to be made in the monitoring and modelling of the Mediterranean coupled climate system (atmosphere-land-ocean) in order to quantify the ongoing changes and to better predict their future evolution to improve scientific support for the development of adaptation measures.

Climate change affects mountain regions, in particular glacier extents and availability of water resources. Moreover, mountain regions require very high resolution modelling to represent small scale processes. Predictive capacities will strongly benefit from a common European strategy on both observations and modelling.

The JPI Climate is therefore in a position to facilitate long-term dedicated process-oriented research for both the Arctic, Mediterranean and Mountain regions.

Process-oriented evaluation of models

The long-term observation data series from comprehensive measurement sites are now 10-15 years old. Using these time series, observations can be implemented for quantifying aggregated feedback loops and thus to test model performance on specific processes. Although this type of research is only just emerging, it is already anticipated that it will be very helpful for future model development.

<u>Long-term research priorities</u>

Enhance fundamental knowledge of key processes/mechanisms pertaining to the European climate

Mechanisms of internal climate system variability important to the European and neighbouring regions are likely to remain a research priority for quite some time. This research includes probing the physical mechanisms behind the North Atlantic Oscillation, Arctic Oscillation and Northern Annular Mode; blocking, thresholds and potential tipping points of the Arctic sea ice, permafrost and Greenland ice sheet; Arctic amplification; and the long-term changes in these systems' responses to anthropogenic climate forcing and change. It also includes addressing the mechanisms that dictate how large-scale variability modulates the occurrence of local extreme events in Europe.

Incorporation of missing key processes in the models

Fundamental advances in understanding key processes and mechanisms need to be incorporated within the development of climate prediction and projection modelling, followed by applications where appropriate (cf. M1.1, M1.2 and M2). As a consequence, the JPI Climate will serve as a coordination platform for incorporating new, enhanced process understanding into the models.

1.3.4 Promote and develop a European climate modelling collaboration environment

The JPI Climate aims to develop a European research infrastructure for climate modelling that encompasses both global and regional models. Global climate models are extensively used to better understand climate and provide climate change projections. Regional climate models are widely used to understand processes as well as to downscale climate change projections to the regional scale required for impact studies. Such a comprehensive research infrastructure on climate modelling will include the organisation of science, data, software, standards, hardware (high-performance computers) and expertise (people and networks of people). A first step has been initiated by the European Network for Earth System Modelling (ENES) in the form of an ongoing infrastructure project supported by the EC (IS-ENES), upon which the JPI Climate can build.

<u>Short-term activities</u>

For the next 3 to 5 years, climate modelling activity will be largely dominated by two internationally coordinated experiments, CMIP5 for global climate models and CORDEX for the regional climate models. Both represent a very large effort on the part of the community and will be extensively used to better estimate model quality, improve our understanding of climate processes and climate changes as well as provide the basis for impact studies. In addition to the climate modelling community itself, these international experiments are also important to a larger, wider community of users.

Document, archive and disseminate model results

There is a need to sustain the European contribution to the internationally coordinated effort behind CMIP5 and CORDEX. Most of this effort is supported by national institutions; however, European collaboration is crucial to sharing common software developments and organising the European data nodes. The ENES community, supported by EC (IS-ENES and METAFOR FP7 projects) and member state activities, plays an important role in the provision of data and contributes to the development of international standards. Nevertheless, such activities require continuous efforts given that the lifetime of these databases may be in the order of 10 years or longer. Current efforts also need to be expanded to include metadata/documentation of both observational and model data. The documentation of the model components and parameterisations must be improved in order to provide the basis for a better understanding of model characteristics.

Improve the modelling environment

The development of climate models would benefit from a stronger integration and interaction within the European modelling community. Further integration should ease access to (sub-)model and parameterisation codes as well as facilitate common developments, as is the case with, for example, the ocean platform NEMO (Numerical platform for ocean modelling) and the OASIS (Ocean, Atmosphere, Sea Ice, Soil) coupler. In addition, further integration should simplify the development of common standards and interfaces for model environments, including downscaling capabilities and data assimilation. The move should also prompt the development of an information system encompassing observational data of the different components of the climate system for both model development and model evaluation. Collaboration will also be crucial to designing next-generation European modelling systems in a coordinated approach.

Further integrate global and regional climate models

The need to provide information on a regional scale for impact studies fosters a stronger integration between global and regional models. In particular, more systematic ensembles of regional model runs will be required, accelerated by ensembles of global model runs in order to provide the optimum information output. This is ongoing with CORDEX, which, for the first time, coordinates experiments on the regional scale and will generate key scientific input to

IPCC's AR5. The entire chain, ranging from global models to regional models, right through to impact studies, needs to be performed consistently and the simulated result databases integrated within international databases.

Develop the high-performance computing system

Climate modelling is crucially dependent on the availability of computing power. All of the computing facilities used by the climate community are generally supported at a national level. At European level, the ESFRI PRACE (Partnership for Advanced Computing in Europe) project is developing world-class facilities. Access to such facilities for the climate modelling community would help perform high-end experiments such as ultra-high-resolution simulations and parallel multi-model ensembles. PRACE needs, however, to be complemented by a system that facilitates extensive complementary simulations and data archiving on different national facilities as well as post-processing capacity at a laboratory level. The JPI Climate could help develop such a European HPC – High-performance computing "ecosystem" for climate. The distributed system developed for CMIP5 (i.e. the Earth System Grid) could serve as a basis. In order to make full use of an improved computing infrastructure, model performance on a thousand or more processors has to be further developed. This involves issues such as improvement of scalability and input/output efficiency.

Interface with the impact community and climate services

Projections for future climate changes provided by global and regional climate models are the basis of advanced impact studies carried out by the climate change impact community and, consequently, are also the basis for the information eventually provided by climate services (Module 2) that are under development. There is a need to develop a portfolio of good practices and a "certification" label that includes documentation and evaluation of climate models for use by climate services communities. The focus should be not least on the different levels of uncertainties arising from uncertainties in scenarios, models, climate variability and spatial scales. While there is a need for supporting documentation (e.g. metadata) on the applicability of available climate model results as input for impact models, such an information flow is not sufficient in itself. A network of expertise linking the respective communities must be developed that also provides feedback to the modelling community from the impact communities and climate service institutions.

Develop European training on climate modelling

Developing training activities on climate modelling would help scientists face the comprehensive array of challenges ranging from multi-disciplinary aspects of the Earth system to numeric, algorithmic and data mining tools. It will reinforce the integration of the European scientific community via shared tools and practices.

Training is also essential to ensure an effective and efficient use of climate information by users; it promotes 'best practice' and scientific discipline in the interpretation of data and provides a mechanism for the harmonisation of climate projections across national boundaries. It also has similar benefits for the wider climate infrastructure (e.g. observational network requirements).

While the JPI Climate's activities' primary focus will be on the European community, training should have a geographically broader agenda and extend to supporting third world countries. This will also benefit Europe itself, if our understanding of the global climate system is improved by promoting climate capacity building and coordination in regions that are currently under-resourced. Such activities could be linked with the CORDEX project in regional climate modelling and with the WMO - GCOS.

Long-term priorities

Climate modelling is a long-term activity. The need to provide information on climate change for society will continue to require further developments of climate models. As the available computing power increases, models will be able to use higher spatial resolution and increase in complexity. The use of multi-model ensemble simulations to infer inter-model and internal variability uncertainties will grow. Improved access to model results will help to better account for uncertainties, as it enables more research teams to analyse them. Europe, with its expertise in climate models, can play a key role in developing a "virtual laboratory" that will enhance model developments and access to model results. This will require:

- Further organisation of model and evaluation databases for climate within the international context for both global and regional models, similar to that initiated by CMIP5 and CORDEX.
- Further integration of the climate modelling community, organising "scientific diversity" while reducing technical diversity, sharing practices and easing access, and combining forces for the development of future high-resolution climate models.
- Further development of the climate model evaluation system on global and regional scales, with interoperable access to model data and observations from the different parts of the earth system (i.e. beyond climatic data).
- Develop the European HPC ecosystem (at European, national and laboratory level) and prepare for future computer architectures, such as exascale computers, which will most probably require the development of new algorithms for models, benchmarking and data management.

1.3.5 Promote and develop a European collaboration environment for long-term monitoring and analysis of the Earth system

Historically, in European Earth system research monitoring, infrastructures and databases have been developed and utilised in isolation of each other. Today, it is acknowledged that only by promoting collaboration and coordination among observation infrastructures and science communities, can climate-related grand challenges be tackled successfully. The EPICA (European Project for Ice Coring in Antarctica) is an example of fruitful European research collaboration of this kind. This awareness has already generated many international and European initiatives and projects, such as ESFRI, GEOSS (Global Earth Observation System of Systems Initiative), GMES and ESA Climate Change Initiative, to develop common visions and processes to support better coordination. These initiatives encompass a certain degree of climate-related monitoring and research infrastructure development: however, many of the important science fields and Earth system components have still not been taken on board – by ESFRI, for example. In addition, existing networks require support to remain competitive at an international level. Ultimately, operational (meteorological) and research-oriented (climate) activities are still mainly developed and coordinated in isolation. For example, basic meteorological variables are mainly collected and coordinated by national weather services that maintain their own climate databases, whereas much of the physical, biogeochemical, atmospheric chemistry and biological data is generated in research infrastructures run by academia. This data is often collected in various isolated databases by national and/or international organisations and networks.

Future challenges are, not least, to 1) increase the interoperability of the various climate data, 2) enhance the coordination of operational and research-oriented infrastructures and networks, 3) reinforce the European competitiveness of previously structured climate science sub-domains, 4) promote the collaboration and data access (availability) and exchange between the Earth system monitoring community and climate modelling community and 5) ensure long-term support for observation infrastructures.

Short-term research priorities

Mapping and developing the European observation system structure

Firstly, it is essential to map existing operational and research-oriented observation systems (and related databases) to provide better coordination and availability of data. Secondly, it is important to ensure coordinated construction of key research infrastructure (RI), e.g. on the ESFRI roadmaps. However, it is also essential to simultaneously address gaps in the ongoing infrastructure processes by identifying those Earth system components and science communities that are relevant, but not yet being developed or even considered. This would be crucial to supporting climate science and reinforcing the international competitiveness of European scientific communities. The JPI Climate proposes to elaborate common strategies for research infrastructures by analysing the maturity and potentiality of the science communities (e.g. current Integrated Infrastructures Initiatives - I^3, funded by the EC) and assist the rapid introduction of the necessary Earth system components by supporting research – for instance, on network design optimisation and data harmonisation. In addition, the JPI Climate can benefit from other global initiatives relevant to Europe. For example, the recent International Polar Year legacy is available for developing into a long-term platform for Arctic research (cf. SAON - Sustaining Arctic Observing Networks).

Data availability and transnational access to research infrastructures

Easy and free data access is a key issue for enhancing and distributing climate knowledge. The role of national data policies and the limited data provision options of smaller groups as potential barriers to collaboration/coordination on a European level needs to be examined. An open data policy and ICT infrastructures supporting database access need to be promoted for transparency and easy data availability.

In addition to an open data policy, it is also important to maximise the use of national and European research infrastructures. Due to the vast variety of climate-related infrastructures, RI access can be facilitated through the provision of remote scientific services (e.g. reference materials, samples, data) or in person (hands-on), for example by performing sample analyses, specific measurements or experiments. The JPI Climate can support and serve as a strategic platform for enhancing transnational RI access management and also organise database utilisation training and scientific and technical tutorials, particularly for first-time RI users.

Interoperability of observations

The environmental observation data is characterised by vast heterogeneity. This is due to the highly variable and complex data, but also occasionally as a result of the measuring methods and/or data processing used. Such heterogeneity creates immense challenges for the process of interoperability. Barriers to interoperability need to be identified and then recommendations generated that address how these may be overcome. Likewise, standardisation and harmonisation of data formats and observation and data processing methods are important to further joint development at a European level. Advanced analytical and modelling software is required, in addition to sufficient computational capacity to perform demanding workflows on vast data sets. These requirements highlight the importance of establishing integrated e-infrastructure environments that integrate observatories, sensors, data, software, models and computation facilities on an appropriately large scale. The JPI Climate will promote and support European integrated e-infrastructure processes that enable better interoperability of data, databases and data processing and facilitate data utilisation by end-users.

