# Mistra SWEdish research programme on Climate, Impacts and Adaptation (Mistra-SWECIA)

## Programme Plan

31 October, 2007

# Introduction

## *Programme title*

Mistra SWEdish research programme on Climate, Impacts and Adaptation (Mistra-SWECIA; SWECIA)

## *Programme Board*

Chair:

*To be designated.*

Members:

*To be designated.*

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## *Period for which funding is awarded by Mistra*

1 January, 2008 – 31 December, 2011 (4 years)

## *Summary*

SWECIA is an interdisciplinary research programme on climate, impacts and adaptation, extending and transcending earlier disciplinary research within climate science, biology/ecology, economics, and social sciences. The Programme will raise a new generation of Swedish interdisciplinary scientists, create a common climate-economics-impacts modelling framework and assessment capacity, to provide useful decision-support to users. The Programme will also advance the international research frontier on climate change, economics, impacts and adaptation.

SWECIA's starting point is that even though mitigation will take place, further climate change is unavoidable, and that the impact on societies and the environment brings about a need for adaptation. Mitigation and adaptation are linked in the sense that under any given socio-economic development, more mitigation implies less adaptation and *vice versa*. So far, however, research has emphasized mitigation rather than adaptation. The current mainstream mitigation research is not easily extended and translated into adaptation as many of the issues and the stakeholders are different.

SWECIA will create a model-based capacity of assessment combining climate, economic and impact modelling into a consistent framework for studies that combine the global interactions with regional-to-local detail in targeted areas and sectors. To start with, the modelling components will consist of existing global and regional climate models, a global economic model with regional disaggregation, as well as hydrological and ecosystem services impact models. Step two will consist of Earth System Modelling on global scale, with enabled regional foci, of climate and climate impacts, as well as coupled climate/economic modelling. Ultimately, SWECIA will lead into a comprehensive modelling framework that allows for both climate and human feedback along the chain from socio-economic developments to emissions and land used to climate and its impacts back to socio-economic developments to emissions and land use… and so on.

SWECIA's model development will include targeted efforts on certain improvements and refined scenario analyses. The application of SWECIA models will run throughout the Programme period, leading into a stream of climate, impact and socio-economic scenarios to users. Special attention will be paid to making these scenarios available to users. The users will also be involved in the planning and design of the scenario and analysis efforts.

SWECIA will certainly not just be a modelling programme. It will look into the adaptation process itself, focusing on learning from past and present success stories and on identifying bottlenecks in adaptation. These issues are interesting in themselves, but they will also help keep the SWECIA research agenda relevant to users and put the results to practical use in promoting anticipatory adaptation to reduce risks and seize opportunities. These efforts centre on regional and sectorial case studies run with the full interdisciplinarity of SWECIA. To begin with, the case studies will focus on the Stockholm region and the Energy Sector. Later on, additional regions and sectors will be targeted.

SWECIA will also reach out to a range of users by traditional means such as workshops, newsletters, scientific publications, internet sites etc. Moreover, special activities will be designed to reach out to international and national climate research and policy processes.

SWECIA is planned to run 10 years. This application focuses on the first, four-year, Programme phase. Useful results will emerge during this first phase. At the same time, a foundation will be laid for the efforts to be followed up during subsequent Programme phases.

## *Sammanfattning*

SWECIA är ett tvärvetenskapligt forskningsprogram som rör klimatprocesser, klimateffekter och anpassning till ett förändrat klimat. Programmet tar steget vidare från befintlig klimatforskning inom områdena meteorologi/oceanografi, biologi/ekologi, ekonomi och samhällsvetenskap. Programmet kommer att fostra en ny generation av tvärvetenskapliga forskare, skapa ett gemensamt ramverk för klimat, ekonomi och effektmodellering och en kapacitet för analys och utvärdering som ger användbara beslutsunderlag till breda grupper av avnämare.

Utgångspunkten för SWECIA är att även om åtgärder vidtas för att minska utsläppen så är en fortsatt förändring av klimatet oundviklig och leder till effekter på samhälle och miljö och därmed till behov av anpassning. Utsläppsminskningar och anpassning är sammankopplade genom att utsläppsminskningar leder till mindre behov av anpassning och omvänt. Hittills har forskningen huvudsakligen inriktats på utsläppsminskningar snarare än på behovet av anpassning. Den nuvarande huvudfåran av forskning kring utsläppsminskningar kan inte direkt omsättas till anpassning eftersom aktörer och frågeställningar delvis är annorlunda.

SWECIA kommer att skapa en kapacitet för analys och utvärdering som kombinerar modeller inom klimat, ekonomi och effekter av förändrat klimat i ett gemensamt ramverk. Programmet innefattar studier som inkluderar globala kopplingar med regionala och lokala detaljer och konsekvenser i specifika geografiska områden och sektorer. Inledningsvis består modellsystemet av existerande globala och regionala klimatmodeller, en global ekonomisk modell med regional detaljnivå såväl som modeller för hydrologiska konsekvenser och effekter på ekosystem och ekosystemtjänster. I steg två kommer modellsystemet att bestå av en global Jordsystemmodell, med en regional motsvarighet och utvecklade effektmodeller, såväl som kopplad klimat-ekonomimodellering. Ett slutmål är ett komplett ramverk och modellsystem för studier av återkopplingar inom och mellan klimatsystemet och samhället längs kedjan från socioekonomisk utveckling till utsläpp och markanvändning tillbaka till klimat, klimateffekter, tillbaka till socioekonomisk utveckling, utsläpp, markanvändning osv.

Modellutvecklingen i SWECIA kommer att innefatta riktade satsningar på modellutveckling och utvecklad analys av scenarier. Tillämpning av modellerna i SWECIA kommer att pågå kontinuerligt under programmet och kommer att leda till en ström av scenarier för framtida klimat, klimateffekter och socioekonomisk utveckling riktad till avnämare. Särskild vikt kommer att läggas på att göra scenarier och analyser tillgängliga till användare. Avnämare kommer också att engageras i planering och design av scenarier och i analysen av resultaten.

SWECIA kommer att handla om mer än modeller. Programmet kommer att studera anpassningsprocesserna i sig genom att fokusera på historiska och pågående åtgärder och på faktorer som hindrar anpassning. Studier av dessa frågor har ett egenvärde, men kommer också hjälpa till att styra forskningsinsatserna så att resultaten blir relevanta för användare och understödjer ett aktivt anpassningsarbete som minskar risker och utnyttjar möjligheter. Denna del av programmet inriktas på regionala och sektoriella fallstudier som utnyttjar SWECIAs hela tvärvetenskapliga bredd. Inledningsvis inriktas fallstudierna mot Stockholmsområdet och energisektorn. Senare kommer ytterligare regioner och sektorer att inkluderas.

Programmet kommer att kommunicera med breda grupper av avnämare genom workshops, nyhetsbrev, vetenskapliga publikationer, webbplatser m m. I tillägg tas särskilda initiativ för att bidra till internationella och nationella processer inom klimatforskning och politik. SWECIA planeras för en period av tio år. Denna ansökan är inriktad på den första fyraåriga programfasen. Användbara resultat kommer att produceras under denna första fas. Samtidigt läggs grunderna för fortsatta insatser som följs upp i kommande programfaser.

## List of acronyms

| | |
|---|---|
| ALADIN | Aire Limitée Adaptation dynamique Développement InterNational |
| AROME | Applications of Research to Operations at MEsoscale |
| CCSM3 | Community Climate System Model version 3 |
| CGCM | Coupled Global Climate Model (an atmosphere-ocean GCM, OAGCM) |
| CSF | Common Scenario Framework |
| DGVM | Dynamic Global Vegetation Model |
| EC-EARTH | A European Earth System Modelling collaboration |
| ECMWF | European Centre for Medium-range Weather Forecasts |
| EMIC | Earth system Model of Intermediate Complexity |
| ERA | European Research Arena |
| ERA-40 | ECMWF Re-Analysis of 40 years |
| ESM | Earth System Model |
| EU-FP4, 5, 6 ,7 | Fourth ($5^{th}$, $6^{th}$, $7^{th}$) Framework Programme of the European Union |
| GCM | General Circulation Model (a.k.a. Global Climate Model) |
| GHG | Greenhouse gas |
| GCTE | Global Change in Terrestrial Ecosystems (former IGBP core project) |
| GUESS | General Ecosystem Simulator |
| HIRLAM-A | European consortium for operational high-resolution numerical weather prediction modelling |
| IAM | Integrated Assessment Model |
| IPCC | Intergovernmental Panel on Climate Change |
| IPCC-AR4 | The IPCC fourth assessment |
| LLNL | Lawrence Livermore National Laboratory |
| LPJ | the Lund-Potsdam-Jena model |
| MCA | Multi-Criteria Analysis |
| MOLUSC | Model Of Land Use SCenarios |
| NCAR | National Center for Atmospheric Research, USA |
| NAO | North Atlantic Oscillation |
| NWP | Numerical Weather Prediction |
| OAGCM | Ocean-Atmosphere GCM (a.k.a. CGCM) |
| PDF | probability density function |
| RC | Rossby Centre |
| RCA | Rossby Centre regional (atmospheric) climate model |
| RCM | Regional Climate Model |
| RICE | Regional Integrated model of Climate and the Economy |
| SRES | Special Report on Emission Scenarios |
| TSF | Technical Standards Framework |
| UNFCCC | United Nations Framework Convention on Climate Change |
| VEMAP | Vegetation and Ecosystem Modeling and Analysis Project |
| WP | Work Package |

# Table of contents

# Part A

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# *1. Vision and objectives*

## 1.1 Vision and objectives

*Climate change is a forceful driver of global change, a serious environmental problem and a major obstacle to sustainable development. Advances in the science of climate change have uncovered how the world warms and that this global warming is almost certainly caused by anthropogenic emissions. Continued climate change is a near certainty due to past emissions and inertia of the world oceans, and is further compounded by the present and projected emissions. In addition to mitigation, adaptation will be an important means to deal with the problem of climate change. The purpose of SWECIA is to facilitate adaptation by means of scientifically sound integrated climate, impact and economic scenarios and research on the adaptation process. In particular, SWECIA will identify adaptation policies and support their development and application.*

International approaches to the climate change problem by mitigation aim at reducing emissions so that the atmospheric concentration of greenhouse gases (GHG) stabilises. How and at which level this will be achieved and the implications for the future climate are still unclear. What is clear is that future climate change, regional impacts and need for adaptation depend crucially on the precise path for future emissions. And that adaptation is, indeed, needed.

Mitigation and adaptation are closely connected. Even though both require regional and local action, the benefits of mitigation will accrue on the global scale, while first-order benefits of adaptation will accrue on the local and regional scales. Adaptation in some specific region can, of course, lead to secondary effects elsewhere. Moreover, mitigation and adaptation are often managed by different actors with different agendas and different budgets.

Knowing how the climate system responds to emissions is needed for both mitigation and adaptation. The more sensitive the climate system, the more urgent is mitigation. Uncertainties about this sensitivity shape the risks associated with alternative mitigation decisions. How global climate change will manifest itself in different regions sets the agenda for adaptation. Uncertainties about regional climate change and impacts thus affect the risks associated with alternative adaptation decisions. It goes without saying that adaptation, as well as mitigation, is intimately linked to economic development, the energy sector, technology, international co-operation, politics and our values.

Climate change is a global, regional and local challenge with links across these scales. To tackle this challenge better than at present, it is necessary to combine findings from natural science and social science. So far, research efforts have typically focused more or less separately on physical, biological, economic and social aspects of climate change. For example, in future emission scenarios, social and economical developments have been treated independently of climate change and its impacts. The resulting scenarios have been put through first carbon cycle and then physical modelling so as to arrive at climate scenarios and, thereafter, go on to impact analyses. In reality, there are interactions across all these systems, not the least because realized climate outcomes shape both human perception and action on mitigation and adaptation. The difficulty of establishing firm mitigation targets can perhaps be seen as an example of the consequences of fragmented knowledge. Similarly, the difficulty in managing adaptation bears witness of the inertia in human attitudes, as adaptation so far has predominantly involved reactive measures to experienced impacts, rather than proactive measures due to anticipated risks. As a result, proactive adaptation actions so far are few. To improve on this unsatisfactory situation, we need better knowledge about climate change, impacts, alternative strategies, and the dynamics of regional and local actors. Due to scale interactions in natural and human systems, regional and local action is always in need of a global perspective.

The Programme addresses the problem of adaptation by regional and local actors, under alternative global developments. In contrast to many other efforts, SWECIA centres on adaptation to climate change, framed in consistent and comprehensive knowledge about the climate system, impacts and socio-economic developments of importance. The Programme will also address adaptation to the impacts of proposed or decided climate policies.

The proposed SWECIA science will deal with

- Socio-economic change and climate change as well as climate impacts during a period from the next few decades up to the next few centuries, with a particular focus on regional and local changes, expressed as risks and opportunities, in probabilistic terms.
- The adaptation process at the level of individual actors including the perceived need, cost, benefits, and means of adaptation.
- The feedback between human and natural systems, explored with methods from different scientific disciplines, with a focus on climate change and vulnerability, while keeping in mind the wider concept of sustainability.

The purpose of the research will be to advance the international research frontier in each of the disciplines involved, as well as to create new cross-disciplinary science. The research will also advance the availability of decision-support by reducing uncertainty wherever possible and by unfolding unavoidable uncertainties. Throughout, the Programme will aim at creating comprehensive modelling capacity to advance the international state-of-the-art. This involves research on key climate and socio-economic processes, as well as an interdisciplinary effort to address the interaction between human and natural systems. More specifically, SWECIA will provide regional assessment of climate change, impacts, adaptation needs, obstacles, risks, opportunities and cost estimates based on a range of scenarios.

Summarising, the Programme will build on a global reference frame, but focus on regional and local adaptation needs, opportunities, processes and actors. The main attention will be on Sweden and Europe. A global reference frame is needed due to the global scale of the climate system, and the significance of the global socio-economic developments and emissions. It will be necessary to consider the developments of factors such as population and technology, and to assess how mechanisms such as development aid, risk sharing (insurance), migration and trade flows can facilitate adaptation in particular and build up sustainability in general.

## 1.2 Significance of the research in terms of solving important environmental problems

*SWECIA's research will significantly contribute to the management of climate change by means of adaptation. Indirectly, the results will also help define the mitigation agenda.*

In addition to addressing the feedback between climate change, biological processes, and socio-economic development, SWECIA's main added value will be to provide deeper insights into the need and possibilities of adaptation. This is a novelty, given that mitigation and adaptation are hardly jointly considered by decision-makers. Nor is there a global consensus on a balance between mitigation and adaptation. Decision-makers involved in mitigation and adaptation often have different agendas and manage different budgets. But climate policy is not a zero-sum game. Higher spending on mitigation does not imply less funding available for adaptation. Most industrialised countries have committed themselves to national policies on mitigation with specific short-term targets, although the long-term targets remain rather fuzzy.

However, no mitigation effort, no matter how rigorous and relentless, will prevent climate change from continuing in the next few decades, due to the long lags in the global climate system (*e.g.*, Friedlingstein and Solomon 2005). As the first impacts of climate change are being observed, it is no longer a question of whether to mitigate climate change or adapt to it. Both types of action are essential in reducing the risks of climate change (see Figure 1).

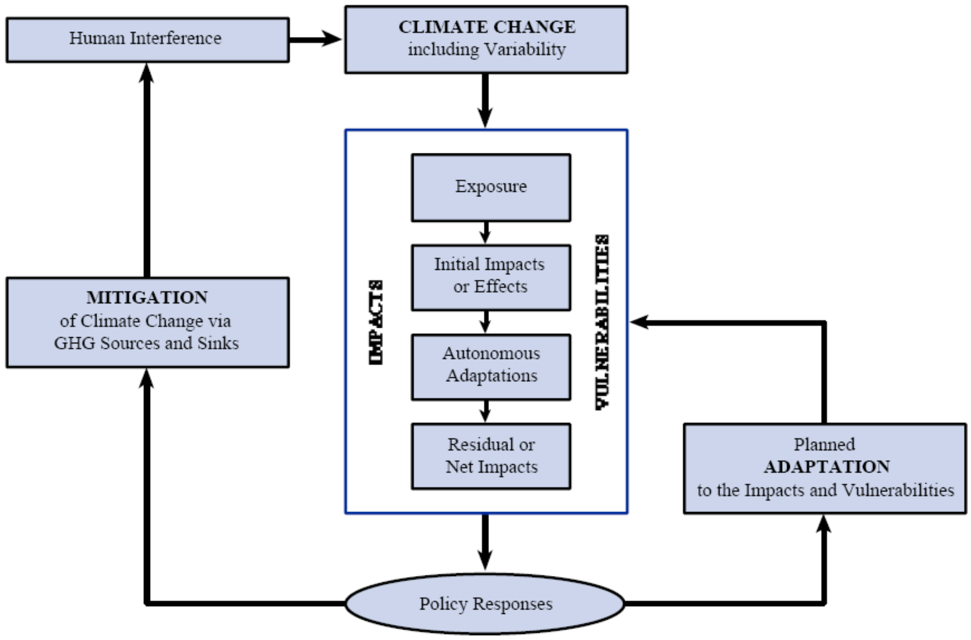


***Figure 1.*** *Climate change, mitigation and adaptation (IPCC 2001b, based on Smit et al. 1999).*

SWECIA will provide new results and significant new knowledge on the consequences, risks, and opportunities associated with mitigation goals, such as the probable climate outcomes for specific emission pathways and reductions, stabilisation targets, the impacts and economic consequences under such developments, and the need, means and opportunities of adaptation.

The most prominent example of an overarching global frame is, of course, the United Nations Framework Convention on Climate Change (UNFCCC). The convention is clear about the aim, if not on the means, of what should be achieved. The targeted level of "stabilisation of greenhouse gas concentrations in the atmosphere…"[1] is not defined. Science can provide policy-relevant information on the matter, without engaging in value judgments (IPCC 2004a). Indeed, in the European climate policy context the UNFCCC Article 2 has been interpreted to mean a rise in global mean temperature by no more than 2°C (WBGU 1995, 1997, 2004; EU 1996). Also more recently, the European Council (7619/1/05) stated:

"The European Council acknowledges that climate change is likely to have major negative global environmental, economic and social implications. It confirms that, with a view to achieving the ultimate objective of the UN Framework Convention on Climate Change, the global annual mean surface temperature increase should not exceed 2ºC above pre-industrial levels."

It is now commonly recognised that the connection between some specific rise in global mean temperature and a specific level of GHGs is not precise. This refers to the paramount scien-

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[1] UNFCCC, Article 2: "The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."

tific uncertainty on climate sensitivity (IPCC 1990, 1996, 2001a, 2004b, 2007a). Due to the complexity of the climate system, atmospheric concentration levels can only be associated with ranges of climate change, whether the latter concerns global mean surface temperature or changes in extreme weather events. A similar inexact relation exists between emissions and the atmospheric concentrations. Carbon dioxide participates in biogeochemical cycling involving the atmosphere, the oceans and the biosphere. At present, about half of the annual emissions of carbon dioxide are captured in the ocean and the biosphere. These uptakes are, however, affected by climate and thus by climate change. Thus, an emission reduction goal is not straightforward to equate with atmospheric composition change and subsequent climatic impacts. The latter also needs to be addressed on regional scales as mentioned above (*e.g.*, Schneider and Lane 2006). Moreover, there are uncertainties about how precisely mitigation can be implemented. Changes in policy measures, such as new technical standards or taxation of fossil energy use, do not map with certainty into specific reductions of emissions, because the world economy and the underlying society, like global climate, is an evolving system.

Scientific uncertainties of these kinds are more and more recognised in the policy-making context. The 2°C target sets the stage for EU climate policy efforts. The setting of any ultimate mitigation/stabilisation target naturally has consequences for how adaptation enters into the agenda. There will always be a demand for information on how specific mitigation pathways shape climate impacts and the need for adaptation.

That considerable mitigation will take place is a starting point in SWECIA. The research will focus on the need and opportunities for adaptation on local and regional scales, while paying close attention to global linkages and interactions within alternative mitigation scenarios.

## 1.3 Significance of the research in terms of promoting Sweden's competitiveness and of creating strong research environments

*The challenge and promise of the SWECIA is to forge together a new line of research, combining the expertise and approaches of different disciplines (physical climate system science, biology, economics and social sciences) into a coherent whole. The research will be conducted in dialogue with users and include a more generic outreach. User dialogue and outreach will serve to promote insights on the relevant questions and available answers, as well as to focus the Programme efforts.*

By the end of SWECIA's ten-years of activity, the following will exist (i) a core group of interdisciplinary Swedish climate scientists, (ii) a comprehensive Swedish capacity of model-based assessment of climate change and adaptation with global, regional and local focus, and (iii) a sustained integrated effort of interactive outreach, decision-support and communication on climate change and adaptation.