Operational and research infrastructures

Many operational monitoring networks are already well-coordinated through WMO programmes (GCOS) or other networks. There is, however, a lack of sufficient support for full implementation. Transnational collaboration has increased overall, common measuring variables (e.g. list of GCOS Essential Climate variables) and databases have been defined, data processing methods have evolved, and jointly coordinated and run European-level research infrastructures are being established. However, interlinks, interoperability and synergies between operational and research-oriented observation networks and infrastructures remain underdeveloped. The JPI Climate is in a position to promote supporting activities such as joint workshops, training, creation of joint platforms for enhanced sharing of expertise, data trans-access, interoperability, identification of gaps/deficiencies in the European networks and inclusion of new observational parameters in the activities.

Reanalyses of the Earth System

Reanalyses of atmospheric and oceanic observations already play a key role in climate research and provide support for the initialisation and evaluation of models as well as climate change and variability analyses. Reanalyses need to be extended to the land surfaces (e.g. soil moisture) to support decadal prediction. Regular reanalyses will remain necessary to allow a consistent treatment of long observational data series, to improve the treatment of observational biases and to take advantage of progress in data assimilation techniques. Due to the substantial infrastructure needed to perform reanalyses, it is likely that they will be performed by operational centres. The JPI Climate will, however, promote joint projects that involve cooperation between the operational and climate communities and which support the production of "climate quality" reanalyses.

Establishing a network of comprehensive measuring stations

In Europe, there are few internationally leading environmental measurement stations that are specialised in measuring complex interactions between various ecosystems and the atmospheres. This process is important for achieving a comprehensive picture of the matter, energy and momentum budgets, and thus an enhanced understanding of the key processes in the environment and in the Earth system. These stations not only continuously measure energy and material fluxes, but can also provide continuous reference profiling of the atmospheric state and components of the hydrological cycle and thus be used to validate climate models and satellite retrievals. The basis for such a comprehensive station network could include stations such as Cabauw, Hyytiälä, Lindenberg, Payerne, Potenza and Pallas-Sodankylä. By establishing such a network of comprehensive measuring stations, JPI Climate could provide a platform (infrastructure) for research activities described in sub-module 1.3.

Collaboration and data exchange between observational and modelling communities

Enhancement of interactions between climate modellers and observational activities is urgently needed. Enabling joint training, workshops and joint projects and developing common methodologies, standards, metrics, and reanalysis would strongly improve this collaboration.

This would yield development of more useful observation products for modelling purposes and to enable better use of models to complement observations.

Long term research priorities

Securing the European structures for a long-term climate and Earth system

Strategies on securing long-term, integrated observing systems for the Earth system components need to be elaborated and implemented in a sustainable manner. Otherwise many initiatives may become short-lived and may not contribute efficiently to European Earth system monitoring. Moreover, the importance of quantifying patterns and trends of ongoing changes will increase as climate change progresses. The JPI Climate can play a key role by coordinating and optimising efforts on establishing long-term European observing networks that address the key components and key variables of the Earth system. In this way, the JPI Climate can support the European contribution to the international initiatives on observations (e.g. on GEO – Group on Earth Observations - GEOSS).

As observation and monitoring activities develop and additional data become available, appropriate efforts will be required to improve and enhance accessibility of data and interoperability. Data rescue, homogenisation and other activities, e.g. regular reanalyses featuring high-resolution, regional scales and coupled Earth system components, will also remain priorities.

Moving towards a socio-environmental information system

To meet our major environmental challenges, a robust socio-environmental information system that encompasses both natural and social features is needed for the future. This information system should be capable of combining data and knowledge gathered over centuries with new observations and a wide range of model results to support a range of integrated, interdisciplinary datasets, indicators, visualisations, scenarios, and other information products. An information system that ensures broad access to both past and future data, especially with regard to societal dimensions, is a long-term JPI Climate vision.

1.4 Links to other existing initiatives and networks/projects

1.4.1 EC projects

In the overall Module 1 research domain, collaboration within Europe has been supported by the EC since the First Framework Programme. Several projects are today supported by FP7 under the Environment and Infrastructure programmes.

The European Network for Earth System modelling (ENES) brings together the European network of global climate modelling groups and also some regional modelling groups. Several ENES-related projects are supported by the EC, for example, the ENSEMBLES project (FP6), now concluded, which included global and regional climate modelling, seasonal-to-decadal modelling, climate impact research as well as efforts regarding observation data. Other ongoing programmes are the COMBINE project (FP7) that focuses on the development of ESMs and simulations for AR5 as well as the EUCLIPSE project on the improvement of cloud parameterisation and model evaluation (FP7). IS-ENES is the infrastructure project of ENES (FP7) and concentrates on the objectives of developing a European climate modelling infrastructure. It is complemented by METAFOR (FP7), which is devoted to the development of international standards of metadata for CMIP5.

The COMBINE (FP7) and THOR (FP7) projects more specifically address the issue of decadal prediction and predictability. COMBINE is tasked with investigating initialisation methodologies and its results will support science that will contribute to AR5. THOR (Thermohaline Overturning – at Risk?) will establish an operational system to monitor and forecast the development of the North Atlantic Thermohaline Circulation on decadal time scales and assess its stability and the risk of a breakdown in a changing climate. The ice2sea project (FP7) focuses on projecting the effect of ice sheet mass balance changes on sea-level changes in the 21st Century and, in particular, investigates processes linked to potential ice sheet instability that are relevant on decadal to centennial time scales.

Many EC FP7-funded projects have been contributing and will continue to contribute to process-oriented research activities under JPI Climate Module 1. These include GHG-Europe – Greenhouse gas management in European land use systems; NitroEurope IP on the nitrogen cycle and its influence on the European greenhouse gas balance; EUCAARI IP on aerosol, cloud, climate, air quality interactions; and PEGASOS – the Pan-European Gas-Aerosol-climate interaction study, to name a few.

Several infrastructure projects support long-term observing networks. ESFRI projects - such as ICOS on greenhouse gases monitoring; IAGOS, on trace components in the troposphere; COPAL research aircraft; EURO-ARGO monitoring the oceans through Argo floats; and the integrated Arctic Earth observation system SIOS - are important infrastructures for the objectives of Module 1. They are complemented by many I^3 such as ACTRIS (Aerosols, Clouds and Trace gases Research InfraStructure network) (FP7) and EXPEER (Distributed RI for Experimentation in Ecosystem Research). GEOmon is an EC project contributing to GEOSS by building an integrated atmospheric system for observing greenhouse gases, reactive gases, aerosols, and stratospheric ozone.

The PAST4FUTURE (FP7) project will provide more detailed knowledge on past decadal variability and enable evaluation of models using observations of the past. The FP7 reanalysis project, ERA-CLIM, will provide important information for model evaluation and analyses of climate variability.

1.4.2 International programmes/projects

The activities under Module 1 are wholly relevant to the objectives of the ICSU (International Council of Science) and the Five Grand Challenges identified in the Earth System visioning process. The JPI Climate can be regarded as a European-level implementation of the ICSU Grand Challenges, which address climate-change issues. The JPI Climate also relies on valuable work previously carried out over many years and decades by the international global change programmes such as WCRP. Particularly notable programmes include the CLIVAR programme, which centres on present, past and future climate variability; GEWEX, which focuses on global energy and water cycles; SPARC, which addresses stratospheric processes and climate; and IGBP with its many relevant core projects, including PAGES (Past Global Changes) for past climate, iLEAPS, focussing on land-atmosphere interactions, IGAC, concentrating on atmospheric composition, and AIMES - an Earth System synthesis and integration project encompassing integrated modelling activities.

Moreover, WCRP organises major international, coordinated modelling experiments such as CMIP5. It includes coordinated global simulations for past, present and future climate conditions to improve model evaluation and provide the basis for climate change studies. Another international collaboration now underway is CORDEX – the largest ever coordinated regional climate downscaling programme that covers several regions of the world and provides key support for improved assessment of regional impacts. The JPI Climate acknowledges and will benefit greatly from the above-mentioned international activities.

2 RESEARCHING AND ADVANCING CLIMATE SERVICE DEVELOPMENT

2.1 INTRODUCTION

The climate science community finds itself increasingly exposed to various groups of stakeholders asking rather specific questions about consequences, uncertainties, probabilities related to climate and climate change. These stakeholders are decision-makers from industrial and other private enterprises, various policy arenas and planning disciplines as well as highly-trained scientists using the data for impact research and applied research. These various categories of "users" are affected by the physical, ecological, economic or social consequences of climate change in very different ways. This corresponds to a wide variety of "user needs" ranging from information on temperature, humidity, wind speed and solar insolation (relevant to for example, building codes or energy consumption) to information relevant for controlling the risks of hazards caused by extreme weather events, communicate climate sensitive health or disease issues, or enable financial service providers to fulfil their tasks in the assumption of economic risks. Even within an individual sector, information requirements may differ significantly depending on the type of users, the types of risks taken and time horizons considered. Hence, many requests for 'Climate Services' need to be resolved in a problem-oriented approach in direct interaction with the stakeholders involved. As a result, Climate Services will be a two-way exchange: not only will climate information be provided to users. But users will influence the development of Climate Services and the underpinning research by defining their needs and developing specific requests for Climate Services. The wide variety of user needs means that a Climate Service must draw on information from multiple disciplines, not just climate science.

Many member states are developing their own Climate Services capacity, sometimes even with multiple providers per country. Each provider is using its own methods/approaches to provide data and information, even though all services are actually based on the same core information (climate models, climate observations, climate scenarios etc.). Contrary to much of the climate research that generally involves a lot of international cooperation, the work on Climate Services is generally organised on a national level. Hence, we find duplication of efforts and a significant degree of inconsistency. Consistency at a European level would be relevant with regard to data availability, improved tool/methods development and for cross-border issues.

There are different definitions of Climate (change) Services, which is a consequence of the wide variety of stakeholders and their differing needs, as well as of the differing functions of the organisations that deliver Climate Services in each country. In some countries Climate Services are being delivered by meteorological offices, whereas other countries (e.g. German Climate Service Center and the US NOAA) are encouraging a more interdisciplinary approach. In each European country the Climate (change) Services are defined somewhat differently. The definition of Climate Services which has been agreed and adopted for the discussions in this JPI is given in the box below.

Definition of Climate Services:

User driven development and provision of knowledge for understanding the climate, climate change and its impacts, as well as guidance in its use to researchers and decision-makers in policy and business.

To stand up to the challenges of developing and delivering Climate Services "in support of human action and adaptation to regional climate change" (Belmont Challenge) in Europe we need to tackle four issues of scientific research and learning in networks:

2.1.1 Improved data availability

The actual value of a Climate Service depends on a number of factors. An important factor is the availability of data. Climate scenarios, essential for Climate Services, describe the likely changes in climate compared to a reference situation. Observational data are essential for the development of climate scenarios and the deployment of Climate Services, yet they are not freely available in each European country, which could provide a barrier to the advancement of Climate Services in Europe.

2.1.2 Better tools/methods for providing Climate Services

Each method used to estimate future climatic conditions for specific regions and periods has its strengths and weaknesses, for instance due to particular underlying assumptions. These limitations are of great significance, but usually they are neither transparent for the users nor sufficiently communicated and assessed. On the other hand, the climate knowledge required to answer the questions of a user is rather contextual. In many cases the complexity of climate model simulations makes it difficult to link them up to existing risk management and policy instruments. Thus, relevant climate knowledge must not only be made available, but also processed/tailored so that decision-makers and impact researchers are empowered to use and act upon this information.

Climate scientists also find themselves challenged to assist decision-makers and impact researchers in understanding the inherent uncertainty and picking the optimal tool for their needs (which could be climate projections, but also more qualitative decision-making tools) as opposed to merely tailoring climate information to meet customer expectations. Currently, several/some of these tools/methods used for Climate Services are developed at national scales and/or the use of the various tools/methods is strongly influenced by the national setting. Developing joint products, methodologies and standards where appropriate or necessary, would help establish systematic exchange and improve the quality of tools and methods, by "peer review", for example.

2.2 Consistency in cross-border settings

Cross-border issues (for instance management of river basins, mountain areas or coastlines) provide a good example of the importance of collaboration and the development of joint products, methodologies and standards. A collaborative approach must be taken to data availability, the development of climate scenarios, an understanding of the strength and nature of the impacts of climate-related events on human activity as well as the nature of the uncertainties involved to arrive at comprehensive and consistent Climate Services in cross-border settings.

2.3 Two-way exchange on climate knowledge

A Climate Service will have to encompass more than the delivery of descriptions of climate data, it should also provide guidance related to the information provided (e.g. interpretation of tables, maps, texts, etc.), the uncertainties associated with it (presenting a map of one climate scenario, for example, does not communicate the information about uncertainties), as well as provide decision support tailored to the needs of the user. In some cases, users will not be aware of how their organization could be affected by climate change, what risks they face, and therefore what information is needed from a Climate Service to help them in their decision-making. On the other hand, the demands of users are expected to become more sophisticated. For many users in the UK, descriptions of climate are insufficient and there is already demand for tailored climate knowledge as well as information on uncertainty, vulnerability, extreme events, thresholds, climate impacts and adaptation options. Prospective Climate Services therefore will have much more to draw on multiple disciplines to be able to convey to users the full range of impacts of climate change, including environmental, social and economic impacts. It should also include elements for consumer-driven products and services which are developed to communicate climate change information and its uncertainties in an objective way to non-scientists, with a clear orientation to the questions that are relevant to the users.

A Climate Service will have to be science-based, but it should contain a strong component of user needs-studies, translation of climate and climate impact data for users and decision support. Thus it will be a two-way exchange: not only climate information to users but for users to inform future research and development of Climate Service and products by defining their needs and developing specific requests for Climate Services. We therefore share the basic definition of Climate Services given in the box above.

2.4 Components and key objectives

In the context of the above issues JPI Climate aims to meet a structural demand across Europe for Climate Services by two following components:

2.4.1 Research component into the development and deployment of Climate Services

The research will be to help develop Climate Services (in a generalized manner, not to support an operational Climate Service), e.g. in understanding user-needs: What information is required to answer those needs, how best to communicate to users particularly around issues such as uncertainty, and how to systemically include stakeholder needs into the development of Climate Services. It will also include economic and political research into the effects the different degrees of commercialization of Climate Services, accessibility of climate data and quality control (not precluding the right of any countries to choose one policy or another). The priority areas for this research component are explained in the subsequent section 3.

2.4.2 Network of Climate Service providers, who can exchange knowledge and share learning

The priority areas for this networking component are explained in section 2.4.

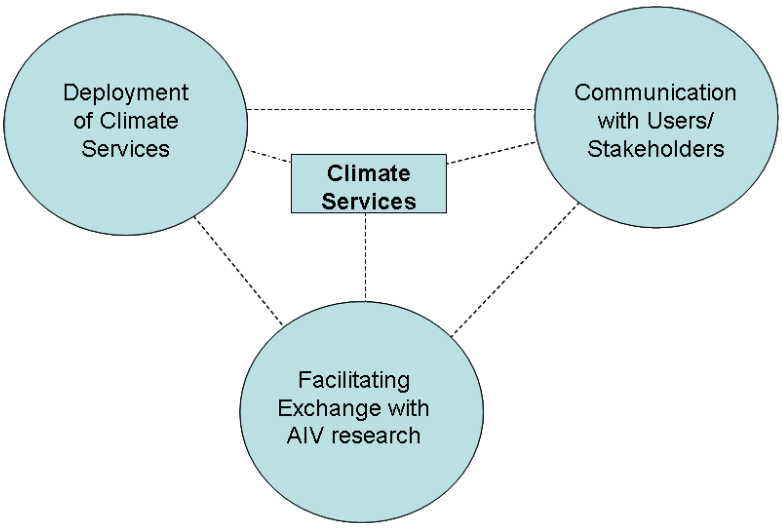
Both components are considered within the expert group to be essential, complementary and urgent to assure the **key objectives** to:

- Improve/enhance the efficiency of the planning and deployment of Climate Services in the individual European countries
- Improve/enhance consistency in the methods/approaches used by the Climate Services in the individual European countries

- Improve/optimise the quality of Climate Services
- Avoid duplication in the development of tools/methods/user inventories
- Improve the communication of climate knowledge to end-users and experts using data for impact research and applied research.

2.5 Research priorities

Developing and delivering Climate Services requires a multi-disciplinary approach – bringing together information and expertise from different research communities: fundamental weather/climate research, climate impact, adaptation and vulnerability research ("AIV research"), as well as economics, political sciences, psychology, and communications. There are a number of research issues/challenges that are relevant and need to be addressed in the path toward the development and deployment of Climate Services. Every member state is encountering similar research needs in this respect. The three areas of priority joint research are depicted in the following graph.



2.5.1 Development and deployment of Climate Services

There is a variety of ways how to govern Climate Services that are both, a matter of exchange of experiences within an European network of Climate Services, and a matter of scientific research in social sciences: How do countries structure its Climate Services? What are the strengths/weaknesses of each model? What structure and mechanisms are effective and efficient in delivering Climate Services and enabling a two-way research? Priority areas of research concern the economic effects of different degrees of commercialisation, accessibility of climate data and mechanisms for quality control.

Commercial versus non-commercial approach

A high degree of openness in the sense of institutional experimentation is probably going to be beneficial for an effective public-private partnership in the delivery of Climate Services, with each country making different choices regarding how to handle the economic and social opportunities offered by Climate Services. The alternative between a purely commercial approach by Climate Service Providers or a completely public service will have to be evaluated within the scientifically established tool set of economic and policy analysis based on national circumstances and lessons learnt. The consequences of relying on the private sector and commercialisation of outputs of public-funded climate knowledge will also have to be analysed. In this case, it will also be necessary to analyse the possible incentive-compatible mechanisms for private providers of Climate Services to establish quality standards.

Data accessibility

The activity of the Climate Services is crucially dependent on data, both from observations and numerical climate scenarios. This initiative will have to investigate possible forms of cooperation and sharing that may lead to the successful development of Climate Service products. The approaches will need to protect data authorship and ownership, but at the same it will be necessary to remove barriers that prevent an effective exploitation of climate information. Though every member state will decide their own data policy, it will be important to explore all possibilities to reach a common data policy so that a fair, competitive and innovation-driven level playing-field is established.

Quality control

If multiple agents are going to deliver climate scenarios or other climate information as Climate Services, users require a guidance system so that they are able to judge the relative quality of the service they are getting. If a private Climate Service organisation develops a tool/product, it is important to provide users and the business itself, with some ways of judging the quality. Quality indicators and protocols will have to be developed and standardised across the European Union to provide a uniform measure of skill and capacity. However: how do you define good quality in Climate Services? Is it possible to have a 'European standard' of quality for climate information? Is a certification process desirable and how it could be delivered – would national meteorological offices offer 'training' in using climate projections which confers quality standard? What would certification mean for liability? How could this be used to approach cross-border issues?

2.5.2 Communication of climate knowledge to end-users

Climate Services will have to be delivered by developing a two-way interaction between the service and the users in order to encompass the needs of different user groups with different climate sensitivities and to ensure the Climate Service provides information in a format that is easily understood and facilitates decision making. What methods and tools are most effective at communicating information about future climate change, its impacts and the associated uncertainties? What kind of representation (diagrams, video, animations) can be used to communicate information about climate? Can we develop tools on how best to do risk mapping? How to communicate uncertainty associated with climate projections, whilst enabling decision-making (i.e. not freezing people into inaction)? The three most general needs are: understanding the needs of users, understanding their 'key vulnerabilities' to climate change, the development of tools/methods for communicating climate information and enhancing decision-makers' ability to deal with the inherent uncertainty of climate knowledge.

Understanding user needs

As mentioned earlier, user needs concerning climate/climate impacts data can differ considerably, even within the same sector. User needs can also change in time. Therefore a continuous dialogue between user groups and Climate Service providers is needed to ensure users have appropriate information and to shape climate research in directions which will provide information relevant for users. Where relevant, reasons for failing to develop such sustained, informed engagement between users and providers in the past will have to be investigated, identified and corrected. Users groups in policy, business community and society in general will have to be identified and their specific needs analysed: What information on climate change/climate impacts/ extreme events/ vulnerability /adaptation options do different user-groups require? What format should that information be in to facilitate operational decision-making (e.g. number of days with a temperature exceeding a specific threshold)? What 'quality' of information do users need to make a decision? Reality is that there will be incremental changes in what science can offer but that decision-makers want 'best estimate' information now; how can the gap between needs of decision-makers and what science can offer be narrowed?

Identifying 'climate sensitivities' associated with decision-makers activities

What methodologies can be used to undertake 'climate sensitivities' research with decision-makers? How can we best help organisations to understand their vulnerability to climate change and their 'coping capacity' and which climate data they need for this? What are the 'relative vulnerabilities' of regions and sectors of society/business?

Tools/ methods to communicate climate information

How present climate information in a format that will facilitate decision-making? What methods and tools are most effective at communicating information about future climate change, its impacts and the associated uncertainties? What kind of representation (diagrams, video, animations) and learning models can be used to communicate information about climate to those just learning about climate change and what impact it might have on them? How do Climate Service providers combine information from different disciplines (e.g. climate science and social research) to support decision-making?

Communication of uncertainties

How should a Climate Service communicate probability and uncertainty in climate projections and climate impacts to users? How do users understand the data and information presented in text, tables, maps, etc. How do users interpret probabilistic information, uncertainties, risks? How can we use information about "framing" to improve communication?

2.5.3 Improving the interface between climate research and its application

Climate Services are strongly based on science that is often at the cutting edge of our efforts. Methods and protocols will have to be devised to facilitate the exchange of data and expertise from fundamental weather/climate researchers to applied research in adaptation, impact and vulnerability ("AIV research") and to operational Climate Services.

Improving the interface between climate and climate impacts research

Improving the interfaces with AIV research aims to mobilise, translate and integrate any knowledge from meteorological research, specifically the ones developed in this JPI, for applied research in the fields of AIV. It aims to shorten the time from research to application and to quantify reliability and skill. It will also communicate and integrate research being conducted in JPI water and agriculture for the core purpose to support communities of stakeholders (including the research community) in making better choices in the face of climate change. Research in Module 2, therefore, will by any means be trans-disciplinary and integrative with regard to facilitating exchange of natural sciences, social sciences and local knowledge.

Improving the interface between research and Climate Service providers

What mechanisms to ensure Climate Services is a two-way exchange (i.e. user-needs shape research)? How do we connect multi-disciplinary communities? How do we ensure newest research is available to Climate Service providers?

2.6 European Network of Climate Services

In order to avoid duplication of efforts and picking on differences in the quality and nature of information being provided from country to country there is a need for a certain degree of consistency of approaches and quality assurance. This is why this Module 2 is also aimed at cooperation between countries within Europe and joint research on and for Climate Services. Encouraging or enhancing permanent cooperation can not be reached by individual short-term collaborative projects, but requires long term commitment. Standardising approaches across Europe for Climate Services would be (at the moment) a step too far, considering the current differences in organisational structures in the various countries and the different scientific opinions on certain approaches, etc. Therefore, it is more appropriate in this early, experimentation phase of the development and deployment of Climate Services that this initiative focuses on the development of a network to share information, tools, case studies, experiences and means to improve Climate Services. The "European Network of Climate Services" (ENCS) would comprise a network of Climate Service providers addressing issues that are going to be more and more relevant as the development and deployment of Climate Services starts everywhere. The purposes of a "European Network of Climate Services" would be to:

- Identify common issues (e.g. urban heat island effect, air quality) or cross-border issues appropriate for joint research projects and initiatives
- Share information on user requirements in various groups of stakeholders and sectors
- Share information and experiences on Climate Services between member states - specifically in geographical regions with similar climate exposure and vulnerabilities
- Establish exchange programmes so that scientists and users can spend time in other Climate Services to experience and learn from others
- Establish a (web-based) forum where the Climate Service providers discuss issues related to the establishment of Climate Services (tools/approaches, communication, essential products, organisation, quality, etc.)