More specifically, the Programme

- builds a new strong and cross-disciplinary Swedish research arena, bringing together physical climate sciences, biology/ecology, economics, and social sciences that contribute to state-of-the-art international research.
- strengthens the ability of Sweden to manage climate change, and to contribute to international climate politics, for example the international climate treaties beyond 2012, capacity building in developing nations, and the definition of the mitigation and proactive adaptation targets.
- provides the building-blocks and a strategy for long-term operations of a national climate and adaptation dialogue arena, "SweCIP" (*cf.* UKCIP), including a demonstration of value during the course of the Programme.

- creates a lasting imprint on strategic environmental research and solutions thanks to a better integration of the long-term global, regional and local goals in dealing with climate change incorporating adaptation, which in turn facilitates sustainable development in areas such as technological change (global and regional energy systems, carbon-neutrality), environmental protection (managing biodiversity), human societies, security and development aid (managing natural resources, physical planning, capacity building).

# 2. Scientific value

## 2.1 Synthesis of existing knowledge and how the proposed work relates to current international research

*The following research fields are of utmost importance for climate and adaptation: climate science and modelling, including biogeochemical cycles and systems and the physical climate system, impact and economic studies and the very process of adaptation itself.*

### 2.1.1 Biogeophysical climate science

The climate features interactions among the physical, chemical and biological processes that couple the compartments of the Earth system: the atmosphere, hydrosphere, biosphere and cryosphere, as well as human activities, sometimes viewed as a compartment of their own: the anthrosphere. The diversity of processes and systems that influence climate variability, and the breathtaking range of scales on which they operate, poses considerable challenges for climate science. The evolution of climate models since their inception in the mid-1970s is also impressive. While the earliest models dealt with exclusively the fast physical processes of the atmosphere, models now incorporate more detail, culminating in current Earth System Models that may include dynamical land surface, oceans, sea ice, sulphate and non-sulphate aerosols, terrestrial and marine carbon cycles, atmospheric chemistry, terrestrial vegetation dynamics and land use. Because all of the coupled Earth system is affected by and potentially influences climate, understanding of the mechanisms in each compartment individually is a prerequisite to climate projections. Although much progress has been made over the last 30 years, important uncertainties remain. Some key ones of these will be addressed in SWECIA, as follows.

Increased computer power makes higher resolution simulations feasible. This is a more or less continuous process directing towards a seamless prediction system for weather and climate (WCRP 2007). State-of-the-art climate models (IPCC 2007a) have a resolution that is twice, or even finer, than previous models (IPCC 2001a). Global climate models nevertheless still have limitations in their ability to describe large scale circulation patterns, such as blocking events that significantly contribute to the natural variability (D'Andrea *et al.* 1998). Recent model simulations appear to be more successful in this respect (Pelly and Hoskins 2003; Mauritsen and Källén 2004) but there are still significant deficiencies. Part of this is coupled to resolution. A very high resolution global simulation with a global nonhydrostatic model of around 5km has been explored (Miura *et al.* 2005; Tomita *et al.* 2005). Indeed, tropical variability is better captured, but the computational expense prohibits longer simulations and thus use for climate scenarios. One important finding is that climate sensitivity depends on processes resolved with high resolution. Lower resolution models do, however, broadly agree with the high resolution experiment results (Miura *et al.* 2005).

Today's climate models capture much of the observed climate. Biases and uncertainties remain. In addition to model resolution, physical process parameterisation schemes are an Achilles heel (*e.g.*, Räisänen 2007, Chen and Yoon 2002, Wang 2004), not least when in comes to aerosols and clouds, and, consequently radiative forcing and precipitation. Furthermore, there are interactions between the physical, biogeochemical and biophysical processes that hitherto remain unaddressed. The biosphere influences climate through biogeochemical and biophysical exchange with the atmosphere. The biospheric part of the carbon cycle has received particular attention as a feedback process that could influence climate trajectories. Through primary production and solution in surface waters, the biosphere and oceans currently absorb about 60% of anthropogenic $CO_2$ emissions, moderating the increase in radiative forcing. Future changes in net primary production, soil carbon losses through increased respiration, and biomass losses in conjunction with deforestation and changing disturbance regimes could conceivably cause the biosphere to switch from being a sink to a source of carbon, further accelerating climate change.

The incorporation of "slow" biospheric feedbacks that has been explored in some models tends to point towards accelerated climate change globally, as increased warming increases soil respiration and enhances drying trends in tropical areas such as the Amazon region (Cox *et al.* 2000, 2004; Zeng *et al.* 2004; Sitch *et al.* 2005). The representation of carbon biogeochemistry in models is relatively primitive and does not take into account recent advances in understanding, for example about the climate sensitivity of soil respiration (Knorr *et al.* 2005). One result of this could be unrealistically large positive feedbacks (Cramer *et al.* 2001; Friedlingstein *et al.* 2003). Global studies nevertheless suggest that a sign shift in the carbon budget of the terrestrial biosphere is feasible during the coming century (*e.g.* Schaphoff *et al.* 2006). The release of previously inactive soil carbon in conjunction with permafrost melting presents a particular concern (Zimov *et al.* 2006). Present carbon cycle uncertainties are large and hinder a clearer targeting of emission reductions.

The magnitude and even direction of net feedbacks of land use and vegetation changes are uncertain, especially at the regional scale, where negative feedbacks such as increased albedo may counteract positive feedbacks, such as carbon losses to the atmosphere and reduced evapotranspiration in a warmer, drier climate (*e.g.* Sitch *et al.* 2005). A widespread conversion of open land to forest in the northern hemisphere could counteract any climate mitigation benefit of carbon sequestration thanks to the additional forest (Betts 2000; Sitch *et al.* 2005). Climate-driven changes in vegetation phenology and canopy gas exchange can also affect rainfall patterns up to the global scale. These feedbacks are potentially significant and need to be understood on the regional scale with regional vegetation and climate models.

Oceanic uptake of $CO_2$ is associated with its dissolution in surface water as well as biological uptake. Part of the latter is fixed to particulate inorganic carbon and may be effectively inactivated by transfer to the deep ocean. Climate change over the last century has marginally reduced ocean uptake of $CO_2$, through increased surface water temperatures and acidification linked to the increased $CO_2$. Model experiments suggest that the climate sensitivity of ocean carbon exchange is relatively small, compared to the terrestrial response (Friedlingstein *et al.* 2003). However, current models do not take account of feedback via changes in biological export, coral growth and land runoff, and might miss changes in ocean circulation. Given the limitations of current understanding, ocean C-cycle feedbacks will not be addressed in the initial 4-year phase of SWECIA. Development of an ocean biogeochemistry model for incorporation in Earth system modelling is planned for a second phase of the Programme.

To use climate model ensemble predictions for applications, a transformation of probabilistic, physical model results to user-specific information is required. Examples of how this can be done for European agricultural applications are shown by Cantelaube and Terres (2005) and Marletto *et al.* (2005). Morse *et al.* (2005) demonstrate the feasibility of malaria prediction and Challinor *et al.* (2005) show how Indian crop yield can be forecasted on seasonal time scales. All the studies referred to above use seasonal prediction ensembles, the methodology should also be applicable to climatic time scales.

### 2.1.2 Earth System Modelling

The main purpose of using models for climate simulation is to assess the climatic consequences of changes due to natural variability or externally imposed forcing. Often such forcing is imposed independently of the response of the climate system, missing the feedback between changes in external forcing and the physical climate system response. SWECIA will conduct research on this field with a hierarchy of climate models.

On the global scale, general circulation models (GCM) of the atmosphere and oceans have been developed over the past few decades (IPCC 1990, 1996, 2001a, 2007a). At first, the atmosphere and the ocean were modelled separately. Later, coupled models became the norm and an indispensable means in climate change research. These models have been successful in simulating past and present-day climates and are used for projections of climate change. Today, climate models are also used for regional simulations (IPCC 2001a, 2007a), in more detailed studies of regional climate change and process-studies at higher resolutions than what is attainable with global models (*e.g.* Christensen *et al.* 2007). Results of global and regional climate models are increasingly used as basis for adaptation and mitigation strategies.

Efforts are underway in Japan, United Kingdom, France, Canada, the US and Germany on "advanced" Earth System Models (ESM). With these we mean coupled atmosphere-ocean general circulation models (CGCM) complemented with biology, atmospheric chemistry etc. Earth system Models of Intermediate Complexity (EMICs) are a variant of the ESM. EMICs have a very coarse resolution and their atmosphere/ocean/land surface model is not as comprehensive as in an advanced ESM or GCM. EMICs are developed to study uncertainties and for simulations of very long time scales (several thousand or tens of thousands of years), *i.e.* ice-age climate variability and the coupling with glacial dynamics.

Physical climate models have hardly been truly integrated with economic models. SWECIA will start with an EMIC and a regionally aggregated economic model, to investigate the dynamics of such a model system in an exploratory fashion. Despite EMICs' limitations in terms of detail, they are suited to investigate large-scale climate variability. Shifts in large scale circulation patterns govern many smaller scale phenomena such as violent storms and flooding, droughts and heat waves. And it is precisely such extreme events that are of interest for extended integrated assessment models. Later, SWECIA will develop true global and regional ESM systems coupled with economic models.

### 2.1.3 Impact studies and the economics of climate change

Climate impact assessment has by now a long tradition. Established methodologies and models exist within various fields. Impacts on biological systems are typically addressed with empirical or process-based models. These relate changes in species distributions, population or community structure, or ecosystem functioning to driving factors in the environment, including climate variables (*e.g.* Prentice *et al.* 2007). Sectorial models, *e.g.*, for agricultural systems and managed forests, translate biological parameters into economically relevant outcomes, such as stem volume growth or crop yield (*e.g.*, Mäkelä *et al.* 2000; Fischer *et al.* 2002). Many such models have been validated with regard to their outcome and state variables (Prentice *et al.* 2007), and their behaviour have been analysed in sensitivity studies and model comparisons (*e.g.*, Smith *et al.* 1997; Zaehle *et al.* 2005). However, a number of knowledge gaps remain, so predictions are associated with substantial uncertainties, particularly when applied outside the domain of modern climate variability (*e.g.* Hungate *et al.* 2003). SWECIA will adopt and build on existing impact models as far as possible, but will also attempt to improve model performance in a number of specific areas.

The direct impacts of changing climate and weather on human beings, for example their health and mortality (Patz *et al.* 2005), have been explored with statistical models (*e.g.* Thomson *et al.* 2006). Lack of statistical power has been identified as a shortcoming in some studies, which depend critically on the availability of data to isolate causal effects (Martens 1998). SWECIA will conduct quasi-experimental studies using rich data on historical weather/climate patterns and outcomes of interest, such as health and mortality, at a very fine spatial grid over long (multi-decadal) time periods, as a means to improve statistical power.

Integrated Assessment Models (IAM) combine the dynamic evolution of the human and economic sides of the earth system. So far, IAMs feature rather simple climate descriptions, deriving future emission paths from regional assumptions about future population, general productivity developments, savings behaviour, the pace of energy-saving technical progress etc., while also allowing for feedbacks within the economic system (*e.g.*, more rapid growth raises the demands on energy, which raises prices and curbs the use of energy a bit). IAMs include feedback whereby climate change leads to damages at the regional level.

The aggregate responses of society and the economic system to climate change are driven by impacts on a range of sectors and direct impacts on human welfare, health and demography. An aggregation of the impacts, by global regions, is needed as a basis for IAM type modelling – a prerequisite to, *inter alia*, interactive projections of greenhouse gas emissions decades into the future. At the national and sub-national scale, a broad picture of impacts on different sectors is needed as a basis for integrated policy development and planning. Few prior studies have addressed multiple impacts in a consistent way using common underlying assumptions (*e.g.* Schröter *et al.* 2005). With its global analysis and regional/local case-studies, SWECIA will describe impacts in multiple sectors based on common climate scenarios and socio-economic assumptions.

From the perspective of the current generation of IAMs, the research proposed in SWECIA will represent a step forward. First, it will consider climate change not only at the global level but also at the regional level. Second, rather than modelling the regional damages as a function of global mean temperature, it will relate them directly to extreme weather events.

### 2.1.4 Adaptation processes, risk frameworks and risk reduction

Much of the research on adaptation appears to be based on the idea that adaptation involves merely the implementation of some technology reducing the impact of climate change. However, adaptation technologies can only be successfully implemented in an appropriate economic, institutional, legal and socio-cultural context. Adaptation strategies are therefore most effective when they are part of a broad and integrated management framework that recognises immediate as well as longer-term sectorial needs. To this end, adaptation has been described as a multi-stage and iterative process, involving four basic steps (Klein *et al.* 1999): (i) Information collection and awareness raising, (ii) Planning and design, (iii) Implementation and (iv) Monitoring and evaluation. The process of adaptation to climate change can thus be illustrated as in Figure 2. Climate variability and/or climate change, together with other environmental stresses brought about by existing management practices, produce actual or potential impacts. These impacts trigger efforts of mitigation to remove the cause of the impacts or of adaptation to modify the impacts. The process of adaptation is conditioned by policy criteria and development objectives and interacts with existing management practices.

Implicitly, many adaptation studies assume that a particular adaptation measure under study can be implemented without any constraints. To set adaptation priorities requires information on the technologies, expertise and other resources available.

SWECIA will go beyond the traditional view of adaptation, where a national agency develops and implements technology-based measures given specific knowledge of future climate conditions. This view of adaptation can be misleading for three reasons (Klein *et al.* 2007): (i) Uncertainties surrounding climate change can make it difficult to project the extent and future impacts in sufficient detail to justify investment in technological adaptation measures, especially at a local scale, (ii) Technological measures have their limitations, in particular if they fail to address non-climate factors that contribute to the vulnerability to climate change, and (iii) Technological measures designed to adapt to specific changes in climate may not address the issues considered as the most urgent by vulnerable sectors and communities.

SWECIA considers a broad set of options available to stakeholders (technological, institutional and behavioural options), the introduction of economic and policy instruments to encourage the use of these options, and research and development to reduce uncertainty and to enhance the options' effectiveness and efficiency.

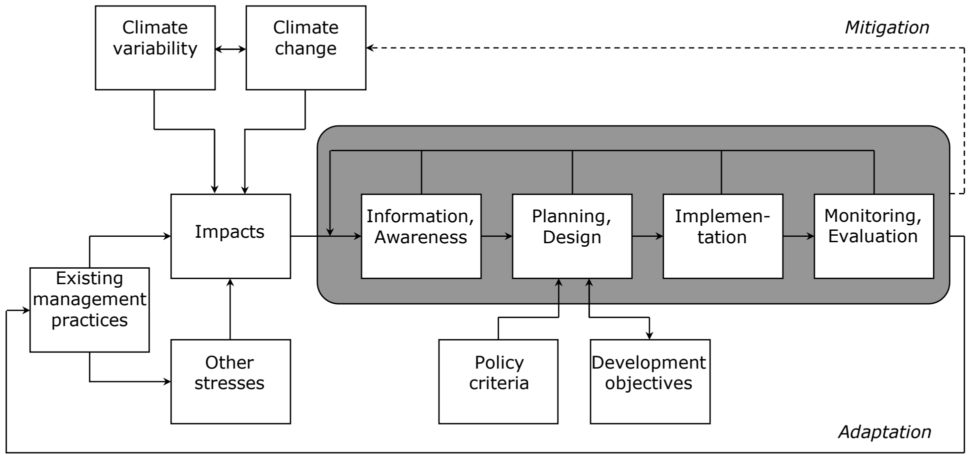


***Figure 2.*** *Conceptual framework of adaptation to climate variability and change (Klein et al. 1999).*

The integration of adaptation measures with non-climatic policies is an emerging research topic. The term "mainstreaming" is used to describe how policies and measures can be integrated into development planning and ongoing sectorial decision-making. Successful mainstreaming would ensure the long-term sustainability of investments and reduce their sensitivity to today's and tomorrow's climate (Beg *et al.* 2002, Klein 2002, Huq *et al.* 2003, Agrawala 2005). Although mainstreaming is most often discussed with reference to developing countries, it is just as relevant to developed countries, because the integration of climate policy with other policies is important whatever the level of development. The institutional means by which such integration can be achieved vary from location to location, from sector to sector, as well as across spatial scales. For developing countries, the UNFCCC and other international organisations can play a part in facilitating the integration of adaptation in policies. In developed countries, liaising with processes of environmental policy integration should facilitate successful mainstreaming.

### 2.1.5 The international and national science arena

The active links of SWECIA to other research networks are detailed in Section 5. In addition, we recognize the following international and national science arenas as very relevant:

*IGBP*[2]

The International Geosphere-Biosphere Programme promotes an international collaborative research effort on global change, covering biological, chemical and physical processes, as well as social systems. The current phase of IGBP focuses on interactions between the compartments of the Earth system. By addressing links between the physical climate, biological and socio-economic systems in an integrative way using coupled models and common assumptions, SWECIA will contribute knowledge of relevance to the goals of IGBP, particularly the component projects Global Land Project (GLP), Integrative Land Ecosystem-Atmosphere Processes Study (ILEAPS[3]) where Lund University is on the scientific steering group and Analysis, Integration and Modeling of the Earth System (AIMES).

[2] http://www.igbp.net
[3] http://www.atm.helsinki.fi/ILEAPS

*IHDP*[4]

The International Human Dimensions Programme is an international research network for interdisciplinary research on the human dimensions of global environmental change, such as issues relating to human security, institutions, urbanization, sustainable production and consumption, and land use change. Two of the current core projects – the Global Land Project (GLP) and Land-Ocean Interactions in the Coastal Zone (LOICZ) – are jointly co-ordinated with IGBP, reflecting the interdisciplinary nature of many current global change research questions. Results of SWECIA research will be of high relevance to the goals of IHDP.

*IPCC*[5]

The Intergovernmental Panel on Climate Change (IPCC) published its Fourth Assessment Report in 2007. Many of the SWECIA partners contributed to it, and to earlier IPCC assessments. Preparations for a Fifth Assessment Report are expected to begin in 2009, aiming at publication in 2012. SWECIA will provide relevant material for consideration by the IPCC Working Groups, and will put Swedish scientists in an excellent position to become involved as authors of relevant chapters.

*EU FP6 & FP7*

The EU Framework programmes support many research projects and networks of relevance here. In those that deal with climate change, impacts and adaptation, SWECIA partners often have an active role already, which means both that duplication of efforts will be avoided and that effective collaborations promoted. Such projects and networks are listed here below or in Section 5, depending on the extent of foreseen linkages with SWECIA.

- *ADAM, ALARM, CarboAfrica, CarboNorth, ENSEMBLES, EPIGOV, RUBICODE, SEAMOCS* (see Section 5)
- *CIRCLE*[6] Climate Impact Research Coordination for a Larger Europe is an ERA-net of research funding and managing agencies. It contributes to climate impact analysis and adaptation efforts by networking national research programmes in 19 countries. The Swedish Environmental Protection Agency and the Research Council Formas are members. Markku Rummukainen is the head of the CIRCLE Advisory Board.

*Programmes (co-)funded by Mistra*

- *Clipore, Heureka* (see Section 5)
- *Climate and Forestry* and *Framtidens skog* Climate and Forestry is the working title of a research programme description by the Royal Swedish Academy for Forestry and Agriculture, in a broad dialogue with the research community (Sonesson 2006). SMHI and Lund University were involved in this. Objectives include an improved understanding of the risks and mechanisms surrounding pest and pathogen outbreaks under future climates, their effects on forest production and their implications for management and adaptation. In the context of the planned case study on the Swedish forest sector, SWECIA will contribute to the goals of Climate and Forestry. A prospective Mistra-funded programme on forestry and land use, considered presently under the name of "Framtidens skog", is another possible arena for joint efforts.

*NBER and CEPR*[7]

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[4] http://www.ihdp.uni-bonn.de/
[5] www.ipcc.ch
[6] http://www.circle-era.net/
[7] http://www.nber.org/ and http://www.cepr.org/

The economists in SWECIA are represented in two leading international networks of economists. The National Bureau of Economic Research is the leading non-profit economic research organization in the U.S. committed to undertaking and disseminating unbiased economic research to public policymakers, business professionals, and the academic community. The Centre for Economic Policy Research is its European counterpart.