- Ensure that research from other national and international research programmes (e.g. CIRCLE-2 ERA NET) is 'plugged into' Climate Service development
- Initiate collaborative learning processes addressing the needs and limitations on both sides for providers of climate information and users from different sectors
- Set up trans-national cooperation structures for the consolidation and integration of approaches and methodologies for Climate Service provision, with a special focus on cross-border and pan-European issues
- Develop joint products, methodologies and standards where appropriate or necessary
- Establish systematic exchange of good practice
- Improve quality by "peer review" of the tools/methods/etc. by other Climate Services
- Develop links to a shared repository of information (e.g. EU Climate Change Adaptation Clearinghouse) which will guide users to information sources on climate change impacts, vulnerability and adaptation.

2.7 Short-term and long-term activities

The complementary scientific research and networking activities within this module can be decomposed into short-term in the next one or two years (up to 2013) and in the long-term activities in the next five or more years (up to 2016).

Short-term activities are:

User requirements: what is available already (national inventories, from the WMO, EUMETNET, etc.) and what can we learn from it (differences/similarities between countries)?

User requirements: What information do users need on short and long term (e.g. is information on extreme events likely to be short-term priority)? How similar/different are the users from different sectors? [This should lead on to the identification of priorities where information is needed – which should then inform future activities within this module of the JPI].

Mapping national Climate Services, i.e. a cataloguing of current Climate Services providers and their services/products/tools

Exchange of experiences with the help of cross-border case studies

General guidelines for some aspects of Climate Services (e.g. how use climate scenarios in various types of situations, what to do and not to do in communication about uncertainties)

Web portal for access to the Climate Services in various countries

Establish a network of Climate Service providers

Long-term activities are:

How to define and control quality of Climate Services

Defining standard/good practices for several aspects of Climate Services

Research into the effectiveness of Climate Services deployment

3 SUSTAINABLE TRANSFORMATIONS OF SOCIETY IN THE FACE OF CLIMATE CHANGE

3.1 Summary of the objectives of Module 3

1. Initiating interdisciplinary research to enhance the understanding of the social context (e.g. politics, economics, society, culture) of mitigation and adaptation responses to climate change in Europe and their impact on European social and economic development.

2. Stimulating research on societal barriers and incentives to respond to climate change, including the role of climate knowledge in public and/or private decision-making processes, given that climate change might also open up new opportunities.

3. Enabling integrated analyses of international, national and regional response strategies by identifying and considering socio-ecological and socio-economic limits and opportunities of mitigation and adaptation strategies, while taking into account other global sustainability challenges.

4. Developing and implementing integrated socio-ecological evaluation criteria for sustainable transformation scenarios and processes, both from a European and a global perspective (e.g. social justice, welfare, satisfaction with quality of life).

5. Supporting an integrated view on the societal impacts of climate change, also in relation to other global change trends.

6. Developing governance strategies, involving governments, businesses and NGOs, for sustainable societal transformations on the regional and (supra)national levels.

7. Facilitating transdisciplinary exchange on the objectives, the framework conditions and the realisation of sustainable societal transformations towards "carbon neutral", adaptive and climate-proof European societies through interaction and joint initiatives with stakeholders as knowledge partners.

3.2 Overview

The growing body of knowledge on climate change, its causes and consequences is not matched by an equivalent understanding of the societal challenges it poses. This encompasses the societal transformations necessary to confront climate change and develop sustainable and equitable production patterns and lifestyles, while at the same time maintaining or raising the quality of life within Europe and on a global scale.

Given the multiple interrelations between societal responses to climate change, other global change processes as well as other societal and environmental mega-trends, research on sustainable transformations of society is an inherently interdisciplinary[1] endeavour. Given the normative underpinnings of the formulated need for sustainable transformations, understanding, developing and implementing social and economic responses to climate change requires transdisciplinary research and action.

3.3 Research needs and directions

If societal complexity is not well understood, even the most rational solutions to climate problems can fail. Socio-cultural realities and decision making are based only to a certain extent on a rational perspective. Socio-cultural realities and decision making mirror different rationalities and are driven by political reasoning and a variety of self-serving interests. Even if a superior goal may be widely accepted, it is not self-evident that individual or collective action will be in agreement with that goal. In fact, climate change is to some degree the outcome of a social dilemma, where individual and collective rationality conflict. In order to develop feasible response strategies, climate change thus needs to be conceptualised in its social dimensions.

For a long time, climate change research has been predominantly conducted in the fields of natural sciences, with increasing interest in technological innovation in the last few years. Only very recently, research has started to address the social science perspective on the challenges of climate change in the fields of economics, environmental policy and planning. This JPI module fosters this recent research strand of conceptualising climate change from a societal perspective, including its economic and cultural dimensions. Moreover, climate change is but one out of a number of other inter-related trends of global change. Sustainable pathways directed to mitigation and adaptation efforts need to take these interrelations into account, such as the risk of coping with one challenge at the costs of others. The JPI module stresses the need to cover such systemic interrelations through integrated, interdisciplinary approaches. In this context, it is relevant to address and elaborate the issue of 'societal transformations' in integrated assessments, model and socio-economic scenario comparisons, where it has been

[1] **Interdisciplinarity** refers to the need for research collaboration among different scientific disciplines. In **transdisciplinary** research collaborations, additionally, non-scientific stakeholders are involved as equals in terms of mutual learning among science and society.

largely excluded in the past. This represents a specific European contribution to these research streams.

Climate change implies a wide range of social, economic and political impacts that call for active and effective transformative responses of stakeholders on different levels of politics, the economy and civil society. The research in this module aims to identify and understand the drivers and obstacles of societal transformations to a carbon neutral, “climate proof” and adaptive Europe[2]. Although the future orientation of European societies and the pathways by which they get there will differ according to specific traditions and characteristics of individual societies, a shared positive vision of such a society and a shared understanding of possible pathways to get there is essential. Research in this field is to be accompanied by considerations as regards the practical implementation of such pathways of sustainable transformations of society. For instance, the notion of an open transformation in contrast to a planned transition from state A to B needs to be explored.

Although this JPI module is conceptualised with a clear focus on Europe, the processes and impacts of climate change appear on a global scale. Climate impacts elsewhere trigger responses in Europe as much as decisions taken in Europe contribute to climate impacts elsewhere. The JPI research aims to take these spatial, as well as temporal, interdependencies into account and thus takes an integrated approach.

Sustainable transformations of societies in the face of climate change challenge research in two respects: In contrast to climate change, being first of all a process defined from a natural science perspective, its impact and the responses necessary to maintain and improve societal well-being extend into the sphere of social sciences. This is the social dimension of climate change. The aspired sustainability of societal transformation reminds us that climate change is just one among several processes of global change influencing the well-being of people and that the outcomes of societal responses to these processes are inter-dependent. This is the systemic dimension of climate change.

3.4 The social dimension of climate change

Climate change impacts depend as much on climate variables as on characteristics inherent to the exposed system. Successful responses to the challenges of climate change require scientific insights on both expected and potential impacts of climate change and their consequences on societies and economies as well as a thorough understanding of conditions and resources for innovative response strategies. In this respect it is important to assess and understand varying perceptions and interests that exist in Europe concerning processes of climate change and differing media representations of the issue of climate change. These differences include perceived impacts, coping with uncertainties, risks, benefits and significance of climate change,

[2] as described in the EU White Paper on adaptation

the appropriate action (now and in future), the willingness to pay and change to avoid risks, and the willingness to accept risk.

In addition to individual perceptions, responding to climate change is also intimately linked to institutional, political and cultural change. This calls for research into the societal preconditions of transformation processes. Learning about climate change is a far-reaching and multifaceted project that involves next to policy-makers all strata of civil societies. In order to facilitate feasible response strategies, climate change is to be conceptualised in its social dimensions. Such research needs to take into account the diversity of societal and individual perspectives and thus allow for stakeholder participation in terms of transdisciplinary social research.

The mere complexity of societies means that a comprehensively managed transformation process is unlikely. This particularly holds true when anticipating controversies, conflicts and rebound effects. In fact, it is highly probable that conflicts will develop when concrete measures are to be adopted to establish pathways of sustainable development. Climate change can add to existing conflicts or trigger new ones. Conflicts arise as climate change and climate policy challenge production and consumption patterns, everyday routines and interests vested in infrastructures, technologies and institutions. These can be related to incoherent objectives between and within social systems, arising from incompatible values, interests and knowledge claims. Conflicts can be expected as a result of differences in perception and interpretation, different views on the fairness of burdens, liabilities and legitimacy. Conflicts may also be related to the implementation and the concrete means of meeting sustainability objectives. Finally, they may be related to power relationships and differing degrees of vulnerability.

In order to govern a process of sustainable societal transformation, it is important to be aware of framework conditions constituted by the cornerstones of working democracies. These involve moral and ethical choices, aspects of equity, social justice, human rights, conflicts of interests, contested knowledge claims, sharing responsibilities and risks. As a consequence, research efforts are required to expand existing insights on the governance of climate change adaptation and mitigation. Implementation deficits in “imperfect future worlds” call for examination. A broad range of possible policies are of interest as boundary conditions for any mitigation and/or adaptation scenario. It is also important to understand what can be learned from history. Social sciences thus constitute an integral part of this JPI module in order

- ...to understand the varying societal perceptions and attitudes to climate risks and opportunities given uncertainty and controversy
- …to identify the social, cultural and economic roots and the conditions (enablers, inhibitors) of societal response to climate change and innovations in terms of sustainable transformation of European societies in the face of climate change.

- ...to analyse and prepare for societal conflicts, possible benefits and governance challenges which are to be induced by both climate change impacts and mitigation policy measures,
- ...to anticipate socio-economic development trends (e.g. population growth, technological developments, effectiveness of government institutions) as a context for climate change response strategies.

Social sciences are also strong in addressing procedural aspects of societal transformations. Investigations into the determinants of societal transformations are required both at the individual and social aggregate level, including the role of private and public organisations and rationalities in decision making and the interaction between both. This raises questions about how to shape responsibilities and understand the distribution of risks as well as potential benefits. It will also highlight problems of policy integration and coherence as well as institutional dimensions of transformation processes.

Finally, climate knowledge is subject to complex societal framing processes that give meaning to this knowledge and shape problem perception. These framing processes need to be studied as part of the policy process in order to help improve communication strategies and means to shape stakeholder interaction.

3.5 The systemic dimension of climate change

Societies are constantly evolving and responding to different challenges of which climate change is but one. Facilitating mitigation and adaptation to climate change need to be an important facet of those transformations – societal transformations in the face of climate change need to be addressed in the context of other transformation drivers and trends.

The regional drivers and impacts of climate change are linked to a complex and global socio-ecological system characterised by feedback processes, delays, uncertainties and indirect effects. Climate impacts elsewhere trigger indirect impacts in Europe while European lifestyles trigger climate impacts in other world regions, now and in the future. For instance, GHG emissions in China relate to European consumption patterns (exported emissions). Research contributions need to consider spatial as well as temporal interdependencies. In this respect potential positive effects and the unequal spatial distribution of climate impacts also need to be taken into account (e.g. global warming is likely to have positive effects on agriculture in temperate Europe over the coming decades, whereas effects are projected to be detrimental in parts of tropical Africa).

Social, economic and environmental sciences will play a key role in exploring the indirect effects of climate change, including interactions with other drivers of global change such as biodiversity loss, human interference with the nitrogen cycle or soil degradation. These interdependencies can also refer to societal phenomena such as migration from so called climate hot spot regions, and their consequences. Sustainable transformation pathways of

Europe in the face of climate change need to consider the multi-facetted, systemic impacts, societal multipliers and mitigating effects and interdependencies between Europe and other regions.