*WCRP*[8]

The World Climate Research Programme has been an umbrella for international climate science since its inception in the 1980. WCRP promotes and co-ordinates research on climate prediction and the effect of human activities on climate. BALTEX[9] (the Baltic Sea Experiment) is a regional network within WCRP, pursuing improved understanding of regional hydrological and energy cycles, their role in regional climate, their ecosystem relationships and socio-economic impacts. In a process similar to the IPCC, the BALTEX Assessment of Climate Change (The BACC Author Team 2008) recently synthesised knowledge of regional climate change and its ecosystem impacts. Two of the applicants had a leading role in the assessment, and one serves on the scientific steering committee of BALTEX.

## 2.2 Theory, research design and methods common to the Programme

*Estimates of future climate change, its impacts and adaptation needs hinge crucially on future socio-economic developments. The comparability of estimates is often hampered because different assumptions about the socio-economic future, climate change, climate impacts and the type and level of adaptation measures are used. This is much due to a failure to integrate insights from climate, impact and adaptation research. SWECIA will close these gaps and provide integrated research, building on common assumptions.*

Impacts and adaptation needs depend on a variety of climate and non-climate factors. Some of the impacts will be dealt without planned adaptation. At the same time, planned adaptation can greatly reduce risks and avoid costs. This is illustrated in Figure 3.

"Type 1" adaptation research (*cf.* Burton *et al.* 2002) is carried out as part of a climate impact assessment by estimating how feasible adaptation might reduce impacts of climate change. SWECIA will, however, focus on "Type 2" adaptation research. Such research contributes directly to adaptation policy by identifying which adaptation policies are needed, and how they can best be developed, applied, and funded. Here, the assessments aim to recommend specific adaptation measures by actively involving stakeholders, emphasising the vulnerability to climate variability, formulating response strategies robust to uncertainty, and by integrating adaptation measures with non-climatic policies.

The SWECIA assessments will build on a climate/economic modelling core that has as a common basis the description of relationships between driving factors and response variables based on observational data and constrained by assumptions about the underlying processes. Models describing the biogeophysical processes of the climate system will be linked to models of the global economy and its driving forces, with common assumptions about exogenous factors – such as the influence of environmental concerns on policy – affecting both systems. The linkages will comprise exchanges of data initially, working towards an integrated, synchronously coupled climate-economy model system before the end of the first phase of the Programme. The system will for the first time provide the capacity to generate fully consistent scenarios of change in climate and socio-economy, accounting for effects of climate on human beings, and of human activities on climate.

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[8] http://wcrp.wmo.int/
[9] http://www.baltex-research.eu

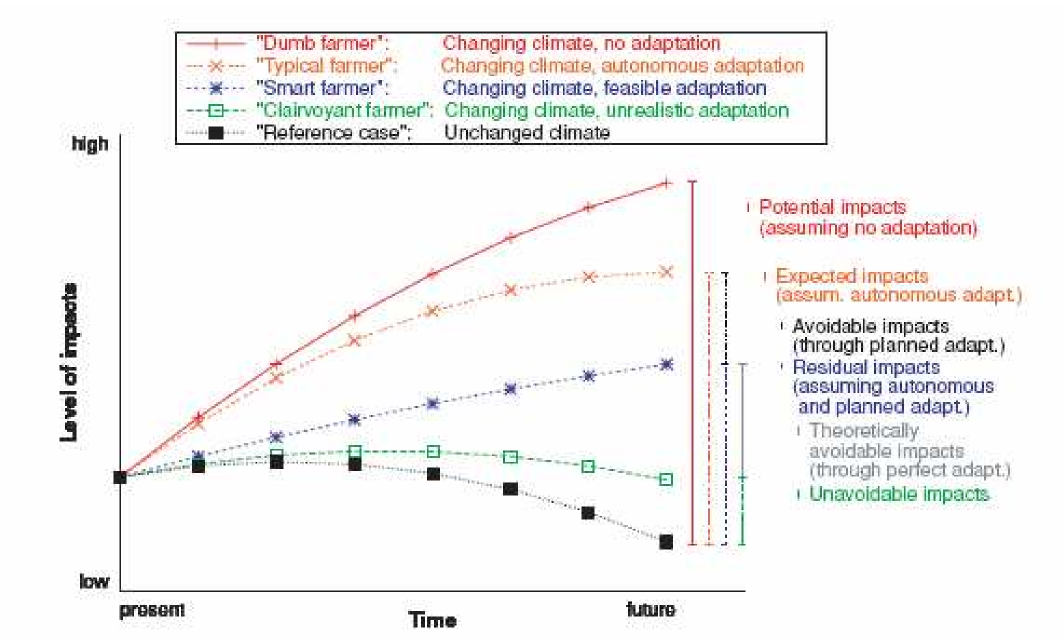


***Figure 3.*** *The individual trajectories show the combined impacts of natural climate variability and anthropogenic climate change. The bars on the right-hand side refer to the impacts of anthropogenic climate change only (Füssel and Klein 2006). The reference case is one of an unchanging climate where the evolution of climate impacts over time is caused by changes in non-climatic factors. The resulting trajectory shows an initial increase in climate-related impacts (e.g., due to population growth) followed by a substantial decrease later (e.g., as a result of economic development). The other trajectories present the impacts associated with a climate change scenario for different assumptions regarding adaptation: the "dumb farmer", who does not react to changing climate conditions at all; the "typical farmer", who adjusts management practices in reaction to persistent climate changes only; the "smart farmer", who uses available information on expected climate conditions to adjust to them proactively; and the "clairvoyant farmer", who has perfect foresight about future climate conditions and faces no restrictions in implementing adaptation measures.*

Assessing the impacts on both the environmental and societal systems of climate change is a prerequisite to translating climate and emissions scenarios into specific decision support for adaptation. The responses of environmental and societal systems to climate change are diverse and complex, especially when viewed at finer scales. As a comprehensive treatment of all impacts is far beyond the scope of any single research programme, SWECIA will focus on a set of specific studies, which are chosen with the following three criteria (impact types addressed are outlined in Section 6.3):

- Importance for society. Some impacts are of major significance to economic well-being, health, culture, etc., either globally or regionally, which is important in itself and implies a strong need for adaptation.
- Importance for feedbacks to the climate system. Some impacts are associated with potentially large feedbacks to the climate system, either directly via biological systems, or indirectly via socio-economic systems. These impacts are also important for society, at least indirectly, and advance warning through climate projections can allow proactive adaptation to reduce negative impacts.
- Importance for science. Some impacts remain poorly understood in terms of their key controlling mechanisms. Recent data and new insights make better understanding or improved modelling a realistic possibility. (We address impact types in this category only if they also fulfil criteria (i) or (ii)).

SWECIA will bridge the present duality in adaptation research that occurs between *top-down* climate/impact modelling extended also to economic modelling, and *bottom-up* studies of the adaptive capacity of relevant physical and natural systems, including institutional and other actor or sector-specific driving forces (Figure 4). Both of these approaches address climate adaptation policy. SWECIA will make progress on both approaches, and bring them together.

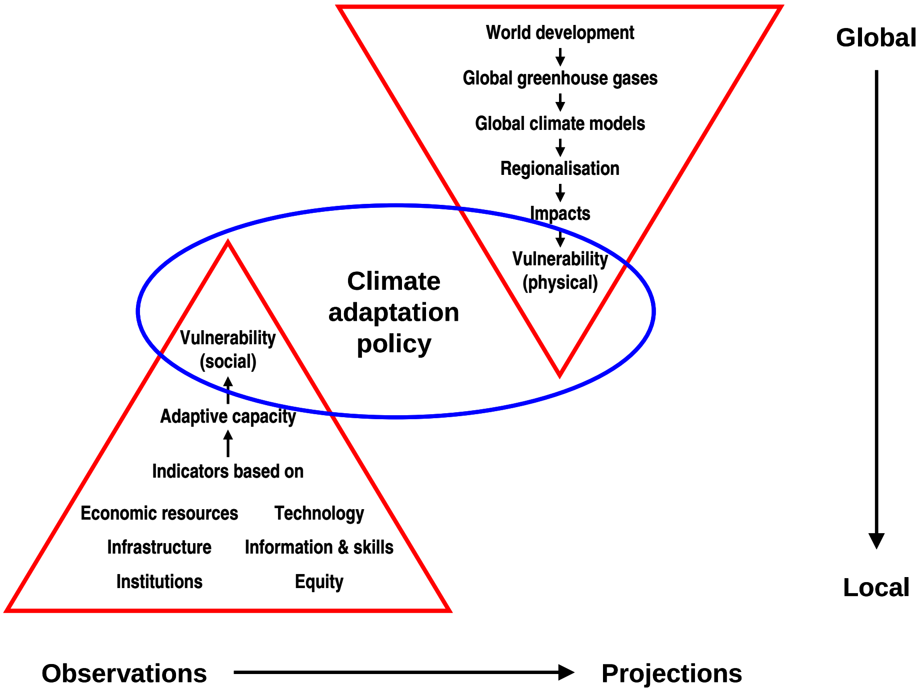


***Figure 4.*** *The top-down and bottom-up research approaches contributing to climate adaptation policy (after Dessai and Hulme 2003).*

Another duality in adaptation research is the distinction between research *for* and research *on* adaptation. The former concerns climate change, impacts, adaptive capacity, costs and opportunities. The latter concerns the adaptation process itself: What makes adaptation successful? Where are the information/decision bottlenecks? What constitutes decision-support? SWECIA will consider research on adaptation as a subset of research for adaptation.

Thus, SWECIA will provide applied science, building on a foundation of basic research. A dialogue with users and an outreach activity will be an essential part of the Programme and strengthens its participatory nature.

The main common research design and methods in the Programme are

- The adoption of a Common Scenario Frame (CSF) in terms of possible world development (demography, economy, globalisation, equity, technology, land use). Initially, we will adopt the existing IPCC SRES (Nakićenović *et al.* 2000), and especially the A1B, A2 and B1 (*cf.* IPCC 2007a). Ultimately, SWECIA will provide new, interactive, socio-economic–climate–impact scenarios, taking uncertainty onboard and translating the results for practical adaptation.
- Development and application of consistent chains of climate, impact and economic models (as a stepping stone) and comprehensive model systems for integrated studies of climate, impacts, and societal costs and benefits.
- The formulation of the results in terms of probabilities and risks, to reflect the fact that future climate change will always be associated with some unavoidable uncertainty and the fact that much of the knowledge is nevertheless robust. In addition to characterising

the range of “reasonably likely” outcomes (like other efforts, *e.g.,* IPCC), SWECIA will also look into the implications of some shock events of low probability but potentially high impact, such as major carbon losses from high latitude ecosystems, or international conflicts.

- Case studies where climate change and impacts, and other drivers of change, vulnerability and adaptation options are analyzed in a consistent fashion. The case studies are set in a broader context to elucidate the local-to-regional-to-global interdependencies and for generalisations of the results.
- Extensive stakeholder engagement with the purpose of (i) consulting on case study research focus and design, (ii) collecting information, (iii) functional and interactive participation in risk perception and policy analysis, and (iv) establishing two-way communication of the research and its results.

## 2.3 Planned scientific deliverables at the Programme level

**Programme phase 1 (years 1-4)**

- Scientific articles, Working Papers and a scientific Newsletter.
- Quantitative global climate-economy model, with regional aggregation.
- Regional “Earth System” Model (RCA-GUESS), with improved high resolution process-descriptions.
- Global Earth System Model (physical climate-biosphere model) available for SWECIA use.
- Integrated global and regional climate-impact-economic scenarios for the 21$^{st}$ Century, based on consistent assumptions as documented in the CSF, providing input to, *e.g.* the expected IPCC Fifth Assessment Report.
- First analysis of global impacts on ecosystem services, due to change in the coupled environmental-societal Earth system
- Relevant information (impact scenarios and adaptation options) to support adaptation decisions within the sectors/regions addressed by the SWECIA case studies.
- A framework that combines climate information with experience in social learning and policy integration of climate integration.

**Later Programme phases (years 5-10)**

- Scientific articles, Working Papers and a scientific Newsletter.
- Coupled global ESM-biosphere-economy model, with human feedback.
- Coupled regional ESM-biosphere-economy model, with human feedback.
- Integrated global and regional climate-impact-economic scenarios for the 21$^{st}$ Century, based on consistent assumptions as documented in the CSF, providing input to, *e.g.,* the expected IPCC Fifth Assessment Report.
- Improved analysis of global impacts on ecosystem services, due to change in the coupled environmental-societal Earth system.
- A regional scientific assessment of climate, impacts and adaptation based on the new models and scenarios.

- Swedish model-based capacity for climate, impacts and adaptation assessment, including user interaction processes.
- A new generation of cross-disciplinary Swedish climate, impact and adaptation scientists.

## *3. Value to users*

*The intended users of the results are national and international policy-makers and regional-to-local decision-makers in the public and private sector. The general public is also seen as a user group. There are, of course, also science users of the research. Indeed, some of the policy-makers' user value will arise from increased internationalisation of Swedish climate research. (See also Part B, Section 8.)*

### 3.1 Value of the research to intended users

#### 3.1.1 Case Studies

SWECIA case studies will be one of the means of creating user value. They allow for in-depth investigations of issues that are relevant to the assessment of climate impacts and decision-making on adaptation. They will address joint impacts of climate and socio-economic change on particular sectors at local to national scales (cross-scale studies), or on a particular administrative unit (cross-sectorial studies), evaluating the adaptive capacity, options and information needs. Apart from providing decision support to a selection of users, the case studies will serve to develop methodologies and practical tools suitable for application to other regions, sectors and users. They will also form a solid basis for recommendations for adaptation policies. A dialogue between researchers and users will help initiate a transfer of knowledge to the wider user community. The rationale behind having both sectorial and spatially defined case studies is that sectorial stakeholders act across multiple spatial and institutional scales, whilst in a spatially defined case study, stakeholders from multiple sectors interact. Sectorial case studies focus is on the vertical exchange of information, while spatial cases focus on the horizontal exchange of information at the same institutional level. Real-world stakeholders are, of course, part of both vertical and horizontal interaction. The cross-scale and cross-sector case studies thus usefully complement each other.

The first two years of the Programme will involve case studies on the region of Stockholm and on the energy sector (see Section 6.4). Additional case studies will follow, widening the scope to rural settings, as well other business sectors, such as forestry and insurance.

#### 3.1.2 Examples of specific user categories

Enterprises that will benefit from the SWECIA research include energy market actors (for example, Vattenfall and E.ON), insurance companies (Länsförsäkringar) and networks (Business Leaders' Initiative on Climate Change, BLICC[10]; World Business Council for Sustainable Development, WBCSD[11]; Combat Climate Change - A Business Leaders' Initiative, 3C[12]). Other prospective users are those Swedish authorities that promote, support and manage adaptation (Naturvårdsverket, Boverket, SGI, SMHI, Räddningsverket, Jordbruksverket, Skogsstyrelsen, Vägverket, Banverket, KBM). National Swedish policy actors and the Swedish climate negotiation delegations will be one important set of users, and municipalities and regional authorities yet another.

### 3.2 User groups involved in the Programme

SWECIA users will be involved in an annual dialogue, consulted for advice, asked to evaluate the user value of results, and involved in case studies and demonstrations of the application of

[10] http://www.respecteurope.com/
[11] http://www.wbcsd.org/
[12] http://www.combatclimatechange.org/

the science produced. Here, we mention briefly that four categories of users are distinguished, depending on how closely they will be affiliated with the Programme:

1) The Programme Board will have user representation and interaction.

2) A broad user reference group will also be set up, with a core from the working groups of the Commission on climate and vulnerability[13] at the Swedish Government Offices.

3) User groups involved in the SWECIA case studies, and other user groups to emerge on, *e.g.*, the Energy Sector, the Swedish EPA and SAREC (the Department for Research Cooperation of the Swedish international development cooperation agency, Sida), to name a few.

4) The society at large.

See Projects 0 and 4, and, especially, Section 8 for details.

## 3.3 Planned user deliverables at the Programme level

**Programme phase 1 (years 1-4)**

- Annual user/stakeholder workshops, home page, a user-oriented Newsletter in Swedish on climate and adaptation science efforts, annual synthesis reports of SWECIA research and how it relates to the international state-of-the-art.
- Participation in climate, impact and adaptation policy processes.
- Scenario database available over the internet including documentation.
- Consistent global and regional climate-impact-economic scenarios for the 21$^{st}$ Century, based on the CSF.
- Mapping and analysis of adaptation processes within the phase 1 case studies, at strategy and implementation levels.

**Later Programme phases (years 5-10)**

- Annual user workshops, home page, a user-oriented Newsletter in Swedish on climate and adaptation science efforts, annual synthesis reports of SWECIA research and how it relates to the international state-of-the-art.
- Participation in climate, impact and adaptation policy processes.
- Mapping and analysis of adaptation processes within the case studies, at strategy and implementation levels.
- Analysis of adaptation strategies within the phase 2 case studies, including their implementation considerations.
- Consistent global and regional climate-impact-economic scenarios for the 21$^{st}$ Century, based on the comprehensive SWECIA model system and assumptions. Updated scenario databases.
- A regional user-oriented assessment of climate, impact and adaptation based on the new models and scenarios.
- Strategy for a sustained, post-SWECIA outreach, science/user-dialogue and information-brokerage activity, building on the established Swedish model-based capacity for climate impact and adaptation assessment, including user interaction processes".

[13] http://www.sou.gov.se/klimatsarbarhet/

## *4. Programme structure*

*The Programme is planned for a total horizon of 10 years, covering 3 phases (4+4+2 years). Each of the phases will provide useful results that stand on their own. Other research efforts are planned to run during the entire length of the Programme. The present application described the first 4 years of SWECIA in detail.*

## 4.1 Outline of Programme structure and reference group

### 4.1.1 Programme structure and its evolution over time

During the now actual phase 1, the efforts will be concentrated on five Projects (*cf.* Section 6 and Figure 5), on (0) planning, communication, synthesis and integration, (1) climate modelling, (2) economy modelling, (3) impact modelling and (4) the process of adaptation.

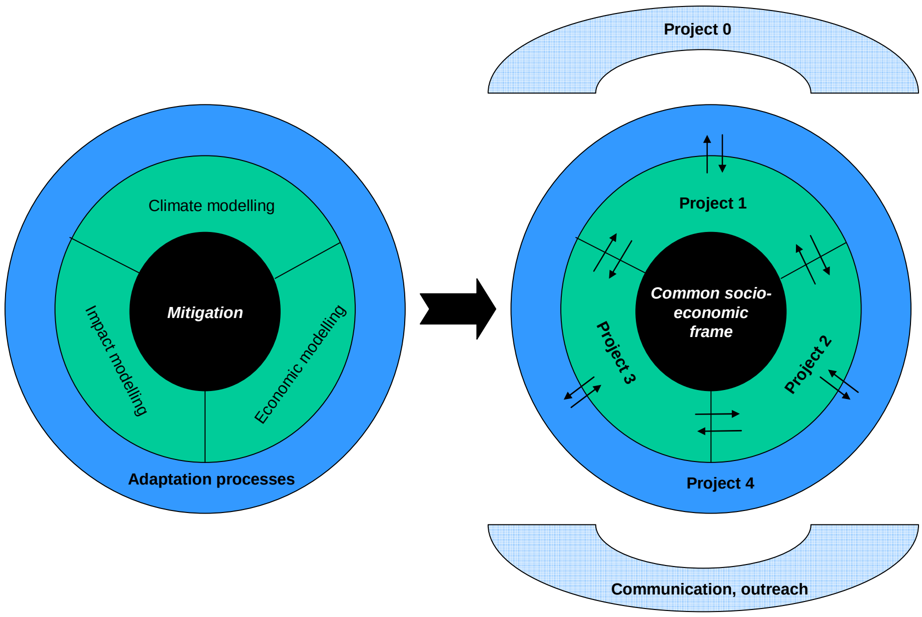


***Figure 5.*** *SWECIA research and organisation circles. The research projects build on common core assumptions that set the stage for climate adaptation. Mitigated, or non-mitigated, futures are translated by climate, impact and economic modelling to adaptation needs and opportunities. Research projects are mutually connected in both contents and organisation. Project 0 overarches the research that ultimately gravitates to communication and outreach to users.*

Each Project involves at least 2-3 of the partners to integrate across disciplines. The synthesis will be a main point of dialogue with users, alongside traditional outreach and communication activities. The case studies will draw upon all Projects.

The planning, internal and external communication, synthesis and integration efforts will be managed in *Project 0*.

In *Projects 1-3*, the climate, economy and impact modelling will build on a common scientific/methodological foundation, to ensure consistent model development and application efforts in the short term, and as a true comprehensive effort in the long term. A hierarchy of models, with suitable aggregation levels, will be developed as the Programme advances. Applications will be provided, encompassing integrated scenarios (socio-economic developments, climate, impacts and costs). The results will be further forged into tools for adaptation and decision-support by users, by emphasising and quantifying inherent uncertainties. For these efforts, the research on adaptation, spearheaded by *Project 4*, will be an important component, elucidating what works and what does not. The initial research here will focus on adaptation that has taken place, to learn about the autonomous component in adaptation. Why have some events not led to adaptation, or the lessons once learned been forgotten? Bottlenecks in implementing adaptation may reflect lacking insights, insufficient advice from researchers, or competition between different decision-makers. Later on, SWECIA research on adaptation will contribute to the implementation of the results of the Programme itself.

All Programme activities provide specific results, such as comprehensive scenarios that can be used to study in depth changes, impacts, and possible adaptation measures. The Programme also addresses inherent uncertainties, *e.g.*, by means of sensitivity and ensemble studies.

Beyond the first Programme phase, Projects 1-4 that contain the science efforts will likely to be recombined, reflecting the science and communication achievements, and SWECIA becoming increasingly more infused by transdisciplinarity. Likewise, the research efforts and user interaction will likely be extended also to additional cases, countries and sectors. In particular, extensions to developing world countries are foreseen.

### 4.1.2 Scientific reference group

SWECIA intends to have reference group, manned by top scientists and user representatives:

- Prof. Tim Carter (Finnish Environment Institute/SYKE, Finland)
- Dr. Roger Street (UKCIP, the U.K.)
- Prof. Martin Claussen (MPI/Hamburg, Germany)
- Dr. Martin König (Federal Environment Agency, Sustainable Development, Austria & Co-ordinator of ERA-Net CIRCLE, Austria)
- Prof. Lena Sommestad (former Swedish Minister of the Environment, Uppsala University, Sweden)
- Prof. Sir Nicholas Stern (UK Treasury. From July 2007, London School of Economics, the U.K.)
- Prof. Rik Leemans (Wageningen University, the Netherlands)
- Associate Prof. Annika Carlsson-Kanyama (Energy and Environmental Security R&D Group, Swedish Defense Research Agency & Programme Director CLIMATOOLS)

The individuals named above have been approached and they are willing to join the SWECIA scientific reference group. The group will be established by the Programme Board.

## 4.2 Arrangements for collaboration, integration and synthesis

The Programme will be a consolidated undertaking. Indeed, much of the planned research is impossible to carry out without intensive collaboration. For example, the construction of regionally disaggregated climate inputs for economic modelling requires close collaboration between meteorologists and economists. The push for an Earth System Model framework requires close collaboration between biologists and meteorologists. As another example, the user interaction activities must involve both social science and natural science experts.

Given the participation of researchers from different scientific disciplines and the combination of natural and social sciences in SWECIA, special efforts will be made to ensure a real and lasting collaboration.

- At the management level, the Programme Director and the Project Leaders will meet, in person every three months to review the progress. More frequent meetings will be held if needed.
- Each Project will be led by senior scientists from different institutions. They will jointly plan, execute and follow-up the activities. Each project will involve at least 2-3 of the partners.
- The Programme will have an internal communication structure with several parts:
    - An annual All Staff meeting for all the contributors, to discuss the results and plan for the future research.
    - A SWECIA science seminar series, with invited guest experts or lecturers.
    - A home page, a presentation template, a mailing list and a logotype.
    - Newsletters, promoting the sharing of preliminary results. These will be also used as a means of soliciting external interest.
- A continuous synthesis, project integration and planning effort will be run throughout the Programme alongside the research in Projects 1-4 (*cf.* Section 6.0).
- Minor part-time researcher commitments will be avoided, to minimise the risk that the Programme is overshadowed by other research. As a rule, senior scientists will be affiliated at least at 30%, postdocs at least at 50% and new graduate students at least at 80% of full time, during periods of their main involvement. Scientists and sub-contractors can be less extensively involved, if their expected contribution is well-defined.

## 4.3 Management structure of Programme

The Programme management will build on the elements shown in Figure 6. These are:

- The Programme Board.
- The Programme Director (PD) and the Project Leaders (PL, *cf.* Section 6)

  The Programme Director is Prof. Markku Rummukainen. He has experience and merits as a research scientist, research leader, science communicator and climate expert. He has earlier Mistra Programme Director experience, having led the Swedish regional climate modelling Programme, SWECLIM, from 2000 to 2003. He has been a member of the Management Group of the SMHI research department and the Head of Rossby Centre, its regional climate modelling research unit. He has experience from the management of major European climate modelling programmes, as well as Nordic research collaborations on regional climate change and its impacts on renewables in particular and the energy sector in general. Presently he is a Research Theme co-coordinator and Management Board member of the ENSEMBLES project, and the Head of the Advisory Board of the ERA-Net CIRCLE. *For more details, please see his CV.*
- A Management Group (PD, PLs, the case study Co-ordinator)
- The SWECIA Programme Host: The Swedish Meteorological and Hydrological Institute. The following resources will be made available to the Programme corresponding to the total of 1050 kSEK/year: Administrative and secretary resources; a part-time Scientific Programme Secretary (PhD-level), technical support (corresponding to 30% of full time) for used model systems at the National Supercomputing Centre or at other supercomputing centres where SMHI accesses resources.

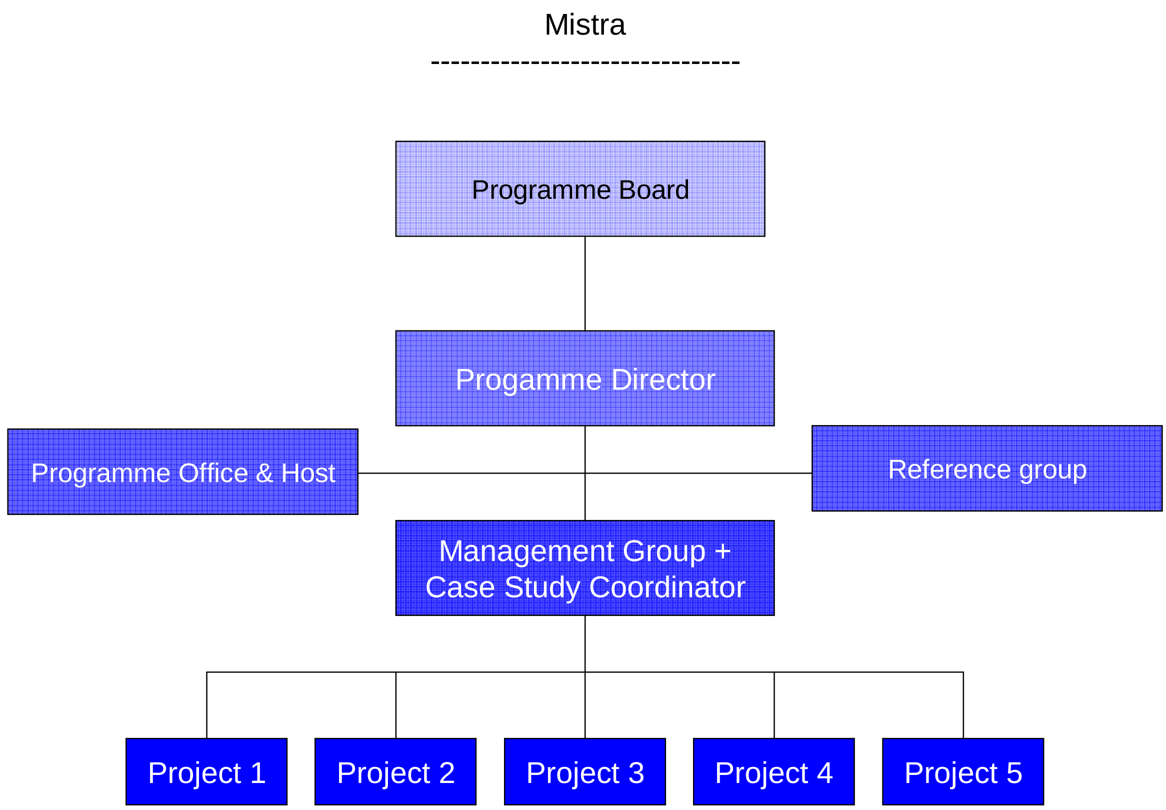


***Figure 6.*** *SWECIA management structure.*

# *5. Skills and networks*

## 5.1 Skills, knowledge and qualifications of the applicant group

**5.1.1 The Rossby Centre, SMHI** (RC) is the climate modelling research unit at the Research and Development department of the Swedish Meteorological and Hydrological Institute, SMHI, with 14 co-workers (advanced climate modelling, impact studies, supercomputing and communication). RC was the core of the Swedish regional climate modelling programme, SWECLIM (Rummukainen 2003, Rummukainen *et al.* 2000) in 1997-2003. RC contributes to national and international research networks on advanced regional climate modelling and scenario analyses, such as in networked Nordic (CWE, CE, CES) and European climate modelling projects (PRUDENCE, PRISM, CLIME, GLIMPSE, DAMOCLES, ENSEMBLES), projects on climate impacts (SEAREG, ESPON) and regional modelling outside Europe (CLARIS). The RC runs the SMHI collaboration on EC-EARTH and on the European ENES and PRISM-sustained efforts on Earth System modelling. RC runs also an active outreach with general and targeted information, such as contributions to the third and fourth IPCC assessments, the third and fourth Swedish National Communications to the UNFCCC, and to the Commission on climate and vulnerability. The key experts in SWECIA are

*Markku Rummukainen* is Associate Professor in meteorology at the University of Helsinki; Adjunct Professor in Geobiosphere Science at the University of Lund. He has a background in research on stratospheric ozone and middle atmosphere chemistry. Since 1997, he has worked on regional climate modelling, building up Swedish activities on this field. He has contributed to the IPCC assessments 2001 and 2007 and to the latest two Swedish National Communications to the UNFCCC. He works actively in many research networks, research communication and as expert, such as in the Commission on climate and vulnerability and the Scientific Council on Climate Issues at the Swedish Environmental Advisory Council.

*Lars Bärring* is Associate Professor at the Department of Physical Geography and Ecosystems Analysis, Lund University. He is an expert on climate variations and extremes, and impacts. He works since 2004 at the Rossby Centre on evaluation and analyses of regional climate simulations and development of impact scenarios. He has been a PI in European projects (ADVICE, WEELS, MICE, ENSEMBLES).

*Erik Kjellström* has a Ph.D. in meteorology from Stockholm University. He has previously worked on chemical meteorology concerning the atmospheric part of the sulphur and carbon cycles (GLOMAC, SINDICATE within EUROTRAC and in EUROSIB), at the Stockholm University and the Massachusetts Institute of Technology. He has worked on regional climate modelling since 2003. His present work focuses on advanced evaluation of regional climate modelling experiments, involving co-operation in Swedish and European research projects like SEAREG, PRUDENCE, and ENSEMBLES in which he acts as a work package leader.

*Jonas Olsson* has a PhD in civil engineering (statistical hydrology) from Lund University (1996). He has much experience in statistical analysis and modeling of hydrological processes, in particular using nonlinear and scale-invariant concepts. He has had a range of scientific commitments including work package leader in EU-projects.

*Patrick Samuelsson,* Ph.D., works with modelling of land-surface processes, lake processes and surface layer turbulent processes for climate modelling purposes and has been responsible for the land surface part of the Rossby Centre Regional climate model (RCA) since 2001. He acted as work-package leader in the EU project CLIME. Through international climate change projects he has experience of applying RCA not only over Europe, but also over South America (CLARIS) and Southern Africa (PUNGWE).

*Ulrika Willén* has a Licentiate of Engineering from Chalmers University of Technology (1994) and an MSc in weather, climate and modelling (1992) from Reading University, UK. Her research cover clouds, radiation and cloud-radiation interactions and dynamical aspects of climate modeling. She has been involved in a number of EU projects for evaluation and development of cloud-radiation parameterizations.

*Klaus Wyser* has a PhD in meteorology from Stockholm University. He is involved in several climate modelling projects aiming at a better understanding of physical processes in the atmosphere and their description in numerical models. He is the Rossby Centre spearhead in global climate modelling with the CCSM3, and now also on the EC-EARTH.

**5.1.2 Department of Meteorology, Stockholm University (MISU)** is a leading Swedish university department in climate studies with a unique combination of atmospheric and oceanic research. The main research directions are: Dynamic meteorology, atmospheric chemistry, atmospheric physics and physical oceanography. In climate research both modelling as well as process studies related to cloud formation and aerosols are central. Large scale circulation studies in the atmosphere and oceans are another core activity. Scientists at MISU were actively involved in SWECLIM as well as in EU climate research projects. In 2006, Stockholm University obtained a Linné-grant for a ten-year basic climate research effort (SUCLIM). The departments co-operating within Stockholm University are meteorology, physical geography, geology and applied environmental research. The key experts in SWECIA are:

*Erland Källén*, Professor in dynamic meteorology. He has worked as a scientist at ECMWF, SMHI, Danish Meteorological Institute, and as a visiting professor at University of Utrecht. His main research area is large scale dynamics of the atmosphere with applications in numerical weather prediction and climate simulation. He is a member of the Scientific Council on Climate Issues formed by the Swedish government and has served as programme leader and chairman of several national/international research programmes and scientific advisory committees. He has been a chairman of the Department of Meteorology, Stockholm University.

*Kristofer Döös*, Associate Professor in physical oceanography. He has previously worked at Southampton Oceanography Centre and at the Institute of Oceanographic Sciences in the U.K. He has a PhD in oceanography from Université de Pierre et Marie Curie in Paris. His main research has been on ocean and climate numerical modelling with particular emphasis on the overturningcirculation and the Lagrangian tracking of heat and water masses.

*Annica M.L. Ekman*, PhD Stockholm University. She is presently Research Scientist at MISU. In 2001-2004 she was a Post-doctoral research fellow at the Department of Earth, Atmospheric and Planetary Sciences, MIT, in the US. Her research interests are in the modelling aerosol-cloud-climate interactions on a local, regional and global scale.

*Gunilla Svensson*, Senior Lecturer, MISU; PhD, Uppsala University. Her expertise is in numerical modelling of the atmospheric boundary layer, including boundary layer clouds, and exchange processes at the surface. She has experience of modelling from the process scale to parameterisations in global models.

*Michael Tjernström*, Professor, MISU. He has research experience in dynamic meteorology and has published over 60 papers peer reviewed papers. His research specialties include the dynamics of coastal atmospheric flows, stratocumulus clouds, surface-exchange processes over heterogeneous surfaces, Arctic boundary-layer dynamics and Arctic climate. He has experience of modelling, from process models to complex regional climate models, and of field experiments on different scales. He was part of the management group for SWECLIM.

**5.1.3 Department of Physical Geography and Ecosystems Analysis, Lund University (INES)** has a long track record in climate and climate impacts research, including the development of process models of ecosystems and the biosphere, and their application to assess impacts, mitigation potential and adaptation options. Much of this work has been in international (*e.g.* GCTE, VEMAP) and European (*e.g.* ETEMA, ATEAM, PRUDENCE, ALARM, ENSEMBLES) collaborations. Ecosystem models originating from INES (FORSKA2, BIOME3, STASH, LPJ-DGVM, LPJ-GUESS) are widely used internationally. INES co-operates with the Rossby Centre to develop one of the first models of the regional climate system incorporating process-based vegetation dynamics and ecosystem biogeochemistry. Other relevant strengths include the integration of modelling with remote sensing for upscaling of field measurements, studies of the impacts of climatic extremes on forest health and growth, and the biogeochemistry of tundra ecosystems under climate change. INES contributes to the current Commission on climate and vulnerability. The key experts in SWECIA are:

*Benjamin Smith*, Associate Professor, INES, an ecologist and ecosystem modeller with broad experience of climate and impacts research. He developed GUESS, the first operational model of physiology-based ecosystem biogeochemistry and individual-based vegetation dynamics, and was co-author of LPJ-DGVM, a widely-used model in global ecosystem studies. Via participation in EU projects (*e.g.* ATEAM, PRUDENCE, ALARM) he has contributed to an emerging understanding of global change, ecosystems and society. He led a recent assessment of climate impacts on land ecosystems of the Baltic Sea region, and contributes to the Commission on climate and vulnerability. In collaboration with the Rossby Centre, he is developing a regional “Earth system” model to explore vegetation and land use change feedback on regional climate.

*Almut Arneth*, PhD in environmental physics, Lincoln University, New Zealand. She is an Associate Professor at INES, where she leads a Marie Curie Excellence research team focused on terrestrial emissions of atmospheric trace gases and their importance for atmospheric composition and climate. Her research includes the testing and development of novel observation techniques to measure surface-atmosphere exchanges of trace gases and aerosols as well as the process-based modelling of terrestrial emissions using the LPJ-GUESS framework. She leads the fire-climate-carbon cycle interactions work package within CarboAfrica, and serves on the scientific steering committee of IGBP/ILEAPS.

*Martin Sykes*, Professor; PhD in plant ecology in New Zealand in 1987. He joined Lund University in 1992 and became professor in 2001. His research group merged with the then Department of Physical Geography into INES. His research is on modelling of ecosystems, vegetation dynamics and biodiversity at local to global scales under past, present and future climates. Increasingly this theme is applied to policy-relevant questions and scales, particularly in the context of Sykes’ extensive participation in EU (FP4-6) collaborations.

**5.1.4 The Institute for International Economic Studies, Stockholm University (IIES)** started out as an independent research institute in 1962, and is now a separate research institute under the faculty of social sciences. The IIES is a leading European research centre with high-impact research in several subfields of economics. Current strengths are in macroeconomics, growth and development economics, public economics, and political economics. A common denominator is the analysis of the effects and determinants of economic policy making. So far, the IIES has not specialized in research on the economics of climate change, but it has extensive experience in developing quantitative equilibrium models and in evaluating alternative economic policy strategies. IIES has very good international contacts, via research collaborations, and from the Institute’s active programme to promote visits by top researchers from abroad. The key experts in SWECIA are:

*Torsten Persson* has done theoretical and empirical research on fields such as macroeconomics, public economics and international economics. He is most well-known for his work in political economics which explores the links between economic polices, political institutions, and economic performance. He has been heavily involved in policy advice, in Sweden as well as in international organizations. Persson took his PhD at Stockholm University in 1982, became a full professor at the IIES in 1987, and has been directing the IIES since 1998. He also holds a permanent (part-time) position as Centennial Professor at the London School of Economics and has been a Visiting Professor at leading universities such as Berkeley, Princeton, and Harvard.

*John Hassler* joined the IIES in 1994 after receiving a PhD in Economics from Massachusetts Institute of Technology and become a tenured professor in 2005. His research covers areas in dynamic macroeconomics and political economics and he collaborates with colleagues in Scandinavia, continental Europe, the UK, the US and Israel. He has been involved in policy advising, *e.g.,* in Economic Council of Sweden for several years. He is a member of the Editorial Board of the Review of Economic Studies and associate editor of Scandinavian Journal of Economics. He is also a fellow of the international networks of academic economists CEPR (based in the U.K.) and IZA and CESIfo based in Germany.

*Per Krusell*, Professor of Economics at IIES. His research interests are in quantitative macroeconomics, economic growth and political economics. He has done extensive research that involves solving and analyzing quantitative dynamic stochastic macroeconomic models with heterogeneous agents. After his graduation from University of Minnesota in 1992, he worked at Northwestern University, University of Pennsylvania and University of Rochester. Since 2004 he is Professor of Economics at Princeton University. Krusell is also a member of the two leading networks of academic economists: CEPR in Europe, and NBER in the US.

*Masayuki Kudamatsu* will obtain his PhD in Economics from the London School of Economics in 2007. The research in his PhD thesis is devoted to empirical work on human health, especially the incidence on infant mortality in Africa under different political regimes, exploiting individual level data available in so called Demography and Health Surveys.

*David Strömberg,* Ph. D. in Economics at Princeton University, Senior Research Fellow at IIES. He has made theoretical and empirical contributions to political economics, not least on the role of the media in the economic policymaking process, and research on natural disasters.