Feasible socio-technological strategies to respond to climate change in terms of sustainable societal transformations require assessments of the capacities of renewable and non-renewable resources, their production dynamics as well as the absorbing and recycling capacity of sinks. To be able to cope with the multi-dimensionality and interrelatedness of climate change, feasible socio-cultural response strategies require assessments of existing environmental management and policy instruments as well as individual factors related to adaptability, such as beliefs, practices, rules and socio-economic demands.

3.6 Key objectives

Europe has taken a lead in the global efforts to reach an agreement on climate change mitigation and adaptation and intends to continue to do so. It aims to establish Europe as a best practice example of a sustainable society with a high quality of life. Hence, it is a question of credibility, but also of Europe's future societal and economic stability to demonstrate that high quality of life is achievable in a carbon-neutral society with significantly reduced resource demand and usage. Besides these societal efforts to mitigate human-induced climate change, quality of life will also depend on societal capabilities and improved climate risk management to cope with the inevitable consequences of already ongoing climate change.

The European Research Area (ERA) has the capacity to make important contributions to facilitate sustainable societal transformations in Europe in the face of climate change. Research in this module explores the pathways from carbon intensive, unsustainable lifestyles to a carbon neutral, "climate-proof" and adaptive Europe. It aims to identify and understand the drivers of and obstacles to a sustainable transformation of society. The future face of European societies will follow different pathways to sustainability that will differ according to specific traditions and characteristics of individual societies. However, a joint European effort to develop visions of transition and to understand possible pathways promises to be much more successful than individual attempts. The development and understanding of sustainable pathways needs to be accompanied by considerations on the practical realisation of the pathways, including practical examples of how they might be implemented, in order to contribute to effective societal transformations.

The objective of sustainable transformations in Europe confronted with climate change has implications for both the thematic foci of this module (research objectives) as well as for the modes of knowledge production (research principles).

3.7 Research objectives

- **Understanding the transformation of European societies in a global context:** Although the JPI module is conceptualised with a clear regional focus on European societies, the processes and impacts of climate change appear on a global scale. Climate impacts elsewhere trigger indirect impacts in Europe, while European lifestyles trigger climate impact in other world regions. JPI research takes these spatial and temporal interdependencies into account and contributes to globally sustainable developments in Europe.
- **Understanding the systemic dimensions of climate change**: Climate change is one of the grand challenges of European and global societies. It is, however, only one among other, inter-related drivers of global change. Sustainable pathways directed to mitigation and adaptation efforts need to take these interrelations into account to avoid the risk of coping with one challenge at the costs of others. JPI research enhances the understanding of the complex societal roots, the systemic interrelations and consequences of climate change.
- **Understanding the social dimensions of climate change**: Knowledge on physical-climatological processes and impacts of climate change is a prerequisite for triggering and directing societal response strategies. Nevertheless, this is not sufficient to realise societal transformations. In order to facilitate sustainable response strategies, climate change needs to be conceptualised in its social dimensions. JPI research contributes to integrating the social sciences in the mainstream of climate change research and supports the integration of climate and societal scenarios.

The formulated objectives have implications on the research priorities as well as the research principles.

3.8 Research principles

- **Integrative and interdisciplinary research**

  The JPI module addresses climate change as a complex socio-ecological challenge. Activities within this module reflect the multi-dimensionality and interrelatedness of this challenge and through interdisciplinary research collaborations avoid oversimplification of research frameworks. In this respect the formulated research questions run across disciplines, motivating researchers to come up with integrated insights.

- **Targeting Society**

  Societal decision-makers are the ultimate target group of the activities within this module that trigger social learning processes towards a carbon neutral, "climate proof" and adaptive Europe. Thus, suitable modes of knowledge production are needed. The active involvement of stakeholder groups in these activities in terms of transdisciplinary research dialogues assures that the activities meet societal knowledge demands and provide researchers with societal system-, target- and transformation knowledge[3]. Research funding needs to consider new measures to support this kind of research adequately.

- **Reflexivity and transparency on normative propositions**

This JPI module is based on the rationale of a carbon neutral, "climate-proof" and adaptive Europe that is related to two normative settings: (i) there is a need for societal transformations and (ii) societal transformations ought to be sustainable. In order to avoid the danger of top-down social engineering, an active and transparent reflection of these propositions is required within the activities of this module. This links up with the above-formulated principle of knowledge co-production in science and society.

3.9 Research priorities

The research priorities of Module 3 are closely linked to the research principles presented above. They are formulated in two complementing directions: **central analytical perspectives** are represented by theoretical concepts and methodological approaches, considered suitable and promising to guide research toward the research objectives of Module 3. Complementary to these perspectives, **key research problems** have been identified in terms of critical bottlenecks of knowledge to societal transformation and concrete sustainability challenges related to societal transformation. Each research priority – opening up to various research questions – can guide the development of specific research activities. The dimensions are interlinked as, for example, a certain process can be looked at from various perspectives.

Research in Module 3 explores new modes of knowledge production and contributes to social learning. Module 3 derives its specific strength from the close connection with the other modules in the JPI. Overall, Module 3 aims at enhancing the connectivity of knowledge between disciplines (interdisciplinarity) and beyond, by bridging between science, society and policy (transdisciplinarity).

3.9.1 Societal capacity to respond to climate change – drivers and inhibitors of adaptation and mitigation

Central analytic perspectives:

- Cultures, values, ethics, risk perceptions
- Behaviour change
- Role of different actors, institutions and networks

[3] CASS / ProClim (1997). Research on Sustainability and Global Change – Visions in Science Policy by Swiss Researchers. ProClim – Forum for Climate and Global Change: Berne.

- Role of human-nature relations
- Role of knowledge and science
- Role of individual and collective capital (e.g. social, financial, symbolic, cultural)
- Trade-offs, synergies, conflicts and co-operation
- Agendas and societal frames, re-framing, assumptions, underlying story-lines, educational paradigms
- Modes and strategies of communication

Key research problems:

- National, regional, local, organisational and individual response capacities (e.g. resources, commitments, responsibilities) in the face of climate change impacts (adaptive capacity) and climate policy measures (mitigative capacity); mechanisms for mobilising these capacities
- Causes for mismatch between public awareness of anthropogenic triggers of climate change and the perpetuation and spread of carbon intensive modes of production and consumption (e.g. priority setting and significance of climate change)
- Causes and consequences of climate-scepticism
- Effects of incoherent societal (e.g. political, economic) objectives and performance indicators (e.g., climate change impacts and GDP)
- Research on the potentials and problems of behaviour change at societal and individual level

3.9.2 Governance of sustainable transformations

Central analytic perspectives:

- Modes of governance: integrated governance and existing governance schemes, multi-level governance, policy coherence, internationalisation of governance and state concepts
- Science-policy interfaces
- Power relations: spheres of influence and decision-making power, conflicting interest groups
- Democratic governance, participation, legitimacy and transparency
- Policy cycle analysis and evaluation (developing adaptive policies under conditions of uncertainty)

Key research problems:

- Coordination of bottom-up initiatives in climate policy in the absence of top-down agreements and connectivity within fragmented governance systems (e.g. role of federalism); allocation of responsibilities to public and/or private actors
- Governing climate change within liberal democracies in a free-market world (e.g. assessment of the effectiveness and transferability of existing instruments)
- The role of the politics-administration interface in policy implementation
- Synergies and trade-offs of climate governance and economic, financial or trade policies
- Research on combinations of mitigation and adaptation policies and practices aimed towards a carbon neutral, "climate proof" and adaptive Europe
- Role of stakeholder's frames and contested knowledge in decision-making processes
- Governing uncertainties

3.9.3 Sustainable responses to climate change

Central analytic perspectives:

- Integrated research on socio-ecological, complex problems and on policy formulation and implementation
- Integrated assessments and comparison of climate change adaptation and mitigation pathways and strategies
- Direct and indirect impacts of climate change and rebound effects of mitigation and adaptation.
- Forces and processes leading to mal-adaptation and mal-mitigation

Key research problems:

- Socio-ecological and socio-cultural limits and resilience of climate adaptation and mitigation strategies (e.g. limits of rare earth metals as constraints for energy efficiencies, societal paradigms as constraints for alternative solutions etc.)
- Trade-offs and synergies among climate change policies and other global change policies (e.g. biodiversity and arable land, demographics, digitalisation of society, urbanisation)
- Interdependencies between the causes and impacts of climate change in Europe and impacts in global climate change hot spots
- Definition of system boundaries and their implications for assessing the sustainability of response strategies (e.g. winners and losers of response strategies)

- Links between direct and indirect impacts of climate change (e.g. impacts on ecosystem services) and unforeseen consequences of these (e.g. for the quality of life). Rebound effects of mitigation and adaptation.

3.9.4 Transformation studies and scenarios

Central analytic perspectives:

- Sustainable transitions and transition management
- Path dependencies and path-breaking
- Real-life experiments, case-studies and historical research on societal transformations; multi-level analysis of transformations
- Unintended side-effects (rebound effects) of transformation pathways and processes
- Strategies for managing climate risks and societal innovation processes

Key research problems:

- Developing and exploring socio-economic response scenarios for Europe as contributions to the "new" socio-economic scenarios used by the IPCC
- Lessons learnt from past and ongoing societal transformations on different scales and in different sectors
- Development of positive societal visions, transformation scenarios and pathways towards a carbon neutral, "climate proof" and adaptive Europe
- Examination of the role of values, framings, power differences, economic and political interests
- Research on innovation processes (triggers for innovation and creativity and dissemination in societies)
- Exploration of synergies with research on post-growth economic concepts and integrated approaches towards social justice, prosperity and well-being.
- Identification of key practitioners, pioneers, forerunners and individuals and institutions as change agents.

4 IMPROVING TOOLS FOR DECISION-MAKING UNDER CLIMATE CHANGE

4.1 OVERVIEW

Response to climate change is likely to require structural transformations. Decisions will need to be taken to trade off the climatic consequences of different stabilisation levels of greenhouse gas concentrations with costs, risks and benefits of development pathways consistent with reaching these levels. Also, aspects of equity and effort-sharing will continue to pervade negotiations at a European as well as an international level. Finally, there are still large uncertainties on climate change patterns and risks, making decision-making more complicated, both for mitigation and adaptation.

These processes require analysis of a range of climate response strategies with their implications being communicated in transparent and intelligible ways. Advanced assessment models and scenarios are essentials tools and metrics for provision of both mitigation and adaptation analyses. Scenarios and scenario-based tools have demonstrated their utility for multi-layered analysis of connections between temporally and spatially distant developments and phenomena. They are designed to track complex interrelations between social and natural systems and also to help understand the underlying forces driving systems' dynamics and projecting its trajectories into the future. In this way they are offering tools for communication between and within the scientific and policy communities about appropriate responses.

Science as well as many public and private organisations and sectors have long-standing traditions in using such decision support tools and instruments, in which scenarios, models and other scenario-based tools play a key role. They are employed as learning tools and as support for planning processes to explore alternatives or the long-term and cross-scale consequences of certain developments or strategic decisions.

Considering the uncertainty in future climate change, "optimal" solutions are difficult to design, and it is necessary to select "robust" policies, i.e. policies that yield positive outcome in as many possible scenarios as possible. Decision-making tools can help make "robust" decisions based on a better understanding of risks and uncertainties, trade-offs and feedbacks as well as opportunities and interdependencies. Finally, these tools can assist decision makers on deciding what should be measured to achieve a desired outcome (since it is often what is measured that is managed).

This JPI module will focus on a European coordinated approach to develop a consistent landscape of climate and socio-economic scenarios and scenario-based decision support in Europe reflecting the perspective of global forces shaping regional and local processes and vice versa. For this purpose, it will focus on four areas of research:

(1) Categorising and communicating risks and uncertainties:

There are diverse user needs for scientific, technical and socio-economic climate change analysis. These evolve over time in response to a range of drivers but need to be framed in a manner to enhance and develop communication. The development of integrated climate and socio-economic scenarios - as pursued by this module – needs to be based upon and motivated by a sound common understanding of these user needs, to enable successful uptake of research results.

(2) Integrating global climate change analysis and assessment:

Global models and scenarios for climate change analysis have evolved into powerful tools for integrating knowledge and making it useful for exploring conditions consistent with managed long-run climate outcomes in a policy context. The JPI will support community efforts to increase integration and consistency of modelling and scenario communities while maintaining or increasing variety, innovation and excellence in global model and scenario development.