**5.1.5 Stockholm Environment Institute (SEI)** is an independent, non-profit international research institute, established in 1989 as an offshoot of the Beijer Institute of Energy and Human Ecology. SEI is working primarily in Asia, Africa and Europe and has a proven track record on user-relevant climate research, including participatory risk and vulnerability assessment, scenario development and analysis, sectorial studies and capacity building. The interdisciplinary work is carried out at local, national, regional and global policy levels. Most activities fall under six programmes (1) Atmospheric environment, (2) Climate change and energy resources, (3) Water resources and sanitation, (4) Livelihood, vulnerability and poverty, (5) Integrated sustainable development studies and (6) Policies and institutions. The key experts in SWECIA are:

*Richard Klein* is a geographer with fifteen years of research experience on human vulnerability and adaptation to climate variability and change. After eight years at the Potsdam Institute for Climate Impact Research he joined SEI in 2006 to lead the Stockholm-based Climate and Energy team and to co-ordinate climate policy research across all SEI centres. He is an internationally leading expert on adaptation science and policy and has been involved in the IPCC since 1994. He has also contributed to the Millennium Ecosystem Assessment and the Stern Review on the Economics of Climate Change.

*Måns Nilsson*, PhD in Policy Analysis from Delft University of Technology, Netherlands and the Director of the Policy & Institutions Programme at SEI. He specialises in policy analysis, institutional development, public sector management and strategic assessment, with emphasis on climate and energy policy and development policy. He has managed research projects in Sweden and Europe as well as advisory and capacity building projects in Southeast Asia and Africa. Earlier he has worked with the UNDP and Vattenfall Energy Systems.

*Åsa Gerger Swartling*, PhD in Sociology, Research Fellow, Programme Co-ordinator and Project Manager at SEI on projects dealing mainly with energy, climate, ozone, air pollution and urban sustainability. She specialises in participatory approaches to environmental policy and management, sociology of science, and policy analysis. She has done environmental and development related fieldwork in Europe and developing. Her recent research focuses on policy integration and stakeholder participation in sustainability assessments and policy making.

*Oskar Wallgren* is a Research Associate at SEI since 2002. He is involved in multidisciplinary and problem-oriented research projects on environmental management and sustainability planning. Key consultancy assignments include development of strategies and approaches for sustainability planning in regional and urban development. He is the SEI contact point for all research assignments concerning regional development planning in Stockholm. He has had various assignments in the water area drawing on a variety of methods and techniques, including scenario analysis of river basins, political and economic analysis, different participatory methods, spatial analysis using GIS, and development of indicators and monitoring strategies. During 2004-7 he leads SEIs participation in the RIVERWTIN project. His SWECIA participation will form the core of his PhD work.

## 5.2 Networks of researchers and users linked to the Programme

### 5.2.1 Networks of researchers

- *ADAM*[14] "Adaptation and Mitigation Strategies: Supporting European Climate Policy" is an integrated research project 2006-2009 for better understanding of the trade-offs and conflicts that exist between adaptation and mitigation policies. ADAM will support EU policy development in the next stage of the development of the Kyoto Protocol and will inform the emergence of new adaptation strategies for Europe. SEI is a member of the Scientific Steering Committee and co-ordinator of the work package "Assessing Potential Impacts and Adaptive Capacity", which is of great relevance to SWECIA.
- ALARM[15] (Assessing LArge-scale Risks for biodiversity with tested Methods) is an EU-FP6 integrated project on risks associated with the climate impacts, environmental chemicals, rates and extent of loss of pollinators and biological invasions on ecosystems and biodiversity. The climate change sub-programme is led by Lund University. ALARM combines models with experiments and monitoring, with a set of scenarios and assumptions revised from the IPCC SRES storylines as a common basis. A subset of ALARM storylines will be adopted as a common framework for the early phase of SWECIA. Model tools developed within ALARM will be available for Project 3.
- *CANES project and the Fridtjof Nansen Institute*[16] *in Norway*. The SWECIA case study activities will run in parallel with the CANES project in which SEI co-operates with the Fridtjof Nansen Institute. CANES is to improve the understanding of how investment patterns in Nordic energy systems are affected by political change aimed at mitigation of and

[14] www.adamproject.eu
[15] http://www.alarmproject.net
[16] http://www.fni.no/

adaptation to climate change. The empirical focal points will be how current and planned climate-induced policies at EU and national levels affect energy demand, supply and infrastructure development in Norway and Sweden, acknowledging their strong interconnectedness. The SWECIA focus on the social learning aspects of the adaptation process will provide a timely and relevant complement to the activities in CANES.

- *CarboAfrica*[17] is an EU-FP6 project dealing with exchanges of carbon and other greenhouse gases in Sub-Saharan Africa. Lund University leads a WP on fire-climate-carbon cycle interactions, contributing also to measurements of ecosystem-atmosphere fluxes. The expected outcomes of CarboAfrica will contribute to SWECIA by providing a dynamic fire model embedded within the ecosystem modelling framework LPJ-GUESS, adapted for application to African ecosystems and human geography.
- *CarboNorth*[18] is an EU FP6 programme on regional carbon and greenhouse gas budgets of Northern Russia and their potential role in climate feedbacks. The project will lead to improved models of carbon cycling in high-latitude ecosystems, incorporating improved understanding of the biological and biogeochemical processes. Lund University is involved in the CarboNorth regional modelling, and will develop an improved version of the LPJ model. This will provide SWECIA with an improved capacity for modelling regional carbon dynamics and feedbacks to climate, particularly at the global scale.
- *CES*[19] is a Nordic research programme "Climate and Energy Systems; Risks, Potential and Adaptation" funded by the Nordic Energy Research. CES follows earlier projects "Climate, Water and Energy" and "Climate and Energy". CES will improve the decision framework of the energy sector in the face of impacts of climate change on renewable resources and the energy system. The Rossby Centre is heavily involved in CES efforts on climate and impact studies, contributing to adaptation support to the energy sector.
- *CLIMATOOLS*[20] is a Swedish EPA-funded programme (2006-2009) on climate change adaptation, aiming for scenario-based decision-support tools to aid in climate adaptation work in Sweden. It is hosted by the Swedish Defence Research Institute (FOI). The potential for synergies with SWECIA is high. Both have the same overarching, but complementary goal of informing the adaptation process. SWECIA concentrates on improved understanding and reduced uncertainty about climate change and its impacts, as a prerequisite to appropriate adaptation. CLIMATOOLS focuses on the delivery of information to stakeholders to act on. Scenario data of SWECIA will be made available to CLIMATOOLS. CLIMATOOLS work on geopolitics and climate change will be invaluable to SWECIA for defining the characteristics of shocks such as international conflicts, to the global economy and exploring their consequences. Joint case studies will be considered.
- *Clipore*[21] The Mistra programme Climate Policy Research develops a knowledge base for stakeholders involved in climate policy. It focuses on emission trading, adaptation and the role of developing countries in climate policy. SEI has recently joined the programme consortium. Links with Clipore will be developed in particular on the role of Sweden in facilitating adaptation in developing countries.

[17] http://dwms.fao.org/temp/carboafrica
[18] http://www.carbonorth.net/
[19] No website has been established yet. Earlier projects: http://www.os.is/ce/ and http://www.os.is/cwe/
[20] http://www.foi.se/climatools
[21] www.clipore.org

- *EC-EARTH*[22] is a new European consortium developing an advanced Earth System Model based on the ECMWF global forecast model. The Rossby Centre is the Swedish driving force EC-EARTH, joined by MISU.
- *ENSEMBLES*[23] is the major present European climate modelling project running in 2004-2009. It aims at (i) an ensemble prediction system for climate change based on high resolution, global and regional Earth System models, (ii) an objective probabilistic estimate of uncertainty in future climate at seasonal to decadal and longer timescales, (iii) quantification and reduction of the uncertainty in the representation of physical, chemical, biological and human-related feedbacks in the Earth System and (iv) linking the outputs of the ensemble prediction system to a range of applications. SMHI and Lund University belong to the ENSEMBLES project. SWECIA will join forces with ENSEMBLES on climate scenarios, impact modelling and probabilistic methods.
- *EPIGOV*[24], "Environmental Policy Integration and Multi-Level Governance" co-ordinates and synthesises research on environmental policy integration and multi-level governance. It focuses on the modes of governance employed at global, EU, national and regional/local levels to support the integration of environmental concerns into other policy areas such as transport, agricultural, and energy policy. Running in 2006-2008, EPIGOV brings together nineteen research institutions from ten countries. Its results will inform research on adaptation processes in SWECIA. SEI is a principal partner in EPIGOV.
- *Heureka*[25]. The Heureka Research Programme develops computerized forest resource analyses and planning systems in response to the need to provide increased output of goods and services, to serve as a carbon sink, recreation possibilities and biological diversity. A changing climate has to be considered. A core part of the Heureka system is to make detailed projections of tree cover. In Heureka, "hybrid" growth models combining (traditional) empirical models and results from process-based models are developed. The process based model has been run, among others, on SWECLIM climate scenarios. SWECIA and Heureka have mutual interest in forest modelling. Heureka in the SWECIA climate scenarios and SWECIA in experiences of Heureka (such as SWECIA's WP3 Package 3.3). The risk for wind throw due to an altered wind climate and risk perception among users could be another area of collaboration.
- *IHDP GECHS*[26] The core project Global Environmental Change and Human Security (GECHS) of the International Human Dimensions Programme (IHDP) studies environmental changes within the larger socio-economic and political contexts that cause these changes and shape the capacity of communities to cope with and respond to them. SWECIA will contribute in particular to Foci 4 and 5 of GECHS: Modelling Regions of Environmental Stress and Human Security, and Institutions and Policy Development. SEI is a GECHS associate.
- *RUBICODE*[27] (Rationalising Biodiversity Conservation in Dynamic Ecosystems) is a concerted action within EU-FP6 for synthesis, assessment and valuation of ecosystem services connected with biodiversity for the identification of risks under global change. By taking into account socio-economic drivers such as land use, forest management and policy, and attaching a price-tag to biodiversity losses, the project aims to provide a rational

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[22] http://ecearth.knmi.nl/
[23] http://www.ensembles-eu.org/
[24] http://www.ecologic.de/projekte/epigov/
[25] http://heureka.slu.se, see also Lämås and Eriksson, 2003. *Canadian J of Forest Res 33*, 500-508.
[26] www.gechs.org
[27] http://www.rubicode.net/

basis on which policymakers can act. Lund University and the SWECIA collaborator Edinburgh participate in RUBICODE. Its results will be useful to SWECIA as a basis and methodology for the economic valuation of ecosystem services, in defining adaptation strategies and in integrated assessment modelling in Project 2.

- *The Stockholm Resilience Centre*[28] is an international cross-disciplinary research centre at Stockholm University that focuses on the governance of social-ecological systems. It combines the expertise of the SEI, the Centre for Transdisciplinary Environmental Research and the Beijer Institute. The Centre is funded by Mistra. SWECIA will benefit from and contribute to the research being developed in the Centre at the moment.
- *SUCLIM*[29] is a cross-disciplinary research programme in the area of climate system processes at Stockholm University. The main focus is on the Arctic climate system (glacial dynamics, paleoclimate information, sea-ice formation, cloud formation processes, ocean and atmosphere circulation dynamics, terrestrial processes). Climate modelling is a core aspect and the interdisciplinary research themes have been designed to use climate models as a common research tool. SUCLIM is funded by VR (Swedish Research Council) for a period of 10 years under the Linné-programme. The partners involved are the departments of Meteorology, Physical Geography and Quaternary Geology, Geology and Geochemistry and the Institute for Applied Environmental Research, all at Stockholm University.
- *SEAMOCS*[30] is a Marie Curie Research Training Network ”Applied stochastic models for ocean engineering, climate, and safe transportation”, co-ordinated by Lund University. It aims at interdisciplinary training and research in statistics and marine climate. SEAMOCS has emphasis on improved forecasting of extreme weather events and technical safety issues, and safety-related consequences of climate change. Experiences from SEAMOCS will have bearing on SWECIA with respect to statistical modelling and risk analysis in Projects 3 and 5. SMHI is one of SEAMOCS met.office nodes.
- *TIAS*[31]“The Integrated Assessment Society” brings together inter-disciplinary and disciplinary scientists, analysts and practitioners who develop and use integrated assessment of policy-relevant problems, for considering multiple objectives of decision-making and identifying policy criteria. As a member of TIAS, SEI can provide SWECIA with insights into modes of integrating and synthesising interdisciplinary knowledge on climate change, and is therefore of particular relevance to Project 0.

### 5.2.2 Networks of users

Please see Section 3.

[28] http://www.stockholmresilience.su.se/
[29] http://www.suclim.su.se/
[30] http://www.maths.lth.se/seamocs/
[31] www.tias.uni-osnabrueck.de

## *6. Component projects*

*The description of the planning, communication, synthesis and integration project*

- *Project 0*

*is described in terms of its significance to the Programme as a whole and the tasks/activities included.*

*The four thematic SWECIA research projects:*

- *Project 1: Climate modelling*
- *Project 2: Climate-economy modelling*
- *Project 3: Impact modelling and applications*
- *Project 4: The process of adaptation to climate change.*

*are described with regard to (i) significance for the Programme as a whole, (ii) the specific tasks/research issues addressed, organised in distinctive but complementary Work Packages, (iii) relationship to current international research and relevant theory, research design and methods, (iv) value to users and details of the user groups involved, (v) planned scientific and user deliverables, (vi) Project Leaders and participants.*

## 6.0 Project 0: Planning, Communication, Synthesis and Integration

### 6.0.1 Significance for the Programme as a whole

The SWECIA planning, communication and synthesis efforts are managed and administered within this project. These will be continuous activities adhering to the instructions by Mistra. In addition, special focus will be on enabling inter-disciplinarity and integrative research.

In SWECIA, researchers, policymakers and other stakeholders will meet and work together. Their different interests, motivations and goals need to be understood and harmonised. A common identification with the objectives and the final product, the will to invest time and energy in mutual learning, and good communication are essential.

SWECIA hosts a richness of disciplines, models and approaches. This calls for integration efforts to promote multidisciplinarity. In one framework that has been created for this, academic, social and physical considerations are encompassed (Tyndall Centre 2006). Alternatively, one can consider social, cognitive and technical dimensions (Hinkel 2008) of integrative research. In the above two mindsets, the academic element in the former conjoins both with the cognitive and the technical dimension in the latter. All dimensions of integration are, of course, interrelated and overlap. Cognitive integration refers to the knowledge that people possess, and how it needs to be integrated in a meaningful way to address a particular problem. Technical integration concerns the production of artefacts by a collaborative team of people. For example, experiments are set up jointly, databases or computer models are coupled and papers written. In SWECIA, the cognitive and technical dimensions of integration, are partially minded already by the chosen research methodology (see Section 2.2), but there also is a need for additional specific means. The ultimate success, however, will rest much on successful social integration, and in the end determines the quality of the overall outcome of the Programme. In accordance, SWECIA will promote the identification of all partners, contributors and users with the Programme. SWECIA, will,

- for its social integration, maintain a regular Programme leadership presence in its projects and at its partners; provide and promote such common identifications as home page, logotype, newsletters, templates; maintain a regular internal working meeting, seminar and Programme meeting activities.
- for its cognitive integration, pull from each partner’s unique knowledge about relevant systems and processes in the form of concepts, data, models and questions to be addressed. Incompatible conceptualisations (terminologies) will be harmonised. The main frame here will be shared (across disciplines) Project leadership, shared supervsion of students, and, of course, the practical tackling of case studies and stakeholder interaction.
- for its technical integration, provide facilities on its home page (electronic manuscript, report and paper repository); the Common Scenario Framework (CSF, see Section 2.2) and a Technical Standards Framework (TSF, contributes also to the cognitive integration); climate/economy/impact model consistency by jointly crafted and maintained interfaces and, later (phase 2), a comprehensive coupled model for these.

### 6.0.2 The specific tasks addressed

<u>6.0.2.1 Planning and management</u>

**Operational management**

The SWECIA organisation of Programme planning and management are described in Section 4.2. The day-to-day running of the Programme will be shared by the Programme Director and the Programme Scientific Secretary. The Programme Director will physically work much of his time at the different SWECIA partner home institutes. The Management Group will meet every three months to follow up the Programme efforts and to work on the joint Programme activities on communication, reporting etc. In between these meetings, e-mailing and telephone contacts will be the main means of communication.

**Scoping activities**

Scoping activities will be preparatory efforts or pilot studies ahead of a possible full-scale activity, which is of high relevance to the aims of SWECIA but either requires extra resources and funding to carry out, or involves research to be started up after the first Programme phase. Scoping studies can also pave the way to some additional targeted research or communication efforts, for which SWECIA will reserve some of its budget.

D=Deliverable, M=Milestone

| |
|---|
| **D0.1** (Yr1) home page, logotype, e-mailing lists, presentation template, stakeholder contact log |
| **M0.2.Yr** (Yr=1-4) Management Group meetings |
| **D0.3.Yr** (Yr=1-3) Programme plan revision |
| **D0.4** (Yr4) Programme plan for SWECIA phase 2 |

<u>6.0.2.2 Communication</u>

**External communication**

See Section 8 for a description.

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|---|
| **D0.5.Yr** (Yr=1-4) Annual Report |
| **D0.6.Yr** (Yr=1-4) SWECIA scientific Newsletter |
| **D0.7.Yr** (Yr=1-4) SWECIA popular Newsletter |
| **D0.8.Yr** (Yr=1-4) SWECIA-presentations at scientific and stakeholder forums, reports, popular articles, manuscripts and journal papers |
| **D0.9** (Yr2) Workshop in conjunction with the Swedish EU presidency 2009 |
| **D0.10.**Yr (Yr=2 and 3) SWECIA Scientific workshop |
| **D0.11** (Yr4) SWECIA phase 1 final conference |

**Internal communication**

SWECIA will have forms of organised internal communication as listed below. The Programme will also have internal working meetings on an *ad hoc* basis, as well as “normal” internal dialogue activity by e-mail and telephone.

- An annual All Staff meeting, to discuss the results and the plans
- A science/methodology seminar series, with invited guest experts or lecturers
- An internal home page

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| **D0.12.Yr** (Yr=2-4) Update of the SWECIA home page |
| **D0.13.Yr** (Yr=1-4) All Staff meeting |
| **D0.14.Yr** (Yr=1-4) SWECIA science seminars (about 8/yr) |

**Co-ordination of the case studies and Stakeholder dialogue**

The case studies are both a research method (especially in Project 4) and a means for collecting the research activities of all Projects. Specific resources are set aside for the co-ordination of case study activities, to

- ensure optimal timing among research activities within the Programme to optimize the participation of and input from stakeholders; perform targeted outreach for the case studies and make sure that the Programme communicates with stakeholders in one voice (stakeholder seminars and conferences; co-ordination with the overall stakeholder dialogue of SWECIA, *cf.* Section 8).
- provide comprehensive case-study-specific feedback to the Projects and to the reporting and synthesis of SWECIA.

The case study coordinator will be responsible for organizing outreach events specifically targeting the case study regions/sectors. He/she is also responsible for putting together the final case study reports in Swedish, based on input from the four Projects (in Swedish).

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| **M0.15** (Yr1) Start-up event Stockholm region case study |
| **M0.16** (Yr2) Mid-term seminar Stockholm region case study |
| **M0.17** (Yr2) Start-up event Energy sector case study |
| **M0.18** (Yr3) Final conference Stockholm region case study |
| **M0.19** (Yr3) Mid-term seminar Energy sector case study |
| **D0.20** (Yr3) Final non-scientific report Stockholm region case study |
| **D0.21** (Yr4) Final non-scientific report Energy sector case study |
| **M0.22** (Yr4) Final conference Energy sector case study |
| **M0.23** (Yr3) Stakeholder seminar case study 3 |
| **D0.24** (Yr4) Final non-scientific report for case study 3 |
| **M0.25** (Yr4) Stakeholder seminar case study 4 |

6.0.2.3 Synthesis and integration

**Reporting and synthesis**

Many of the results are expected to be published in top scientific journals. Special SWECIA synthesis efforts will add to this by putting the Programme achievements in perspective with existing international relevant state-of-the-art research, including explanatory outlooks on the international research field. Thus, the project results will continuously be synthesised into coherent “packages” for easy accessibility by stakeholders, not least as a Working Paper series made available on-line. The first Working Papers will focus on existing knowledge and updates of earlier syntheses (such as by IPCC).

**Scenario databases and common SWECIA standards**

The global and regional scenarios will be crafted in the Common Scenario Framework (CSF, see Section 2.2) that will be defined in detail at the beginning of the Programme. A technical standards framework (TSF, *e.g.,* such as implemented in the EU ATEAM project[32]), will also be adopted, providing a database/manual of the input and output variables linking the various activities, projects and models within SWECIA, including the units, temporal/spatial scale,

[32] www.pik-potsdam.de/ateam/

formats etc. It will be formulated according to a dialogue at the outset of the Programme and revised regularly to take account of developments.

The scenarios, as well as the supporting manuals and documentation will be provided on SWECIA homepages in a joint scenario database. In addition, information on how to locate and access other relevant databases of observed climate, impacts and to the degree possible, adaptation measures will be collected and provided. These efforts will build on the earlier provision of regional climate scenario data by the Rossby Centre of SMHI[33]. Feedback from users will be collected in order to steer successive development efforts on scenario analysis and provision. Synergies will be sought with the Swedish authorities' adaptation internet portal hosted at SMHI[34].

**D0.26** (Yr1) Basic SWECIA scenario database available on the home page

**D0.27** (Yr1) Common Scenario Framework (CSF) designed and in use; Technical Standards Framework (TSF) formulated and in use

**D0.28.Yr** (Yr=1-4) Working Papers on SWECIA research and results, contributions to national strategies, reporting and international syntheses (*cf*. various entries in Section 8.3)

**D0.29** (Yr4) Scientific and Popular synthesis of SWECIA phase 1

### 6.0.3 Project leader and participants

- *Prof. Markku Rummukainen,* SMHI (Project Leader)
- NN, Programme Scientific Secretary
- Oskar Wallgren, SEI (Case Study Co-ordinator, deputy Project Leader)
- Prof. Erland Källén, MISU
- Prof. Torsten Persson, IIES
- Associate Prof. Ben Smith, LU
- Dr. Richard Klein, SEI

[33] *E.g.* http://www.smhi.se/sgn0106/leveranser/sverigeanalysen/ and http://www.smhi.se/sgn0106/leveranser/mallar.htm
[34] http://www.smhi.se/cmp/jsp/polopoly.jsp?d=9315&l=sv

## 6.1 Project 1: Climate modelling

### 6.1.1 Significance for the Programme as a whole

Climate models are the tools for scientifically based projections of future climate change. They are built on a physical understanding and the core in any comprehensive set of model components for biospheric feedbacks, geochemical feedbacks and socio-economic interactions. In traditional climate science the different components are considered separately. SWECIA will integrate them into one modelling framework. We will also study how uncertainties are propagated through a hierarchy of coupled model components. The uncertainties are due to inadequate modelling assumptions as well as an incomplete knowledge of the parameters governing the problem. We will make use of ensemble simulations to investigate a range of parameter values in a multi-dimensional model space. The number of dimensions to be considered depends on model complexity as well as the availability of computing power.

Climate models come with varying complexity. This is to some degree due to a balancing act between keeping the computational cost down and still to include the complexities of the climate system. Models of different complexity have different strengths and weaknesses. Physical and biological modelling has been combined into Earth system Models of Intermediate Complexity (EMICs). In the recent IPCC (2007a) report it was concluded that adding carbon cycle feedbacks into climate projections had a significant impact on the estimation of upper ranges of future climate change for a given emission scenario. It has also been shown recently by Scholze *et al.* (2006) that regional variations in the climate change variables are very important to the characteristics of the response of the biological system. Economic modelling has so far not considered these aspects. Most economic and social science modelling takes a global perspective and considers regional variations in a parameterised fashion. Coupling to economic models has so far been attempted with globally averaged energy-balance type of climate models where regional climate variability has been parameterised using stochastically generated climate variability.

A range of modelling approaches is needed to cover the global, regional and local scales. In SWECIA, such a range of approaches will be employed, including EMICs, an advanved Earth System Model (ESM) and regionalisation (Regional Climate Models, RCM, and statistical models). These approaches will be further developed and evaluated, as a base for improved climate change projections and one corner-stone of impact and adaptation studies. There will likewise be a range of climate model applications addressing some basic research issues and to provide input to the economic, impact and adaptation studies in Projects 2, 3 and 4.

The SWECIA modelling goal is a coupled physical, biological and economic system so that more consistent sets of scenarios can be constructed. This will advance the state-of-the-art coupled modelling of the biogeophysical climate and economy by integrating between global and regional climate models (Project 1), economic models (Project 2) and biological/ecosystem models (Project 3). For Project 4, Project 1 will provide local-scale climate scenarios and analyses for the framing of the adaptation needs and opportunities.

### 6.1.2 Specific research issues addressed

Changes in the frequency and intensity of severe weather events have a much larger impact on the society than slow changes in average properties. Physical climate models are used to calculate the response of weather variables such as temperature, winds, precipitation etc for changes in greenhouse gas concentrations. The forced climate change will, however, to some degree be masked by the natural variability, especially on the short term and on the smaller scales. Violent storms and unusually warm or cold spells will occur every now and then even if external parameters such as greenhouse gas concentrations remain unchanged. Through a series of simulations, changing statistical properties of the climate system, under different greenhouse gas emission scenarios, will be calculated. These changes will subsequently be fed into economic models, on a regional as well as a global scale.

Even if GCMs and RCMs are able to capture most natural weather fluctuations biases and uncertainties still remain. These are to a large extent dependent on the parametrization schemes in the models (*e.g.,* Räisänen 2007). Some of the most important ones are the parameterizations of clouds, and, consequently of precipitation. Present-day global and regional climate models tend to underestimate heavy precipitation while they simulate light precipitation too frequently (Sun *et al.* 2006, Deng *et al.* 2007, Bärring *et al.* 2006). An improvement in horizontal resolution and better descriptions of clouds can improve this (Tompkins 2002, Pincus *et al.* 2006). In SWECIA we will work on the cloud parameterisation problem as well as other physical processes that influence global and regional climate variations. Within the EC-Earth co-operation an initial focus is on the coupling between the world oceans and the atmosphere. Within SWECIA we will contribute to this work through an analysis and interpretation of coupled model results and the specific formulation of sea-ice processes.

A feature that is highly dependent on model resolution is the ability to simulate wind speed in connection with intense cyclones (Bengtsson *et al.* 2006, Rockel and Woth 2007), which can be alleviated by higher resolution. The same is true for the description of atmospheric blockings (Pelly and Hoskins 2003), which is important for some weather events, and the simulation of wind gusts, particularly in complex terrain (Goyette *et al.* 2003). In SWECIA we will study synoptic and large scale processes that determine the wind variability. We will use high resolution regional models to better describe wind maxima and investigate how large scale flow variability changes affect the regional distributions of wind changes. To study large scale flow variability we will follow the recent work by Brandefelt (2006) and the methods described in Brandefelt and Källén (2004) and Mauritsen and Källén (2004). Furthermore, we will make use of statistical concepts developed by van den Brink *et al.* (2004).

Regional attribution of climate change is more difficult than on global scale, partly due to the large variability, but also due to local forcing agents and feedback mechanisms. An important local forcing agent is the atmospheric aerosol. A major part of the tropospheric aerosol burden is of anthropogenic origin. Emissions of sulphur have recently dropped in Europe and North America, but increase in other parts of the world. Emission scenarios indicate large increases in tropical regions. Episodic events of mineral dust emissions in dry areas are also expected to increase in areas like the Mediterranean region and parts of Africa with increasing dryness. Climate models have shown that aerosols not only have a strong influence on the radiative balance, but may also strongly influence other important climate parameters, such as the surface latent and sensible heat fluxes and precipitation patterns (Wang 2004, Jiang *et al.* 2006, Zhang *et al.* 2007). This may have significant implications on, *e.g.,* the distribution of flood and drought areas. At present, any estimates of these effects are however highly uncertain as our knowledge of the atmospheric aerosol cycle, and its proper representation in models, is still rather limited. Aerosols will also affect human health, in particular urban regions in developing countries are suffering from health problems due to high aerosol concentrations. The effect of aerosols on economy is thus at least twofold: It may change climate variability patterns as well as human health, both of which have a direct economic influence.

The descriptions of cloud and precipitation formation in global models are also a source of uncertainty in climate change scenarios. In SWECIA we will investigate large scale flow variability and the mechanisms related to climate change. In particular we will attempt to understand how large scale redistributions of heating and cooling areas due to greenhouse gases and aerosols will affect flow regimes such as blocking and tropical waves. In addition there is a coupling between aerosol emissions, urban health problems and economic activities.

In addition to mathematical or statistical models *per se,* some effort will be invested in developing the utility of climatic indices within impact and adaptation studies. By climatic index we mean a mathematical quantity computed directly from weather or climate information to succinctly summarise complex relationships between climate and a climate-sensitive response variable, *i.e.* some form of climate impact. Climate indices have been found useful as a basis for dialogue between scientists studying impacts and stakeholders engaged in adaptation to climate change, for example, in the context of the Commission on climate and vulnerability.

Carbon cycle feedbacks will be dealt with in connection with a coupling of ESM and biology models. We will focus on the terrestrial carbon cycle. On the time scales considered, the terrestrial system has the largest potential for feedbacks (Scholze *et al.* 2006). The oceanic circulation that is less likely to contribute to strong carbon cycle feedbacks on a centennial time scale will be addressed in the later phases of SWECIA.

### 6.1.3 Work Packages

The work during the first four years of SWECIA can be broken down into 3 complementary Work Packages (WP):

WP1.1 Global climate system modelling

WP1.2 Regional climate system modelling

WP1.3 Climate change scenarios

**WP1.1 Global climate system modelling**

*Objectives*

Global modelling of the physical and biological climate system will be pursued in order to investigate processes that determine climate change on a global scale. We will also couple this with models of economy and society, thus linking the climate system change with society. One purpose is to investigate how changes in the physical climate system can be linked to the biological system which in turn determines the radiative forcing from changes in GHG concentration and land surface properties. The climate and biological models will be coupled together and further integrated with the economic models of Project 2. GHG concentrations are determined by human activities which in turn are closely related to the dynamics of the economy and society. Sudden changes in the physical climate may trigger changes in the biological as well as the economic system, both of which influence the GHG concentrations. We will look at the problem from a risk perspective, *i.e.* exploring the likelihood of sudden changes that may have a significant impact on the climate system as a whole through the feedbacks described above. The risk perspective also applies to changes in the naturally varying parts of the physical climate system, *i.e.* large-scale circulation changes.

*Research questions*

- How likely are significant changes in the large-scale circulation patterns given a change in global forcing of the physical climate system?

- What is the influence of aerosol changes on large scale circulation dynamics?

- How do changes in heat waves, drought and large scale wind forcing affect aerosol emissions and the terrestrial carbon cycle?

- How well can we capture changes in extreme events, such as storm track changes and heat waves that are likely to significantly influence biological and human life or damage economic production, capital stocks, or other infrastructure?

*Methods and approach*

EMICs will be the first class of models used in SWECIA. We are currently using a number of these, including the PUMA (Fraedrich *et al.* 2005) and the MIT model (Adcroft *et al.* 2004). The particular EMIC chosen will depend on practical aspects such as computer code efficiency and coupling possibilities. The regional aggregation of EMICs matches that of the SRES scenarios and economic models. EMICs are computationally effective for explorative mapping of parameter and uncertainty spaces, such as abrupt events. The EMIC will in SWECIA be coupled to a biogeophysical model (LPJ, Sitch *et al.* 2003, 2005) and an economic model (Project 2). This will lead into an interactive, coupled system where the development of population and technology drives emissions of GHGs, and biological and economic changes feed back to greenhouse gas emissions and climate. In focus will be not least how economic and biological processes are affected by extreme climatic events. Thus, the EMIC will be completed with statistical relations between large-scale flows and small-scale extreme events to provide an interface to biogeophysical and economy models.

The second class of global climate models used by SWECIA is the comprehensive GCM. At present, we use the CCSM3 global climate model system for studying large scale circulation dynamics, palaeoclimate change (Brandefelt 2006) and stabilisation scenarios (Wyser *et al.* 2006). It will be used also in SWECIA. We will also take part in a co-operative global climate model effort on the European arena, the EC-EARTH.

EC-EARTH is a new state-of-the art ESM, now under development as a European collaboration. It builds on the ECMWF's seasonal forecast system, a sophisticated weather prediction model. New modules for the ocean, coupler, sea-ice, land surface processes, and biogeochemistry will be added. In a first stage, however, the ECMWF's seasonal forecast system needs to be transformed into a CGCM. This involves technical (allowing for long runs, reducing amount of output, model porting) as well as scientific efforts (reducing model drift). Model components will be added in the second stage. An important development is the description of aerosol properties. Depending on how the EC-EARTH initiative develops we will decide on which global model tool to use for the planned future activities with ESMs including couplings to economic models

In SWECIA, we shall develop and use EMICs and comprehensive CGCMs for

- climate studies that involve the planetary scale bearing on regional and local phenomenon, such as oscillations (*e.g.*, how might the statistics of NAO be altered by global warming), North Atlantic storm tracks and teleconnections (*e.g.*, how does tropical convection relate to the climate in Northern Europe?) and the interaction between changes in aerosol properties and convectively driven circulation systems in the tropics (Wang 2004; Ekman *et al.* subm.).

- the production of boundary values for regional climate and impact models (see WP1.2 and Project 3) using first the SWECIA CSF (see Section 2.2) and later the results of Projects 2-3.

- for integration with the economic modelling in Project 2.

*Integration with other SWECIA projects*

Initially EMICs and statistical downscaling techniques will be used to investigate the relations between the physical climate system, biogeophysics (Project 3) and economic models (Project 2). In the longer term, we see results from CGCMs as providing new and more robust climate scenario results to be used in Project 4 as well as Project 0.

**WP1.2 Regional climate system modelling**

*Objectives*

Regional models are the principal tool to translate global physical climate model results into the regional detail necessary for national and local impact and adaptation studies. WP1.2 will develop the capacity of the present Swedish regional climate modelling system to simulate better and more of the variables requested by end-users/stakeholders. This involves better spatial and temporal resolution as well as better representation of key processes and efforts to ensure that their representation in the regional model is consistent with the driving GCM (link to WP1.1).

*Research questions*

- How can a regional model system be coupled with economy and biology models?

- How can urban effects be included in a regional model?

- How to efficiently include detailed topographical effects in a regional climate model?

- How do land surface properties, ground frost etc. affect the regional and local climate system?

- How well are heavy precipitation events and prolonged dry spells simulated in a regional climate model?

- How representative are mean and extreme wind speeds in a regional climate model?

*Methods and approach*

*Model resolution.* Regional models will be used for providing input to national and local adaptation studies (“meso” and “micro”). Swedish regional climate models at the Rossby Centre are already applied for a number of regions with state-of-the-art grid scales of ~50 and 25km. The present models manage resolutions down to around 10km. Further increases are complicated as a non-hydrostatic formulation is required and convective clouds become partly resolved. A very high model resolution is nevertheless needed to look into weather and climate extremes and for highly variable topographic conditions (*e.g.* urban environments). We shall collaborate with higher resolution model development in numerical weather prediction contexts in HIRLAM[35]. Urban areas will also be implemented in RCA (*cf.* characteristics of a town (albedo, heat capacity, hard surfaces).

*Improved representation of precipitation.* We will include stochastic clouds, and later a similar approach also for both precipitation and temperature. The idea is to provide coupled distribution functions for the sought parameters, conditioned on atmospheric variables in the model, such as humidity and cloud parameterizations. This will provide a range of outputs rather than a single value for each grid points. An advantage is the ability to create more realistic precipitation time series, since the extreme values exist within the probability density functions. Another advantage is the ability to create ensemble output from a single model projection. The work process will start with distributions based on the sub-grid scale information that is already available in the model for convective/frontal cloud formations. This will lead to better modelling of the effect of climate change on extreme events, such as flooding of urban areas and prolonged dry spells.

*Storms and extreme winds.* Increased horizontal resolution improves the simulation of mean and extreme wind speeds, but special gust parameterisations are still needed. A preliminary evaluation of these advances in RCA (Kjellström *et al.* 2005) will be extended to wind speeds

[35] http://www.hirlam.org

over sea and over land. A diagnostic storm tracking algorithm will also be implemented (*e.g.*, Hodges *et al.* 2003). Results from improved models will be analysed with respect to storm frequency and intensity as well as the climatology of mean winds and extremes.

*Climate vegetation feedbacks.* Climate and vegetation effects due to feedback mechanisms involve complex non-linear processes. As most land use changes are driven by human activity, capturing the full complexity of the climate-vegetation system requires integrated climate and dynamic vegetation models. Building on progress already made, SWECIA will implement a first version of such a model system of RCA and GUESS (Smith *et al.* 2001). This will lead to investigations of the response of vegetation to changing climate and *vice versa*. The coupled system will also be used to study the effect of land management scenarios.

*Ground frost change with implications for infrastructure.* One area of infrastructure where ground frost plays a role is for heavy transportation. This includes road and rail networks in northern and central Sweden, not least the extraction of timber from forest cutting areas. Transportation without ground frost would be devastating for the road system of today. We will prepare a model system that can simulate the processes connected to soil freezing with detail. This will open for studies related to melting of permafrost, something that might release methane captured in permafrost layers.

*Statistical downscaling methods*. In SWECIA, statistical downscaling (Wetterhall *et al.* 2006, 2007) will be used to model specific weather outcome at specific points, such as heavy precipitation in urban areas. These methods will be combined with an integrated urban runoff model for the case study of Stockholm (Amaguchi *et al.* submitted). To a great extent climate at local scales determine the specific impacts on many sectors, and therefore the appropriate adaptation strategies. The efforts will be integrated with SWECIA's climate modelling.

*Integration with other SWECIA projects*

The objective of this WP (to include specific components/parameterisations requested by end-users) will be carried out in close collaboration with Projects 2, 3 and 4. This involves concentrating on climate variables and indices that are most relevant for Projects 2 and 3, as well as steered from the Project 4 dialogue with users.

**WP1.3 Climate change scenarios**

*Objectives*

The overall aim of this work package is to provide users with climate change scenarios that are relevant for their specific applications. This breaks down into (i) To derive climate change scenarios on relevant scales and to analyse new scenarios produced with the global and regional models outlined in WP1.1-1.2, for end-users in terms of specific climate variables and climate indices. While some users will require regional scale information others will require an even finer resolution. This objective will be carried out in close cooperation with WP4.1. (ii) To compare the SWECIA scenarios with other scenarios to explore even better the uncertainties in simulated climate change.

*Research questions*

- What relevant climate change information on appropriate temporal and spatial scales can climate models provide end-users with?

- How can a few additional regionalisations help to better illustrate the overall uncertainties in regional climate change?

- How can climate change information from a few regional climate change scenarios be put into a broader perspective?

*Methods and approach*

Different users have different perspectives on the information required for adaptation to climate change. During the work with the Commission on climate and vulnerability a large set of various climate indices have been derived in co-operation with users. SWECIA will provide a scientific underpinning for user-oriented indices and investigate the derivation of new indices beyond period-averages, *e.g.* extreme percentiles during a 30-year period.

Downscaling of reanalyses like the ERA40 is used to evaluate regional models. Traditionally, this is done in terms of simulated means and some variability aspects. SWECIA will also evaluate in terms of climate indices.

Climate change scenarios will be produced and analyzed as input to Projects 2-4 and 0. In addition to available climate change scenarios, such as the IPCC-AR4 data set at NCAR/LLNL, PRUDENCE, ENSEMBLES and CES runs, SWECIA will perform own simulations and analyses of extreme events with an emphasis on Sweden. By carefully combining choice of boundary conditions, emissions scenarios and initial conditions, different sources of uncertainty will be explored (Christensen *et al.* 2007, Déqué *et al.* 2007). To begin with, the SWECIA simulations will be made at a rather coarse horizontal resolution (50km) in order to allow many simulations, based on the SRES emissions and different GCMs. The regionalisations will be transient, from present conditions to the end of the 21$^{st}$ Century. SWECIA will use its successively improved models (WP1.2). Emphasis will be on (1) the next couple of decades (the effect of sampling natural variability and choice of boundary conditions on overall uncertainty) and (2) the rest of the century (the role of boundary conditions and emissions scenarios). Building in part on ENSEMBLES, probabilistic scenario construction techniques will be incorporated.

*Integration with other SWECIA projects*

Climatological data from downscaling of reanalysis products will serve as an input for WP3.1 to determine impacts of weather-related phenomena. A comprehensive set of climate change scenarios covering various aspects of uncertainties will provide a better representation of possible future climate. This will form a basis for adaptation studies and serve as input for impact modelling in WP3.2-3.3. The climate change scenarios will be made accessible in Project 0, where the probabilistic sets of climate scenarios will also provide for risk assessments. Land-use scenarios from WP3.3 will be used in the climate scenarios. Information on end-user requested climate indices from WP3.3 and WP4.1 will be used as input.