(3) Nesting scenarios at different levels:

Appropriate reflection of cross-scale dependencies in scenarios at different scales will be a precondition for well-founded and informed decision making in Europe. This requires a system of nested scenarios at different geographic levels. Therefore, this JPI underscores the need for the development of scenarios at the European or regional and country level consistent with global socio-economic and climate scenarios and linked to existing work on the development of emissions inventories and projections.

(4) Linking scenarios and decision tools:

Future decision support tools and instruments should be able to capitalise on a coherent and integrated landscape of climate models and scenarios at different scales. They need to be nested within a shared analytical framework in order to allow comparable assessments of key vulnerabilities, risks and uncertainties for regions and industries, societies and economies as well as globally linked value chains.

Key objective

This module will be catalysing the analysis of robust and sustainable development pathways through (1) bottom-up analysis of user needs in terms of key climate risks and uncertainties, (2) integration of climate scenarios, (3) nesting of scenarios on different scales, and (4) linking scenarios to tools for decision-making.

4.2 Objectives

4.2.1 Categorising and communicating risks and uncertainties

It is obvious that most of the wide range of potential users is not adequately prepared to interpret the complexity of model simulations and to understand the uncertainty attached to various scenario components. On the one hand such understanding needs appropriate categories that help identifying key risks and uncertainties of sectors or organisations to climate change. On the other hand it needs appropriate venues for two-way, cooperative and iterative communication processes that have to be sustained over a long timeframe.

Key objective:

Understanding user needs in terms of potential climate related risks and uncertainties that matter to different user groups and establishing effective and sustained communication processes between scenario communities and stakeholders on these issues.

4.2.2 Integrating global climate change analysis and assessment

The provision of scenarios which allow fully integrated assessments of the differential impacts, associated risks, residual damage, and marginal costs and returns of different development pathways remains a challenging goal. A focus within this module will be to support ongoing community initiatives that aim at bringing together modelling teams from different regions and disciplines to enhance integration, consistency and connectivity of various analytical approaches, including assessments of other global dynamics than climate change.

Key Objective

Support development of robust and inclusive global scenarios that are consistent with global assessments of climate change and enhance communication of these via increase interdisciplinary and trans-discipiliniary development within and outside the climate change community.

4.2.3 Nesting scenarios at different levels

Global models and scenarios are proven value-adding tools for strategic policy-making for mitigation and adaptation. They capture the technical, demographic and economic considerations related to transition strategies consistent with particular climate mitigation or adaptation objectives. However, too few of the other factors that influence the rate of transition, such as institutional and behavioural aspects, are reflected. These are strongly related to regional and local institutional regimes, cultures and value systems. Over the past few years, climate model (statistical and dynamic) downscaling methodologies have become more refined[4]. This needs to be complemented by sets of nested socio-economic scenarios for regions or sectors to support decision-making on mitigation and adaptation.

Key Objective

Stimulate the development of nested models and scenarios to increase linkages between top down scenario analysis to bottom up emissions analyses, independent scientific verification of analysis of emissions and sinks as well as vulnerability, impact and adaptation policy.

4.2.4 Linking scenarios and decision tools

Decision-making tools should enable users to take account of constraints imposed by the climate system as well as global ecological and societal systems. Just as the scenarios they refer to, they need to consider the dynamics of biophysical, social and economic systems in conjunction. This JPI will aim to make knowledge on best practice co-development of model and scenario based decision-making tools systematically available, in order to analyse the potentials and limits of the development of such tools with active stakeholder participation. It will foster meaningful science-practice interaction with the objective to increase the capacity

[4] This does not mean that research necessarily reduces uncertainties, but the processes underlying the uncertainties may be better understood.

of model and scenario communities to integrate knowledge and deliver results of high practical value.

> **Key objectives**
>
> Forster iterative dialogue between science and practice and provide decision support tools and instruments that are nested in a consistent scenario environment from global to local scales.

4.3 Research Directions

4.3.1 Categorising and communicating risks and uncertainties

There are a number of critical factors for the effective uptake of results from climate research: the ability of scientists to understand user needs, the ability of users to specify their needs and interpret related climate information, and the capability of both users and scientists to communicate about needs and limitations on either side. Experience shows that relevant climate knowledge needs to be contextualised and interpreted so that decision-makers are empowered to act upon this information. Climate change needs to be placed in a wider context of decision-making in which factors other than climate often play a dominant role.

For decision-makers, strategic response options are usually expressed in terms of risk governance, framed as one of many factors to be considered and measured in terms of impact and likelihood. The combination of these two factors has distinct implications, due to the inherent uncertainties of climate related risks. For example, a high-impact risk that is believed to have a low likelihood would appear the same as a low-impact risk with high probability in quantitative terms, but appropriate responses would be very different. Also, qualitative or cumulative risks are difficult to assess, while ratings of likelihood tend to be based on the assumption that something that has not happened in the past will never happen. These are standard pitfalls not necessarily specific for the management of climate related risks. But climate change poses new kinds of risks that should trigger a fundamental reassessment of risk management practice and the statistical basis it is predicated on.

Utility of scientific and technical knowledge on climate change depends on close interaction and effective communication between researchers and stakeholders to attain a common understanding of key risks and uncertainties. Integrated climate and socio-economic scenarios need to reflect the concerns of a variety of stakeholders, including politicians and elected representatives, private and public sector leaders, as well as scientific and non-scientific experts. Questions related to the costs and benefits of international greenhouse gas emissions reduction obligations are very much different from questions related to appropriate responses to local climate risks. It is certainly not a straightforward process to establish and maintain a dialogue which would allow the systematic charting of this domain. It will have to be facilitated by a reciprocal, cooperative mode of communication between science and practice. It will also have to include efforts to circumscribe distinct user groups and their decision making processes and contexts, while recognizing potential climate knowledge “value chains”. Successful science-practice interaction depends on improved understanding of the 'how' and 'why' of strategic decision-making – the institutional dimension of effective adaptation and mitigation – and the role of scientific knowledge in such processes.

This is a concern cutting across all elements of this Joint Programming Initiative, including Module 2, which will play a key role with respect to the communication of scientific results, and Module 3, framing decision-making on climate change as a process of social learning involving scientific, policy and practitioner communities. Climate models and scenario analyses as addressed in this module are very relevant instruments to integrate knowledge and explore possible outcomes of strategic decisions. Therefore, this Joint Programming Initiative aims to develop a comprehensive understanding of how to clearly communicate robust analysis and information as well as the associated risks and uncertainties. It also aims to identify the key actors in climate change, what kind of issues they currently face, how decisions are taken and how they are linked across scales and through institutions.

Research priorities

In various national research programmes efforts are underway to develop methods, scenarios and other tools in support of specific aspects of climate decision-making under uncertainty. A number of European research projects have analysed the potential climate risks for a number of sectors. However, these efforts are fragmented and not comparable, neither between the national projects, nor between the national efforts and European research.

The JPI will aim to consolidate such knowledge and foster new research on differentiated categories of risks and uncertainties that matter to stakeholders and at the same time provide useful elements for the framing of user-driven scenario development. This can also cover basic categories of spatial and temporal scales that practitioners find relevant for their work.

This initiative will also aim to identify key risk parameters to be quantified in terms of sector sensitivity to specific climate impacts and/or foster systematic and comparable risk exposure mappings on different scales.

This JPI will also endeavour to systematically explore the way companies, civil organisations, groups of citizens or individuals look at the problem of climate change, how they frame it and in which way their attitudes might influence individual or collective decisions. It will foster research into the mechanisms of transmission that allow new information on climate change pervading stakeholder groups, sectors or markets to be taken up in public or corporate decisions. Also, preconditions of traditional institutions need to be understood in terms of developing the interdisciplinary competencies and infrastructures to proactively address these issues.

This research is of cross-cutting relevance for the entire JPI. It will largely be facilitated by the promoters of Climate Services (see description of Module 2), because a deeper understanding of categories of climate-related risks and uncertainties as well as success factors for effective communication on the interface between science and practice is at the very heart of these services. Some of these issues will also be addressed through Module 3 of this JPI.

Module 4 will be complementary in the sense that it concentrates on the consistent relation between sectoral development plans and policies, risk governance schemes and tools, and existing models and scenarios. This includes the development of stakeholder driven, scenario based decision making tools and instruments useful for transforming climate knowledge into decision-relevant information (see 4.4).

Links to other existing initiatives and networks/projects

The understanding and mapping of user needs for climate information builds on and will consolidate and extend earlier work. For example, in the context of climate change impacts and adaptation, the PESETA study of the EU's Joint Research Centre analysed the potential climate risks for a number of sectors, namely river floods, agriculture, tourism, coastal systems study and human health. Follow-up work supported an impact assessment for the development of the EU White Paper on Adaptation, that focused on the role of water and ecosystems. Currently, ongoing work for the EU Commission involves the further development of methods to assess vulnerability and adaptation in water management and identify climate threats to agriculture and forestry, fisheries, regional and territorial cooperations and the physical infrastructure. This is work in support of the adaptation strategy that the Commission has planned for 2013. FP6 projects such as A-TEAM and ADAM led to early insights into possibilities to assess vulnerability to climate change and response options. The FP7 SCENES project developed scenarios for water demand and management, while other FP7 projects such as CLIMSAVE, MEDIATION, CC-TAME, CLIMATECOST and RESPONSES are also developing methods to support climate impact assessment and policy development. The IS-ENES project likewise aims to deliver a climate model service and support the dissemination of model results, which is particularly directed at the impact community as users of model results.

Furthermore, current activities within the ERA-Net "CIRCLE2" will provide a useful starting point and stepping stone for follow-up activities. A series of CIRCLE workshops will aim to frame the discourse on climate-related risks and uncertainties from a sectoral user perspective, starting with the simple observation that, to date, although a great deal of insight is available on a disaggregated level, much can potentially be learned from consolidating experience from different case studies. Hence, CIRCLE will primarily aim to provide an initial assessment of what is already known about climate-related risks and uncertainty in risk governance in different sectors. It will bring together analyses available on various scales in Europe relating to the sector-specific perception of climate related risks, concrete measures taken in terms of risk governance and tools employed.

Finally, this research priority will constitute a natural link to other JPI's, namely the envisioned JPI's on water, agriculture, urban development and the aging society.

4.3.2 INTEGRATING GLOBAL CLIMATE CHANGE ANALYSIS AND ASSESSMENT

Global scenario work can be classified in three types of models and analytic frameworks: climate models (CM), Integrated Assessment Models (IAM), and models and other approaches assessing vulnerability, impacts, adaptation (VIA). Global energy models which are used to analyse international mitigation are assumed to be captured under IAMs.[5]. These global scenario communities are working towards an integrated analytical framework. This process, within the scientific communities, has been catalyzed by the requirements of the IPCC's 5th Assessment Report .

The process draws on a set of "Representative Concentration Pathways (RCPs)" as common assumptions regarding radiative forcing. However, a specific level of radiative forcing can result from different combinations of economic, technological, demographic, policy and institutional futures. This is why the RCPs are envisioned to be complemented by "Shared Socio-Economic Pathways (SSPs)", in order to allow VIA and IAM communities a comprehensive coverage of the range of key assumptions in these fields. These SSPs could be a set of simple narratives consistent with a lean set of quantitative projections for socio-economic boundary conditions structuring the space of plausible socio-economic futures.

[5] Please note that the JPI will not enter into the field of assessing individual technologies for mitigation, though such assessments are supposed to be reflected on an aggregate level by the assumptions underlying socio-economic scenarios.

The scientific infrastructure to carry out the work largely exists (established modelling teams, centres and platforms) including a high level of coordination within the CM and IAM communities. Although coordination is mainly being implemented within these communities, there remains a distinct lack of both interdisciplinary exchange between these communities as well as trans-disciplinary exchange with the various stakeholders that require climate information for policy making, planning or investment decisions. The VIA research is still not very well coordinated, although at the global level UNEP has taken the initiative to change that through PRO-VIA (Programme of Research on Climate Change Vulnerability, Impacts and Adaptation). While JPI Climate does not intend to include actual VIA research, it will play a supportive and catalyzing role in developing a better coordination between national as well as European VIA research[6], because better coordination would be necessary to reach the JPI's objectives in terms of integrated scenarios.