### 6.1.4 Relationship to current international research and relevant theory, research design and methods

*Global and regional climate modelling.* So far simulations of climate, biology and economy are commonly treated separately, thus excluding possible interactions between the physical climate system, biological processes and society. Some attempts have emerged at coupling comprehensive physical climate models with biological processes (*e.g.,* Claussen *et al.* 2002). Earth system modelling is a comparatively new concept, today pursued at a few climate modelling centres/collaborations (such as Hadley Centre, IPSL, COSMOS, EC-EARTH). Restrictions in computing capacity as well as unresolved coupling issues necessitate development efforts. SWECIA will contribute to the ECMWF and EC-EARTH efforts. The latter links to other ESM efforts by means of building on the PRISM[36]-standards and the PRISM-sustained effort that the Rossby Centre is a part of.

Also regional downscaling experiments are now being pursued at higher resolutions than previously. In the PRUDENCE project a couple of years ago the standard resolution was 50km. In the present ENSEMBLES project it is 25km. These resolutions can be used even in long integrations of >100 years. In limited studies, RCMs have been applied at even higher resolutions (3-12 km) to better represent extreme events (Walser and Schär 2004, Yasunaga *et al.* 2006, Christensen and Christensen 2007, Goyette *et al.* 2003). The HIRLAM programme aims at a numerical weather prediction system with a horizontal resolution of 2.5km by 2009 in collaboration with ALADIN and AROME. SWECIA will collaborate with these efforts.

*Key climate process parameterisation development efforts.* The resolution in GCMs and RCMs of today prohibit a proper simulation of storms (Bengtsson *et al.* 2006, Rockel and Woth 2007) and affects the ability to describe atmospheric blockings. Increasing resolution improves the simulations of blockings (Pelly and Hoskins 2003), and of wind gusts. Present-day global and regional climate models tend to underestimate heavy precipitation and simulate light precipitation too frequently (Sun *et al.* 2006, Deng *et al.* 2007, Bärring *et al.* 2006). An improvement in horizontal resolution alleviates this some. A better description of clouds can provide further improvement (Tompkins 2002, Pincus *et al.* 2006). These avenues will be explored in SWECIA.

Ecosystem processes are sensitive to climate change but also affect the atmosphere via surface energy exchange, evapotranspiration, momentum transfer and, indirectly, via controls on GHG concentrations and their associated radiative forcing. Only a handful of models incorporate a carbon cycle, and even fewer take account of vegetation or land use changes. SWECIA will work for a state-of-the-art biosphere module based on validated dynamic vegetation models, incorporating new understanding and experimental results (see also Project 3). Land use changes will be taken into account and based on scenarios consistent with the CSF framework (in the initial stages of SWECIA) and economic modelling (once available from Project 2). The land use scenarios are developed as part of Project 3.

*Statistical downscaling and/or local-scale scenarios.* Statistical or empirical models are applied alongside regional climate modelling to obtain local information from GCM results (*e.g.*, Benestad 2002, Hanssen-Bauer *et al.* 2003). The quality of GCMs (Lionello *et al.* 2003) and the stationarity of empirical relationships might be questionable in many cases. SWECIA will use statistical downscaling for the most local studies and application, guarding against pitfall by a careful assessment of the chosen statistical model also in extreme climate situations (Wetterhall *et al.* 2007).

*Specific scenarios and sampling uncertainty*. The PRUDENCE project provided a unique material of more than 25 regional climate model simulations based on several GCMs, RCMs and SRES. Much of the differences between the different simulations could be related to how the different GCMs simulate the large-scale climate (Déqué *et al.* 2005). The choice of RCM was also found important for the uncertainty about higher order variability like daily variability and extremes (Kjellström *et al.* 2007, Rockel and Woth 2007). Similar work is currently being done for North America in the NARCCAP[37] project.

The European ENSEMBLES project (Hewitt 2005) develops an ensemble prediction system for climate change, in order to produce objective probabilistic estimates of uncertainty in future climate. ENSEMBLES regional modelling will focus on Europe and West Africa (the

[36] http://www.prism.enes.org/
[37] http://www.narccap.ucar.edu/abstract.html

AMMA region, GEWEX 2006). New methods to construct probabilistic estimates of climate change are being tested. These include weighting of models based on their performance and convergence criteria (Giorgi and Mearns 2003, Tebaldi *et al*. 2005). The Rossby Centre is actively involved in these parts of ENSEMBLES.

### 6.1.5 Value to users

Climate model simulations are at the heart of climate research. To make projections into the future climate models are the only simulation tools available that can give useful information. Our model development efforts in parallel with an analysis of model results leading to an improved understanding of the processes underlying climate variability will lead to

- More reliable climate scenario results.
- Better resolved climatic variables such as wind speed and precipitation changes.
- Better description of uncertainty limits and an improved understanding of natural *vs.* forced climate variability.
- User requested scenario parameters such as growing season index, thunderstorms and lightning, etc. that can be tailored to specific user needs.
- The basis for assessing how specific regions and societies may be affected by climate change.

### 6.1.6 Planned scientific and user deliverables

DX.Y.Z; D=Deliverable, M=Milestone, X.Y = specific WP (1.0 signifies a deliverable that is common to all WPs of the project), Z = running number, or Programme Year.

*Year 1*

**D1.1.1** A strategy for data exchange between EMICs, economy and biology models. Exploration of coupled model properties. (→D1.1.3, Projects 2-3)

**D1.3.1** A first set of regional climate change scenarios building on state-of-the-art GCMs downscaled with the RCA3, at 50km resolution, will be completed and analysed for Europe. At least 3 different GCMs will be used. The main focus will be on the SRES A1B emissions scenario. The regional climate change scenarios will be put into a broader perspective of climate change by comparing to the range spanned by the IPCC AR4 AOGCMs. (→WP3.3, Project 4)

*Year 2*

**D1.1.2** Aerosol module suitable for the SWECIA global and regional models constructed and tested. (→D1.1.3, D.1.3.4, D1.1.7)

**D1.1.3** First tests of EMICs coupled to biology and economy models. In particular, an evaluation of the effects on the economy and the biology of climate events and an assessment of the feasibility of further developments of the modelling concept. (→D1.1.4, Projects 2-3)

**D1.2.1** Improvement in the RCA regional climate model: of wind speed and gustiness, sub-grid scale clouds, precipitation and land surface properties including soil freezing. The existing wind gust parameterisation is improved, especially as to the land/sea contrast and for areas with complex topography. Explicit soil ice will be implemented. Methodology for downscaling RCA precipitation to urban scale (*i.e.* point scale) and application to Stockholm for use in the urban runoff model. (→D1.3.3)

**D1.2.2** Fully coupled version of RCA and GUESS is evaluated. The dynamic vegetation model GUESS is coupled to RCA to allow for vegetation/climate feedbacks. Inconsistencies between GUESS and RCA will be addressed and improvements in the RCA soil set up will be enabled to better support GUESS with forcing data for vegetation dynamics. (→D1.3.3)

**D1.2.3** RCA evaluation with respect to intensity and frequency of mid-latitude cyclones. A statistical cloud scheme coupled to a moist turbulent kinetic energy (TKE) scheme will be introduced in RCA and evaluated in a 10km resolution version of RCA. (→D1.3.5)

**D1.3.2** A comprehensive set of regional climate change scenarios, at 25km resolution, building on at least 5 GCMs and more than 10 RCMs (from ENSEMBLES and CES) are analysed with focus on Sweden in order to produce probabilistic climate change scenarios. (→WP3.3)

*Year 3*

**D1.1.4** Plan for future coupling of economy and biology models with a comprehensive CGCM, based on EMIC studies. Decision on the advanced ESM for SWECIA. (→Projects 2-3, Phase 2)

**D1.2.4** The RCA stochastic cloud scheme coupled to precipitation and temperature distributions in the hydrological models and evaluated for the present climate. A decision on new RCA-hydrological interface. (→D1.3.5)

**D1.3.3** First regional climate change scenario including the SWECIA representation of soil freezing processes (from WP1.2) will be completed and analysed. Climate change signals coupled to new implementations/improvements in RCA will be analysed. These relate to soil freezing processes, wind gustiness and climate/vegetation feedbacks. (→WP3.3)

**D1.3.4** First 20$^{th}$ Century and climate change scenario with the SWECIA CGCM/advanced ESM. The work associated with this deliverable includes setting up the model for the SWECIA applications, importing boundary conditions, performing and supervising the runs including quality-check of the results. Also, analysis of the results aiming at investigating the suitability for using the simulated climate as boundary data for the regional climate model is done. (→D1.3.7; WP2.1)

*Year 4*

**D1.1.5** Report on changes of planetary scale phenomena bearing on regional scales (oscillations, storm tracks, blocking) in climate change scenarios forced with aerosol and greenhouse gas changes.

**D1.1.6** A study of one *vs.* two-way couplings of EMICs and biology/economy models to capture features associated with climatic shocks (such as “carbon bomb”, methane release). (→WP2.1)

**D1.1.7** A completed PhD thesis in the area of climate modelling and aerosols.

**D1.2.5** High-resolution RCM integrations for present climate for Sweden using both reanalysis and GCM boundary conditions, utilizing double-nesting strategy, to achieve a resolution of 5km or better. Analysis targets, especially local wind and precipitation. (→Phase 2)

**D1.3.5** A first regional climate change scenario, for Scandinavia at 10km horizontal resolution, including the new parameterization of statistic clouds and moist turbulence (from WP1.2) will be completed and analysed, based on the SWECIA global model. (→D1.2.5, WP3.3, Project 4)

*Years 1-4*

**D1.0** Peer-reviewed articles will be produced throughout the Programme.

*Years 5-10*

Development of a more integrated earth system model on the regional scale, with a fully coupled atmosphere-ocean model, improved river routing scheme, and aerosol module. Also the global ESM will be complemented by, *e.g.*, a river routing scheme and ocean biogeochemistry.

The coupling during phase 1 of the EMIC and economic model (Project 2) will be extended to the global and regional ESMs, in pursuant of the comprehensive model system of SWECIA.

Studies related to melting of permafrost and carbon storage in northern ecosystems. The strong warming projected by climate models in the Arctic region (IPCC 2007a, ACIA 2004) will lead to increased thawing in permafrost areas. This will change surface hydrology and vegetation with consequences for infrastructure, forestry and agriculture. It will also lead to a release of methane from the frozen wet lands that will enhance the anthropogenic greenhouse effect. So far, most projections for the Arctic have been performed with global climate models and thus lack resolution needed to account for the complex surface heterogeneity.

SWECIA modelling applications focusing on other regions, such as Africa.

### 6.1.7 Project Leader and participants

- *Prof. Erland Källén*, MISU (Project Leader)
- Dr. Erik Kjellström, Rossby Centre, SMHI (deputy Project Leader)
- Associate Prof. Lars Bärring, Rossby Centre, SMHI
- Dr. Klaus Wyser, Rossby Centre, SMHI
- Fil. lic. Ulrika Willén, Rossby Centre, SMHI
- Dr. Patrick Samuelsson, Rossby Centre, SMHI
- Dr. Jonas Olsson, SMHI
- Dr. Annica Ekman, MISU
- Associate Prof. Gunilla Svensson, MISU
- Dr. Kristofer Döös, MISU
- Prof. Michael Tjernström, MISU
- Associate Prof. Ben Smith, LU
- NN, PhD student, MISU.

## 6.2 Project 2: Climate-Economy models

### 6.2.1 Significance for the Programme as a whole

An essential part of SWECIA is to develop a set of new model frameworks to study the interactions between the human economic system and the biogeophysical climate system. For short, we refer to such intergrated frameworks as climate-economy models.

Economic activity is not evenly spread over the world. Some regions are richer and more active than others. Climate change is not going to affect every region in the same way. Many existing climate-economy models, such as RICE (Nordhaus and Boyer, 2003), have a regionally disaggregated economic side, but an aggregate global earth system side where climate often is represented by global mean surface temperature. The economic processes, like adaptation, directed R&D and policy change, as well as the induced costs, are likely to depend on the regional distribution of climate change, and the modelling needs to take account of such regional differences.

The economic activities of most interest for climate change are forward-looking. Individual actors and markets act on expectations of the future climate, among other aspects. Moreover, they take risk into account. Investments, perhaps particularly in R&D, have uncertain returns, which depend on climate outcomes. The value of investments hinges on how returns correlate with consumption and production. Measures which provide some insurance can be more valuable than others, even if their expected return is lower, especially for investments with long horizons (*e.g.,* Weitzman, in press). Similarly, the value of measures for mitigation and adaptation heavily depends on their *ex-post* pay-off in case unlikely, but seriously damaging, outcomes are realized. To properly address positive as well as normative issues, the treatment has to be dynamic and probabilistic of both the economic and the biogeohysical system Compared to use of the SRES storylines (Nakićenović *et al.* 2000), SWECIA should generate risk scenarios generated from consistent climate-economy modelling in the mode of modern macroeconomics.

A key aspect of our approach is to take into account the two-way interaction between the biogeophysical climate system and the human economic system. Our aim is to construct a fully integrated model where future paths for the climate and the economy are solved simultaneously. In the early stages of the project, the interactions have to be more limited so that models for each system can be solved separately. However, definitions of regions, time resolution, etc, in the corresponding models in Projects 1 and 2 will be put on a common footing already from the beginning, to allow construction of truly consistent scenarios. This way, Project 2 will be closely connected with the research on climate processes in Project 1. Likewise, it will draw closely on the study of climate change impacts in Project 3. It will deliver comprehensive world scenarios to be used as input to the impact studies in Project 3 and as background information for the case studies in Project 4. It may also help guide the climate modelling in Project 1 towards those aspects of future change that are the most central to understand from the viewpoint of future damages. We firmly believe that the collaboration between different groups of researchers will bring climate-economy modelling a significant step forward.

### 6.2.2 Specific research issues addressed

Climate models and Earth System Models (ESM) typically take as a given starting point some future path (scenario) for the concentration of greenhouse gases or their emissions into the atmosphere. However, this approach does not take into account the two-way interaction between the climate system and the human economic system. The pace of economic growth directly affects the emissions of greenhouse gases. Climate change affects the general level of economic activity, but also the expected profitability of directed research and development (R&D) towards energy-saving technologies (such as cars with better fuel economy) and emission-reducing technologies (such as Carbon Capture and Storage), with a feed back to emissions. Explicit modelling of these interactions will be the overarching issue for Project 2.

Existing climate-economy models are valuable tools for consistent analyses of climate and the economy. But we think there is ample scope for improvement in the modelling. The lack of information on the regional and probabilistic distribution of climate change has implied that such models have rarely been used to evaluate the scope for adaptation. Most models treat the sources of technical progress – especially the efficiency of energy-saving technologies – in a relatively crude way, and as independent of realizations of climatic outcomes. We aim at improvements in three areas: (i) Interactions between the climate and the economy will be allowed to differ across regions, (ii) Uncertainty about climate outcomes will be modelled explicitly and allowed to influence adaptation behaviour by agents and evaluation of different policies for adaptation and mitigation, and (iii) Technological progress will be modelled as a reult of purposeful forward-looking investments in R&D, driven by expectations about future prices and opportunities.

We will also analyse the scope for economic adaptations mechanisms operating on a global and regional level. Examples are international insurance mechanisms using existing or new financial markets, trade and demographic mobility.

### 6.2.3 Work Packages

The work during the first four years of SWECIA can be broken down into 3 complementary Work Packages (WP):

WP2.1 Integrated and regionally disaggregated climate-economy models

WP2.2 Evaluation of the scope for global adaptation mechanisms

WP2.3 Purposeful Research and Development (R&D) and directed technical change

**WP2.1 Integrated and regionally disaggregated climate-economy models**

*Objectives*

The main aim of WP2.1 is to build a set of models that have the same regional structure on the economic side and the climate side, and which incorporate economic decision making under uncertainty.

*Research Questions*

- How do differences in the regional consequences of global climate change and their interaction with regional economic development shape the mutual feedbacks between economic development and climate change?

- How do regional distributions of temperature, precipitation, and windspeed outcomes, including extreme events as heat-waves, droughts and severe storms, affect capital stocks, production and human welfare, and how do changes in these distributions following global climate change affect regional investment behaviour?

- How large is the uncertainty about future economic and climate outcomes at the regional level, given the inherent uncertainties about future developments of factors such as population, technical change, global-to-regional climate patterns, properties of the carbon cycle, and the damages caused by changing weather?

*Methods and approach*

We will start out with a model structure encompassing 5-10 geographical regions. These may be economically interlinked to each other by trade in goods, technology and inputs in general equilibrium. The regions will also be linked to a climate model with appropriate resolution to produce distributions of weather outcomes for each of the included regions. The present state of knowledge suggests that weather outcomes will change in quite an asymmetric way across regions as the global climate warms, *e.g.*, with larger effects on mean temperatures in Northern Europe than closer to the equator (IPCC 2007a). We will also include a larger set of weather outcomes than temperature, especially rainfall and wind-speed. Moreover, we will explicitly include natural weather variation over time. Although model tractability requires that we limit the number of regions in the global disaggregation, all regions need not be symmetric in size and detail. In particular, it will be relatively straightforward to describe a smaller region like Sweden in greater detail. Because a small region has limited impact on global outcomes, the interaction is largely unidirectional.

We will also start out by modelling each region's economy as a single sector. This is not realistic, of course, but simplification is needed because solving even such a simple model will be a non-trivial task, given the forward-looking choices of consumption and investment under uncertainty (see further below). As the team gains more experience, richer models will be built, where each regional economy is disggregated into sectors of particular interest. The highest priority here will be to distinguish sectors that are more or less intensive in their land-use (or water-use): *e.g.,* agriculture and forestry *vs.* industry and services. Those extensions will allow us to investigate an additional set of mechnisms, incuding the economic causes of changes in land use and, importantly, the climate effects of alterations in land use such as deforestation.

We envisage representing prospective weather events of interest in a given region and future time period by a set of statistical distributions, conditional on the concentration of $CO_2$ in the atmosphere. Through the climate part of the model, these distributions will shift (and perhaps change shape) gradually over time, with shifts in the concentration of $CO_2$. The inclusion of regional weather events in the modelling will allow for a much more precise analysis of the damages of climate change than the current practice of approximately translating a given global average temperature into regional damages.

The extension on the climate side requires modifications on the economic side of the models. In today's climate-economy models agents in each region typically make savings/investment decisions under perfect foresight (if these activities are modelled at all). With our modifications, they have to tackle investment problems under uncertainty, because of the future risk of damage to capital stocks and production (and hence the return to capital). Moreover, forward-looking behaviour in existing models is often assumed to be of a knife-edge variety, such that it responds little to future events. While such assumptions certainly simplify the analysis, they become restrictive in contexts where one may expect large future changes in the standard of living. To inject more realism into consumption and investment in the model, we need to work with utility functions that imply a more general intertemporal response to variations in prices, incomes and interest rates.

Except for these non-trivial modifications, the first set of models will have a structure comparable to best-practice climate-economy models such as RICE (Nordhaus and Boyer 2000), which has served as a point of departure for a number of extensions.

In brief, our model will work as follows. In any given time period, given realized weather outcomes and economic outcomes, the model produces specific industrial emissions of $CO_2$.

These regional emissions provisionally end up in the global atmosphere. A carbon cycle directs carbon flows between the atmosphere, the biosphere and the ocean. This changes atmospheric concentration which, in turn, affects climate and shifts regional distributions of next period's weather outcomes. And so the stochastic dynamics continue.

*Integration with other SWECIA projects*

This work package is impossible to carry out without an intensive collaboration between the different teams in the Programme already from the very beginning. Specifically, the construction of the regionally disaggregated conditional (on global GHG) distributions for weather outcomes requires the parallel development of relatively simple climate models (EMICs) in Project 1. More generally, we hope to draw on the findings in Project 1 on ESM modelling to include a simple, empirically based, up-to-date sub-model of carbon cycle. We will also draw heavily on the impacts on a variety of economic and human outcomes estimated in Project 3 (and, of course, in other work, see, *e.g.*, Tol 2002 for a summary).

As for integration in the other direction, WP2.1 will contribute to a revised CSF, *i.e.* consistent joint scenarios for economic growth and climate change as valuable input for the other projects, especially for Project 3. These inputs will consist of probabilistic forecasts of regional output, investments, trade, emissions, demographics, and so forth. The degree of detail will be low in the early stages of the project. For example, we will start with a simple one-sector model, but may add additional sectors in each region once the simple modelling works well. The stochastic nature of the modelling will allow us to quantify the uncertainty associated with the future outcomes of interest. Moreover, we may add to the uncertainty about future climate, uncertainty about developments of socio-economic variables, technology, etc. to generate probability distributions about future outcomes (Persson and von Below 2007).