Also, coordination is needed between scenario makers and users, to make scenarios more relevant for actual decision-making and policy design. There is clearly a lack of resources so far to drive and coordinate the process of scenario integration at a pace and level of ambition necessary to deliver timely information to all parts of European society for the highly dynamic field of climate policy and strategic decision making.

This JPI will aim to stimulate further interaction and integration of communities engaged in global climate and socio-economic scenario development, both for the 5th IPCC Assessment Report as well as beyond. And it will encourage interaction of these communities with other global modelling communities analysing questions of e.g. trade, transport and infrastructure development, population, development, health or food.

The value of the controlled comparison of model results and analysis of model differences has been widely recognised especially by the CM and IAM communities, though to a lesser extent in the field of vulnerability, impact and adaptation research. The harmonisation of key assumptions (RCPs, SSPs) and the controlled variation of those assumptions across an ensemble of studies or a set of model comparisons, constitute important initial stepping-stones on the path towards analytical framework integration, in particular when employed to examine single-subject matters of high practical concern.

Such analyses enhance the connectivity of various approaches and modelling communities by harnessing the collective capacities of a variety of experts for the purpose of finding solutions to real problems. Systematic model inter-comparison can provide a scientific apparatus to

6 A role that might be strengthened in case the ERA Network CIRCLE would not be continued after 2013.

investigate possible transformation trajectories under different (normative) assumptions. It can generate a deeper understanding of the underlying reasons for certain model outcomes and may allow qualified estimations of uncertainties. Furthermore, it enables discussion on the practical consequences of integrated policy integration scenarios, particularly where policy fields overlap, intersect or contradict and strategic planning is not straightforward.

Short-term research priorities

The global SSPs are likely to be finalised by the middle of 2011 and then taken up by researchers working on more specific regional or sectoral impacts and response options. There little time left to derive a more integrated insight from new scenarios to enhance the quality of the 5th IPCC Assessment Report (AR5). The report will be published in 2014. Any literature to be considered formally in the report needs to be published by 2012.

For this purpose and as part of this JPI, the development of a set of model comparison projects in envisaged, fast track activities designed to challenge different modelling teams to generate tangible outcomes from a European perspective for AR5. The results should be instrumental in catalysing low-emission development pathways that are robust in terms of uncertainties in the climate as well as in socio-technological systems. Meaningful subjects for model comparison include:

- Investigation of the possibility of very low stabilisation scenarios consistent with the 2°C or even a 1.5°C limit of global warming, including second best policy solutions
- Improved capacity of standard economic models to generate more realistic policy scenarios (including appropriate representation of the EU regulatory framework);
- Models to enhance the understanding of the dynamics of urban development and infrastructure and their role in shaping future climate change;
- The establishment of a joint analytical framework of assumptions for energy and economic models, that will enable differentiated but consistent model development at all relevant scales (European, national, sub-national).
- Limits of adaptation in different terms, e. g. economic/financial, institutional/political, cultural / social;
- Possibility of reaching thresholds or tipping points in the climate and socio-economic systems and the subsequent consequences, including risks and uncertainties regarding the stability of societies.

- Assessment of the propagation of uncertainties through different types of model, including the question on how to link probabilistic information from global models and scenarios to impact models that are not capable of processing such data.

One element research strategy element will be the extended comparison of IAM of EU provenance with IAM developed by teams from the US, Japan, China and possibly India, in collaboration with the Stanford Energy Modelling Forum. Another element should engage the services of different VIA teams to compare existing representative models or case studies to try and jointly draw general practical conclusions that support, for example, adaptation policy making. Systematic comparison should become a viable investment in enhancing comparability and consistency of VIA analyses and moving towards a theory of adaptation. JPI Climate would provide a sustained platform to facilitate such comparisons.

Comparison of climate modelling experiments is not going to be supported primarily through this module – such comparison is well-organized under a series of inter-comparison exercises, like CMIP5 of the World Climate Research Programme (WCRP), and rather linked to Module 1 of this JPI.

Long-term research priorities

The JPI will endeavour to support CC, IAM and VIA communities in their commitment to a long-term research strategy that aims at developing an integrated framework for climate scenarios. Such scenarios should enable the assessment and quantification of key risks and uncertainties, damages and benefits, as well as include improved and more consistent cost estimates for climate mitigation and adaptation. The scenarios should also encompass non-monetary valuation methods to quantify damages not expressed in changing market values (such as welfare implications from ecosystem change).

In addition, leading modelling teams from both IAM and VIA communities should be challenged to perform policy instrument assessments within their standard models by exposing these to other formalised and non-formalised assessments of the same policy instruments (carbon tax, emission trading schemes, technology subsidies etc.). The outcome should allow conclusions to be drawn regarding the effectiveness and design of policies as well as the strengths and weaknesses of individual modelling approaches. It should also pave the way for improving the integration of policy aspects into scenarios.

Finally, integrated global change scenarios are to be developed that provide a sound understanding of risks and uncertainties related to various possible climate futures and are consistent with plausible trajectories in key areas (e. g. socioeconomic, technological and environmental conditions, greenhouse gas and aerosol emissions and climate).

Links to other existing initiatives and networks/projects

Any ambitions to integrate global climate change analysis and assessment need to be mindful of the fact that there are plenty of scenario development and comparison projects and processes underway. For example, the Energy Modelling Forum is spearheading such community driven efforts and is accumulating valuable knowledge on how to set up a viable dialogue between scientific and non-scientific experts.

The project "Assessment of Mitigation Pathways and Evaluation of the Robustness of Mitigation Cost Estimates (AMPERE)" is funded under the FP7 and will establish a common platform dedicated to climate-economics modelling research activities in Europe. It will addresses uncertainties in the quantification of climate change mitigation costs. Performed by a consortium that includes 17 partners from Europe and 4 from Asia, part of the portfolio will encompass model development, validation, performance assessments and inter-comparisons. The impact expected is akin to some of the objectives of this JPI; namely, a better quantification of the costs of climate change mitigation, increased consistency in cost-related information for policy making and high-quality input for international assessments including the 5th IPCC report.

Generally, community activities designed to develop common ideas and guidelines to foster consistency and integration of climate scenarios across different scales are very relevant reference points for the implementation of this module.

These activities not only include community driven activities set up in support of the 5th IPCC assessment report, but also initiatives such as PRO-VIA (Programme of Research on Climate Change Vulnerability, Impacts and Adaptation), proposed by UNEP in order to redress the lack of organisation and coordination within the VIA community.

These and other activities need to be systematically mapped and regarded as important starting points for this module.

4.3.3 Nesting scenarios at different levels

Narrative storylines and socio-economic scenarios of development pathways that focus on trends at international system and large region scales need to provide enough flexibility for interpretation at more detailed scales or consistent links to scenarios developed for regions or sectors. It should be acknowledged that scenarios are always developed for specific purposes, and sets of nested, integrated scenarios should explicitly be developed to address specific climate policy questions posed by the stakeholders.

For example, many VIA studies, analysing the robustness or performance of different locally- or sectorally-relevant adaptation strategies, tend to use locally-derived scenarios that reflect development choices on a respective level. These need to capture a sufficiently large range of plausible futures and be embedded in a broader context of plausible socioeconomic or climate futures and consistently represent the global forces shaping local conditions in terms of climate policy objectives as well as climate change impacts, vulnerability and adaptation.

Equally important, key policy decision makers are highly focused on the GHG inventories reported annually to the Commission and UNFCCC. Such reporting requirement have generated highly detailed activity and process models which are applied to key economic sectors and areas such as energy, transport and land use. Information from these systems are the key determinant of achievement of emissions targets and key drivers of sectoral and cross sectoral policy development at national and local levels.

There is a shared objective across Europe to move the GHG inventories, which are effectively coarse national sectoral and systems models, from the use of default information to science based emissions models. This is required to reflect policies and measures which would otherwise be missed in accounting, trading etc.. This work shall be assisted by pan-European research as many issues are similar across Europe. Individual or collective emission targets need to be scientifically robust and where possible independently scientifically validated.

The ongoing scientific development of these systems is essential for improved policy and adequate accounting and verification of these at international levels. Mismatches between top-down scenario analysis and bottom up emissions and emissions projection analysis can be problematic for all levels and in worst cases lead to misguided policy development.

Scale differences, thus, constitute a fundamental challenge for different kinds of models and scenarios and research is required into make scenarios useful and translating relatively coarse information of global scenarios into the relevant geographical scale. In particular, impacts as well as socio-economic and emissions variables specified at relatively large spatial scales need to be translated to values at country or grid level.

Developing nested socio-economic scenarios is not only a prerequisite for informed decision making. It also constitutes a grand methodological challenge. A number of national, regional and local studies have been undertaken based on global scenarios that attempt to translate their assumptions into smaller spatial resolutions. Each approach has revealed its strengths and weaknesses relative to specific fields of application. Obviously, there is no single best technique identifiable as different approaches work better for different needs. Methodology and the choice of methods need to be transparent enough that the communities readily recognise the technique available for their particular need.

For the above reasons, even though it is desirable to advocate for a variety of methodological approaches, European integration calls for a consistent and coordinated way of translating global socio-economic scenarios transparently and reliably for different regions and sectors in Europe and to develop a comparable, overall European picture. This will need to be linked to dynamical and statistical methods for downscaling climate models that are increasingly utilised to produce regional climate information for impact and adaptation studies. It will also support the pursuit of more consistency in terms of facts and figures relating to climate change in the European countries, and also pay due attention to free scientific data exchange within Europe.

Research priorities

All member states will soon be confronted with the challenge to assess the specific regional implications of the new set of scenarios generated as input for the AR5. The JPI will target development of coherent sets of regional, national and European scenarios by the expert community within the participating countries of this JPI. This will be a big step forward compared to the fragmented and uncoordinated approach in the past. But there is clearly a lack of resources and structural support for coordinating this work at a scale necessary to produce coherent and timely output for climate policy and strategic decision making across Europe.

This JPI will provide the means to support, continue and expand the development of nested scenarios. Besides being able to build on experience drawn from a number of FP7 projects, examining the potential of up-scaling successful national approaches to the European level would also be possible (one example might be the so called 'climate effect atlas' developed in the Netherlands). Comparison and assessment of the strengths and weaknesses of different methodological approaches will also be organised to develop a consistent set of climate and socio-economic scenarios. The shared methodological knowledge will be employed to develop a consistent and coordinated set of scenarios at resolutions relevant to meet different regional and sectoral concerns in Europe.

Furthermore, this JPI will serve to enhance research co-operation in movement of bottom-up analysis to higher scientific levels as well as the provision of independent scientific verification of analysis of emissions and sinks. It will provide platforms to increase linkages between top down scenario analysis through nested modelling to bottom up emissions analyses.

Analysis of such issues will also be fostered through module three. The social scientific research can be useful to gain qualitative insights into the validity of general assumptions which are often not explicitly addressed in global scenarios. It may gain policy relevance if linked consistently with the integrated scenario work.

Links to other existing initiatives and networks/projects

European teams are making important contributions to the downscaling of global scenarios. It is a clear advantage in this context that the community working on downscaling issues is already very well organised through the World Climate Research Programme's Task Force on Regional Climate Downscaling (TFRCD). TFRCD has set up a framework called the "COordinated Regional climate Downscaling Experiment (CORDEX)" which endeavours to improve coordination, quality and coverage of international efforts in regional climate downscaling research.

There has also been a small number of national initiatives to develop national or regional socio-economic scenarios within the context of the previously developed sets of global scenarios at the time of IPCC's earlier assessment reports (for example those being pursued in the Netherlands or Finland, the success of which should be followed and evaluated to incorporate lessons learned into other national initiatives). Similar initiatives are currently under preparation with a view towards the new global scenarios.

Nesting of scenarios also holds a number of methodological and conceptual challenges, the resolution of which is of direct practical relevance for e.g. European adaptation strategy implementation and mitigation policies, for example. It will be important to assess the potentials of up-scaling advanced national scenario approaches to a European level and equally important in this respect to review experience drawn from FP7 projects like ADAM and RESPONSES as a starting point for the development of a research portfolio. The PLUREL project funded under FP6, which comprises 31 partner organisations from 14 European countries and China, is another point of reference, particularly with respect to regional adaptation of scenario storylines and modelling data derived from scenario modelling at higher scales. The project started in 2007 and terminated in 2010.

4.3.4 Linking scenarios and decision tools

A useful set of model-based tools will acknowledge the procedural character of assessment and strategic planning, e. g. through participatory approaches with stakeholders. They will enhance learning about the probability of future effects of current behaviour and at the same time teach us the limits of our ability to predict. This is assuming that any likelihood may simplify decision making and any kind of prediction, even about uncertainty, may help buy time to learn if expressed in terms of probability. It is important to note that the role of scientific climate information differs in different areas of decision-making under uncertainty. While science can provide directly useable information to underpin decision-making for long-term issues, its role would be much more limited with regard to decision-making on shorter term questions

A general observation is that stakeholders are extremely interested in the derived consequences and impacts from changes in climate. The link of climate scenarios and Integrated Assessment Models with VIA research and analysis becomes very relevant in this respect. But equally challenging is the development of tools linking relevant climate related information to other sources of information that need to be taken into account in relation to specific decision making.

Utilisation of such tools depends on improving the customisation of information from climate change analysis through continuous science-practice interaction and dialogue. In addition to the integration and nesting of climate models and scenarios, fostering this kind of interaction will be one of the major undertakings of this JPI and will require incorporation into its design at numerous stages. This module, however, sets out to research priorities related to the methodological progress towards tools and instruments that enhance the capabilities of practitioners and decision-makers to identify and quantify direct and indirect climate change risks to corporate planning, operational processes, public policies or sectoral economies and develop suitable risk governance.

Short-term research priorities

The JPI will contribute to assembling the joint experience in this field of interactive development of model- and scenario-based decision making tools and instruments in the diverse European countries. It will aim to analyse how such tools and instruments can be linked consistently to interpretations of integrated climate scenarios at different levels of scale. It will commence by defining more clearly the possible role of differential stakeholders (change agents) in building scenarios and how they might interact with scientists and it will analyse the potentials, barriers and limits of common learning processes.

Long-term research priorities

The JPI will aim to establish science-practice laboratories as continuous and common learning environments for modellers and stakeholders. They should facilitate interactive development of innovative decision-making tools to improve decision processes in specific sectors under conditions of high uncertainty and complexity.

Depending on social contexts as well as spatial and temporal scales of decision processes, such tools will have to meet different requirements in terms of robustness, error-friendliness, redundancy, diversity, integration, fuzziness and 'decision spaces'.

A major undertaking of these science-practice labs would be the application of various modelling approaches to specific problems of practical concern and the comparison of their explanatory power relative to providing solutions to the problems in question. Such approaches would start by analysing and defining the actual decision-making concern and evaluating the actual capabilities of a model in this respect. It would then compare available models and define what would have to occur to enable them to provide solutions to the decision-making problem.

This process would lead to identifying the methodological and conceptual gaps as well as data requirements that would need to be addressed by the respective communities. It would also facilitate progression towards one - or competing – concept(s) that would frame decision making under climate change in terms of how decisions are taken, what information counts and what methods are best suited to communicate this information.

A practical approach would suggest linking the science-practice labs to different policy fields, including:

a) *Effective management of greenhouse gas emissions* linked to country-level targets consistent with sub-national targets and measures, at sector or city level, for example.

b) *Risk governance and adaptation policy* linked to EU policy objectives and processes, translated consistently into national or sub-national strategies, and linked to other policy fields in terms of mainstreaming, synergies and conflict resolution.

c) *Opportunities and innovation management* with a market-based perspective.

While stewardship of any such lab certainly needs to be with a small number of high profile, lead institutions in Europe, the scope of contributing partners could be very broad, depending on the topic under investigation. The labs should aim to harness the collective capabilities of participating experts from Europe and beyond, coequally including modellers and users of models within the enquiry process. They would also provide a scientific apparatus to investigate sectoral plans and strategies under different sets of assumptions. The results should catalyse low-emission development pathways and adaptation strategies that are resilient in terms of uncertainties in the climate as well as within socio-technological systems.

The implementation of these science-practice labs will require a long-term and strategic funding perspective that allows for failure and iteration. Additionally, it will require continuous strategic support of community-driven processes that target the integration and appropriate scaling of knowledge as well as the differential understanding of user needs for climate information as described previously in this module.

Links to other existing initiatives and networks/projects

The multitude of relevant initiatives and activities make it difficult at this stage to define such long-term activities without more extensive consultation of key players and stakeholders. Such consultation would be in the form of transparent and open processes in collaboration with existing platforms and organisations.

5 INTER-LINKAGES BETWEEN RESEARCH AREAS

Joint Research Area of Module 1 and Module 2:

There are multiple relations between the various areas of investigation outlined in each of the modules.

Results from decadal prediction, as well as from global and regional climate change projections, including abrupt nonlinear responses, provide needful information for a wide range of policies and practitioners. An improved understanding of the processes that govern natural climate variability over the decadal time horizon and the assessment of decadal predictability at regional scale, constitute crucial requirements for the climate services community. Such activities specifically address the space (regional) and time (decadal) scales that are extremely relevant for the design and implementation of the adaptation strategies.

Developing interaction between climate modellers and climate services will help define the data needs for users, from both observations and models, and identify uncertainties of climate predictions and projections. It will identify those climate processes relevant for the climate service community that are not sufficiently resolved by the current models. Such interactions will improve the availability and utility of both model and observational data suitable for the quantification of these processes.

Notwithstanding, research results in Module 2 should be integrated into Module 1 research from the very beginning, with a special focus on those aspects that are of particular relevance for society, for example, physical thresholds based on adaptive capacities.

Joint Research Area of Module 1 and Module 3

Module 1 will document key climate phenomena of relevance to society such as extreme events and possible tipping points, which are then introduced into Module 3, and also provide data needed to understand societal needs in Module 3. Module 1 will also document the range of scenarios which impacts society. The strong regional focus on decadal prediction experiments will help and quantify the climatic drivers that locally impact on societal dynamics. Interactions with Modules 2 and 3 should help better understand how climate change results and uncertainties are perceived by a wide range of agents.

Module 3 will contribute to Module 1 by:

Identifying knowledge requirements from societal/decision-makers' and systemic-scientific perspectives, for instance with respect to socio-ecological impacts of climate change and constraints in mitigation strategies

Identifying societal reactions to climate change impacts and changes in the modes of production and consumption on various spatial scales as a basis for elaborate GHG emission scenarios

Generally dealing with uncertainties inherent to the results being produced by modelling and observation analysis.

Analysing and facilitating interactions between the different scientific communities of modellers and observers. Discussing research results on the natural variability of weather conditions and societal responses in the short- and long-term.

Exploring human climate interactions, such as land use issues and associated feedback.

Conducting research into possible contributions from studies on managing common goods, in terms of what insight can be derived from these studies in relation to dealing with impacts of climate change as global scale common good problems. Generally, it is desirable to have mutual collaborations based on a case study approach, whereby the two following examples are of interest.

Researching the consequences of reaching tipping points: for instance, a possible collapse or weakening of THC is currently widely discussed as one of a number of "low probability – high impact" risks associated with global warming.

Researching the different ways of how shorter-term (e.g. decadal) projections can be interpreted in societal contexts and implemented into actual decisions. A case study would probably have to choose a regional and/or thematic focus.

Researching relations between societal development and climatic conditions based on paleo-climatic analysis and analysis of current climatic development paths.

Researching the information needs of decision-makers, i.e. role of risk aversion, comprehensiveness and uncertainties of knowledge.

Joint Research Area of Module 1 and Module 4

Climate models developed in Module 1 will enable the investigation of possible mitigation strategies important for decision-makers. Interactions between the two modules may also emphasise methodological aspects for different kinds of modelling systems. Model intercomparison tools developed in Module 4 assist in the assessment of uncertainty propagation throughout the prediction system, from initialisation through the prediction models to societal response and the ultimate results. Specific studies on the mutual interaction between climate and anthropogenic drivers, and "laboratory studies" concerning drastic climatic events and the societal response, should be coordinated with Module 4. Expertise from Module 1 can help address policy issues such as geo-engineering technologies for mitigation.

Module 1 will provide access to important community driven initiatives in the CM community, which will need to be accessed and included when developing further integrated climate scenarios. In addition, increased prediction capacities will enhance the explanatory and projective value of scenarios and perhaps at some point become powerful in terms of defining the possibility space of transformation pathways.

Joint Research Areas of Module 2 and Module 3

- Understanding effective science-society communication and interaction. Explore ways of how to make communication and interaction with users more effective (latter priority M2).
- Exploring the role of climate knowledge and other motivators for decision making as input for the development of climate services and identifying the needs of knowledge users.
- Identifying key decision making/stakeholder groups for societal transformation in the face of climate change as potential climate service target groups.
- Exploring their possible roles as change agents and also reflecting on the extent to which scientists act may act as change agents.
- Establishing a learning community across Europe to promote a sustainable and adaptable Europe.
- Study on the potential for involving users in the further development of climate services. Gaining an insight into the use of climate services as a departure point for joint further development.
- Research into the governance of climate services as multi-institutional networks of organisations.
- Enabling of sustainable societal responses to climate change through climate services.
- Investigating optimal ways to create dissemination and outreach in terms of results.
- Development of long-term perspectives for social dynamics in the context of future adaptation strategies (priority M3).

Joint Research Areas of Module 3 and Module 4

- Outcomes of the systemic analysis of responses to climate change as constraints/framework conditions for the exploration of possible scenario and decision-tool ranges.
- Exploring the role of knowledge and other motivators as well as knowledge uncertainty for decision making as input for the development of decision-making tools.
- Integration of the rationales of real-world decision making into socio-economic scenarios
- Assessing and understanding the relevance of uncertainty from a societal perspective.
- Reflecting on the role of public policy.
- Research into the decision making processes and expected outcome of country negotiations at the COP (dynamic decision analysis).
- Integration of socio-economic scenarios and reflection of different models of society.
- Model inter-comparison exercises to systematically confront the basic assumptions, processes and outcomes of model building exercises.
- Advice and reflection on stakeholder participation in developing decision making tools.
- Action research using decision-tool prototypes; user-driven design.

Joint Research Areas of Module 2 and Module 4

Module 4 is driven by improvements in integrated impact modelling, not by the idea of servicing customers. The integration of stakeholder/decision-maker perspectives will therefore be an important element of M2-M4 interaction. For example, in relation to the question of how to deal with uncertainties in impact modelling. Stakeholder decisions are not always driven by research outcomes, but rather how well they meet user needs. We may require 'stakeholder-adaptable tools' for decision making and stakeholder feedback should certainly be included in the development of tools geared towards decision-maker target groups from the very outset. There is a societal need to compare integrated assessment models. Customers will also need an estimation of model quality and, wherever possible, the inclusion of validation procedures. Furthermore, M2 may well inform M4 of sector-specific threshold values or response capacities.

Module 2 is working on a perspective on climate services that will need to be central to any activity related to Module 4. Climate services are a crucial link and interface between actual stakeholder concerns and the scientific modelling and scenario communities. In turn, Module 2 will need to play a moderating and guiding role for the entire JPI in terms of a differential understanding and mapping of actual user needs as well as regards key risks and uncertainties that matter to stakeholders. Besides scientific progress towards the integration of approaches, much of Module 4 should help efforts in climate service development to enhance scientific community capacities to deliver services of high practical value.

Thus, there is clear reference to a number of concerns emanating from the discussion on climate services: for example, the need to downscale from global climate models to regional and then to local impacts; understanding natural variability and uncertainties in climate projections; the need for quality control; and the definition of guidelines for consistent climate scenarios to enable consistent comparison of different results from different models.

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