**WP2.2 Evaluation of the scope for global adaptation mechanisms**

*Objectives*

The main objective of this work package, which will largely draw on research pursued in WP2.1, is to quantitatively investigate the importance of different types of adaptation mechanisms that may operate at the global level.

*Research questions*

The damages due to realized weather events in most regions would be expected to increase as climate changes over time. Since the regional fluctuations are imperfectly correlated in any given time period, this increases the global scope for sharing the cost of the adjustment to such events among regions, after their occurrence (*ex post*), and for the mutual sharing of regional risks before their occurrence (*ex ante*). We can think about these as reactive adaptation and proactive adaptation, respectively. The main research question then becomes

- How much may different forms of adaptation, through global or regional market and adjustment mechanisms, help diminish the future costs of climate change?

*Methods and approach*

Examples of *ex post* adjustment (reactive adaptation) would be international trade in goods and services, lending and borrowing, and migration. Examples of *ex ante* risk sharing (proactive adaptation) would be trading in financial markets, especially insurance markets. By closing down *vs.* opening up these mechanisms in a well-specified climate-economy model, one can, get an estimate of how much a region will be maximally be able to diminish its costs of damages due to climate change by being able to borrow and lend internationally, or by purchasing insurance internationally. (When doing such an analysis it will be a good idea to keep the region of interest relatively small, because a simple version of the model would implicitly assume that any damaging weather shocks that wash out within the region will lead to compensating flows within the region.) It is not that we expect any qualitatively counter-intuitive result here. Being able to interact internationally will most likely be beneficial in all dimensions. However, the main issue here is not qualitative but quantitative: just how much could international markets conceivably help?

In this connection, it will be especially interesting to consider also the possibility of relatively unlikely climate related events that lead to large-scale global or regional damages. An example of the former would be a fast increase in GHG concentration through, *e.g.,* a "sudden" release of such gases from the biosphere. Drastic, rather than smooth, changes can also be due to economic and political developments. For example, some paths could lead to a breakdown of important global markets for trade and financial services. Such drastic events can partly be endogenised in our modelling by introducing thresholds for some variables such that if the threshold is passed, a drastic regime shift occurs.

Modelling drastic but unlikely catastophic events ties in with an ongoing debate among leading economists about the appropriate way to think about consumption uncertainty (Barro 2007, Weitzman 2007). The main problem with this analysis would be to calibrate the perceived or model-suggested probability and its change over time of large scale catastrophic events. A more modest (but less appealing) approach is to model the consequences of catastrophic events conditional on their occurrence.

Explicit modelling of heterogeneous regions interacting in a world economic and climate system will allow us to assess welfare outcomes both for the "whole world" and for specific regions. This is helpful, since an important part of the ongoing international discussion about future policy is really about how the impacts of climate change, and mitigation costs, can and should be internationally shared. So far, that discussion has mainly been implicit and qualitative. SWECIA will help make it explicit and quantitative. In the absence of world government, multilateral agreements on mitigation and adaptation must be self-sustaining, *i.e.* it must be in every nation's own interest to participate. The process of devising such agreements, it is necessary to have a quantitative assessment of how the welfare costs of climate change and the costs of mitigation and adaptation are regionally distributed.

*Integration with other SWECIA projects*

As in WP2.1, we rely on close collaboration with scientists in the Programme from other disciplines than economics. The scope for *ex ante* and *ex post* adaptation mechanisms to operate at the global level hinges on the future correlation of regional climate realizations, especially for extreme weather events. A meaningful calibration of such regional correlations requires a great deal of climate modelling input from Project 1. To get a handle on the probabilities of singular large-scale events, and how these probabilities conditionally change over time, will also require close collaboration with both Project 1 and Project 3.

**WP2.3 Purposeful Research and Development (R&D) and directed technical change**

*Objectives*

The research in WP2.3 will be tilted towards the end of the first four years of the Programme. Its main objective is to extend the current generation of climate-economy models with a more satisfactory modelling of technical change, including technical change specifically directed towards improving (carbon) energy-saving or emission-reducing technologies.

*Research Questions*

- How fast different regions manage to improve the energy efficiency of their production process?

- How does this form of technical change depend on current and expected future energy prices, and the uncertainty about those prices?

- To what extent can energy-saving or emission-reducing technical change in different regions be stimulated by regional policies, technical standards, or programs that facilitate international technology transfers?

- How do regional differences in the rates of growth affect the pace of emissions?

*Methods and approach*

In this work package we will try to construct climate-economy models that incorporate elements of directed technical change, *i.e.* purposeful and forward-looking investments by firms and individuals active in the R&D process. These investments may either be steered towards improving technology in general, or towards improving the efficiency of certain factors – in this case energy. (In developing regions it may be more appropriate to model the adoption of existing technologies from the rich regions of the world, but with a similar trade-off.) How much resources are vested in R&D would depend on the expected (distributions of) carbon prices, and expected government policies supporting the investments in clean technologies, or mandating certain technology standards.

In modelling technical change, we would distinguish innovations and inventions. The former are gradual improvements, adaptation and diffusion of existing technologies, whereas the latter are major technological breakthroughs. Innovations and inventions have different economic impacts (*e.g.*, Galor and Tsiddon 1997). Furthermore, while the process of innovation, at least in the aggregate, is relatively predictable and smooth, inventions are less predictable sudden events that, if they occur, may drastically affect subsequent developments. For example, cheap, reliable fusion power certainly requires a major technological breakthrough. If and when this will happen is very uncertain, but after a breakthrough global development may look very different.

In the earlier stages of the project, technology needs to be modelled in an aggregate and abstract way. In later stages, we hope to be more concrete, specifically addressing particular technologies for adaptation and mitigation. This will require input from, for example, specialists in engineering sciences.

To a certain degree, one can see a response of the pace of energy-saving technical change to a future path of higher energy prices (or of the pace of emission-educing technical change to a future path or higher emission charges) as a form of autonomous adaptation, whether the hikes of energy prices come about because of higher energy taxes, or because of increased demand for energy as countries such as China and India continue to catch up with the West.

In this context, we note that modern economic growth is quite different from growth in earlier periods such as the industrialization era. Current output growth in developed countries often takes the form of new varieties of goods with higher technology content than existing goods; new cars are simply more sophisticated than old cars, and they command higher value. But this form of growth requires basic resources and uses energy to an extent which is quite different than what we observe as China and India begin to industrialize, or if Africa were to industrialize along the same lines as the West did in the past.

In summary, the nature of growth, which clearly responds to environmental pressures, is an important component of any long-run evaluation of the interactions between the economy and the climate, and it will be examined in detail in this work package. Because of this the same global rate of growth will have very different consequences for future emissions, depending on how that growth is distributed across different regions at different levels of development.

*Integration with other SWECIA projects*

Links exist to Projects 1 and 3, although less direct ones than from WP2.1-2.2. There is an obvious link from this WP to the case study of the energy sector in Project 4, as well as to SWECIA efforts beyond the first Programme phase.

**6.2.4. Relationship to current international research and relevant theory, research design and methods**

No existing, fully specified, unified dynamic global/regional equilibrium model of climate and the economy (such as RICE) that we are aware of has a regionally disaggregated climate model. Moreover, existing models approximate regional damages and with different polynomial functions in a single climate output, namely global mean surface temperature. Some well-known integrated assessment models, such as IMAGE[38], or PAGE2002 (Hope 2003) in the Stern Review, do not really have a fully specified economic growth model by region, only a short-cut to get a path of global emissions. So we believe that modelling weather outcomes at a *regional* level, as well as modelling the direct damages of climate change as a result of the *distribution* of regional weather outcomes, are both genuinely new to climate-economy models.

From the viewpoint of modern macroeconomics, the research in WP2.1 and WP2.2 amounts to constructing quantitative dynamic stochastic general equilibrium models with heterogeneous agents (different wealth, capital stocks, and technologies in different regions). This is a research topic at the current research frontier (see Krusell and Smith 2006). Successful modelling requires highly advanced numerical solution methods. The natural approach is to use a recursive formulation of equilibrium. The optimization methods often used to solve existing climate-economy models will not work here; in fact, the restrictive assumptions used in the existing literature likely came about due to limitations in model-solving techniques. Existing solution methods also have their roots in the intended use for the first-generation models, namely to find a globally optimal path for mitigation efforts.

Some modelling questions arise in climate-economy models because of their global and long-run nature: the appropriate choice of utility functions and discount factors, and the appropriate way to address uncertainty. At first sight, these may appear to be technical problems. But as has been illustrated in the discussions following the Stern Review (Stern 2007), they raise a number of fundamental ethical principles and touch upon puzzles in economic theory (see *inter alia* Dasgupta 2006, Nordhaus 2006, Tol 2006 and Weitzman, in press). The importance of rare large-scale events is, of course, informally recognized in the literature (*e.g.* Mastrandrea and Schneider 2001), and sometimes informally added as a risk premium on top of other damages of climate change in existing models. We have seen no explicit treatment of large-scale damages, however.

When it comes to WP2.3, first-generation climate-economy models just assumed an exogenous and given rate of technological improvement (sometimes at a changing rate over time). A next step was to introduce "induced technical change" in the form of so-called learning by doing, *i.e.*, a technology becomes more efficient the more it is being used (see Clarke and

38 http://www.mnp.nl/image/

Weyant 2002 for an overview). While this was certainly a step forward, energy-saving technical progress is still a passive by-product of production rather than the result of purposeful choices in the R&D process. By and large, the modelling has not yet incorporated results from so-called new growth theory, where the pace of general technical innovation and the diffusion of new innovations to non-innovating regions are systematically related to the resources purposefully invested by firms active in the in R&D process (Aghion and Howitt 1998, Grossman and Helpman 1991, Romer 1990). More importantly for our purposes, existing research has not incorporated the insights from the more recent growth literature on directed technical change (*e.g.* Acemoglu 2002), whereby purposeful investments in R&D can be steered towards raising the efficiency of a certain factor of production, such as energy. WP2.3 can thus be understood as introducing aspects of directed technical change into climate-economy models (*cf.* Bosetti *et al.* 2006).

### 6.2.5 Value to users

Consistent climate-economy models, incorporating the features listed in the WP2.1-2.3, will be valuable tools for analysing the consequences for different regions, and generations of people, of alternative strategies to implement climate policy, such as stabilizing the global emissions. This kind of information should be valuable decision support for international policymakers trying to find a suitable compromise.

The possibility to gauge the quantitative importance of various forms of *ex ante* or *ex post* adaptation to climate change, *e.g.,* the gains from smoothly operating global insurance markets, or the response of energy-saving technology to future (distributions) of energy prices should be of value to the same public decision-makers. It may also be of use for actors trying to forecast the future stress on global or regional financial markets, or energy markets.

Having independent modelling capacity to generate consistent scenarios for regional economies and regionally relevant climate change, will also be of value within the Programme itself, for related research pursued elsewhere in the scientific community, and for other users of such scenarios. For example, as already mentioned in this section, many scientific users now take the SRES scenarios as a starting point for analyses of specific issues, such as land use. The CSF we will begin with follows this same approach. As our modelling gets under way, new consistent and independent scenarios – *i.e.* a new CSF – will be derived on the basis of clearly stated assumptions about socio-economic, biological and geophysical primitives. This will be of value for users inside and outside the scientific community, and may become particularly important when trying to evaluate the uncertainty associated with different outcomes.

### 6.2.6 Planned scientific and user deliverables

DX.Y.Z; D=Deliverable, M=Milestone, X.Y = specific WP (2.0 signifies a deliverable that is common to all WPs of the project), Z = running number, or Programme Year.

*Year 1*

**D2.1.1** A first climate-economy global model with a limited number or regions is constructed, where the regional structure and time structure is consistent with the EMIC modelling in WP1.1. The emphasis is on developing methods to solve models where weather events of interest in different regions are represented by statistical distributions that are gradually altered by climate change. At this stage, the aim is generality and model robustness, rather than realistic details. Main recipients: researchers inside SWECIA.

**D2.2.1** Pilot studies of the scope for adaptation for specific regions are undertaken. At this early stage these are done in "partial equilibrium", *i.e.* world market prices, interest rates, etc. are assumed to be determined outside of the model. Main recipients: researchers inside SWECIA.

*Year 2*

**D2.1.2** In close collaboration with Projects 1 and 3, the global climate-economy model is calibrated more carefully to particular regions including the damages caused by realized weather events. Main recipients: researchers inside SWECIA.

**D2.1.3** Specific model versions are developed, which allow some regions (Sweden, Europe) to be studied in greater detail then others when it comes to economic structure and impacts of realized weather events. Main recipients: researchers inside SWECIA, policymakers involved in climate mitigation and adaptation.

**D2.2.2** Relying on the first models developed in WP2.1, specific studies are undertaken of the adaptive capacity of financial markets, insurance markets, international trade and (perhaps) migration at the global level. Main recipients: researchers inside SWECIA, policymakers involved in climate adaptation, analysts in financial markets.

*Year 3*

**D2.1.3** Climate-economy models are used to generate consistent long-run scenarios needed in studies such as those in Project 3 of land use, ecosystem services, etc. Main recipients: researchers inside and outside SWECIA.

**D2.2.3** The modelling is integrated with that in WP2.1. The prospective regional benefits of various forms of adaptation at the global level are thus analysed in a fully specified climate-economy model. Main recipients: researchers inside and outside SWECIA, policymakers involved in climate adaptation.

**D2.3.1** Specific studies of technical change directed towards energy-saving innovations are undertaken Main recipients: researchers inside SWECIA.

*Year 4*

**D2.1.4** The climate-economy models are developed into flexible tools that can be re-calibrated and adapted to specific user needs. Main recipients: researchers outside SWECIA, policymakers involved in climate mitigation and adaptation, analysts in financial markets, various groups of stakeholders.

**D.2.1.5** Disaggregation of regions in the climate-economy models into different sectors, based on their land-use (distinguishing agriculture and forestry from industry and services). Main recipients: researchers inside and outside SWECIA.

**D2.2.4** Different scenarios with different assumptions about regional developments are modelled and used to gauge and illustrate the adaptive capacity of the world economy, including the adaptive value of global insurance mechanisms under the possibility of rare events causing large damages. Main recipients: researchers outside SWECIA, policymakers involved in climate adaptation, analysts in financial markets.

**D2.3.2** Endogenous and directed technical change with regard to energy efficiency is introduced into simple versions of the models produced in WP2.1 and WP2.2, Main recipients: researchers outside SWECIA, policymakers involved in climate mitigation, analysts in the energy sector.

*Years 1-4*

**D2.0.Yr** (Yr=1-4) Peer-reviewed articles will be produced throughout the Programme.

**D2.0.4** A PhD in Economics and a PhD in climate-economic modelling.

*Years 5-10*

Integrated global and regional earth system-economic models that can be used for scenario simulation of climate and economic variables and that, by construction, are jointly consistent. Herein a richer variety of sectors will be included, especially those that are intensive in their land-use (or water-use): *e.g.*, agriculture and forestry *vs.* industry and services.

### 6.2.7 Project Leader and participants

- *Prof. Torsten Persson*, IIES (Project Leader)
- Prof. John Hassler, IIES
- Prof. Per Krusell, IIES and Princeton.
- 1-2 PhD-students (NN), IIES
- Prof. Erland Källén, MISU (deputy project leader)
- NN, PhD-student, MISU

External collaborators:

- Dr. Conny Olovsson, Stockholm School of Economics
- Prof. Anthony Smith, Yale University

Note: Collaboration with existing groups of climate and environmental economists, in Sweden (such as at Chalmers and Gothenburg university) and abroad, will also be sought.

## 6.3 Project 3: Impact modelling and applications

### 6.3.1 Significance for the Programme as a whole

Assessing the impacts on both the environmental and societal systems of climate change is a prerequisite to translating climate and emissions scenarios into specific decision support for adaptation. Some aspects of climate will affect human beings and their activities directly, *e.g.*, the effects of heat waves or drought periods on productivity, health, and mortality, or the effects of severe storms on coastal damage. Other important impacts will be mediated by changes in ecosystems and the services they provide to society, *e.g.*, the provision of food, fuel, fibre, clean water, recreation opportunities and genetic resources (Hassan *et al.* 2005). Impact studies can also be conducted in order to specify critical amounts and types of change, *i.e.* the resilience (or its converse: vulnerability) of different systems.

Project 3 will contribute to the Programme as a whole by providing methodology, models and scenarios of specific climate impacts. In the context of the case studies (Section 6.4) potential adaptation strategies with respect to actual or prospective impacts will be defined and evaluated with respect to stakeholder objectives. The SWECIA stakeholder dialogue will be an integral part of this process of defining adaptation strategies and identifying relevant goals. Impact scenarios produced as part of the case study will form part of the material presented to stakeholders as a basis for studying the adaptation process itself in Project 4.

Impact studies in Project 3 will inform the Earth system and climate modelling in Project 1, and, similarly, the climate-economy modelling in Project 2. On the one hand they will provide process information for incorporation in the systems models (*e.g.*, vegetation, land use and carbon cycle changes). On the other hand, they will serve to focus attention on thresholds, interactions, geographic areas, etc., where a reduction of uncertainty in climate- and socio-economic modelling may particularly improve the assessment of impacts.

### 6.3.2 Specific tasks/research issues addressed

The impact types we will focus on, based on the motivation outlined in Section 2.2, are: (a) carbon balance of the terrestrial biosphere, with a particular focus on boreal and arctic ecosystems, (b) water supply, (c) agricultural, forest and biofuel production, (d) land use, (e) human productivity, health and mortality.

Impacts on biological and biophysical systems and their associated “goods and services” are often studied using process models: numerical simulators that emulate the dynamics of the system and its driving processes as driven by observed or modelled data, *e.g.*, on climate. Although the complexity of such models makes them relatively sensitive to their parameterisation, they are considered more robust compared to empirical approaches in which observed relationships between input and response variables may not be conserved, for example when applied to a warmer, high-$CO_2$ world (Mäkelä *et al.* 2000). We will employ suitable, well-validated process models to analyse climate impacts of type (a)-(c), where necessary recalibrating or otherwise adapting the model for the specific case (region, sector) to be addressed. For some types of ecosystem impacts, however, existing models are unsatisfactory. In these cases, new model components will be developed or incorporated in existing models, and thoroughly evaluated against observational data. The choice of models and the justification for the model development work planned within the project is explained in Section 6.3.4.

For impacts on complex systems that involve combinations of environmental and social dynamics (impact of type (e) above), understanding of system dynamics is generally limited, and an explicit process-oriented approach may be so complex that the development of a quantitatively credible mathematical model is unrealistic within the horizon of the proposed Programme and for application at finer, regional scales. We will then adopt the alternative approach using statistical techniques to study impacts of various weather outcomes on a certain outcome in the past, and then use model projections of the same weather outcomes in the future to get a sense of the possible impacts. This method is suitable, for example, for the study of impacts of weather outcomes on human health.

Land use change will be modelled using an optimisation approach, developed and refined in previous and current impacts research focused on the European scale (Rounsevell *et al.* 2006a,b). The approach recognises three levels in the derivation of land use scenarios that move from qualitative descriptions of global socio-economics, over regional (*e.g.* European) sector driving forces, to quantitative projections of regional land use change. An assessment is made of the total area requirement of each land use, based on commodity demands at the regional level. Scenario-specific spatial allocation rules apply these land use quantities in geographic space across the modelled region.

A global analysis will explore impacts of future climate, emissions and socio-economic change on a few key sectors, helping to describe the global context in which adaptation decisions must be taken, and informing climate and socio-economic modelling in Projects 1 and 2. The common scenario framework (CSF), initially comprising a representative subset of SRES storylines, their assumptions and associated emissions, provides the common frame linking the Projects (Section 2.2). The CSF ensures that scenarios from the three projects, taken together, constitute a consistent picture, or alternative pictures, of the future world.

Regional and sector-specific impacts will be assessed within the framework of the case studies, a Programme-wide activity. The stakeholder dialogue, likewise a Programme-wide activity will be an integral component.

### 6.3.3 Work Packages

The work during the first four years of SWECIA can be broken down into 3 complementary Work Packages (WP):

WP3.1 Quasi-experimental statistical studies

WP3.2 Global impacts and feedbacks

WP3.3 Regional impacts and adaptation

**Work Package 3.1: Quasi-experimental statistical studies**

*Objectives*

In this work package, statistical methods will be used to test hypotheses and develop statistical models of climatic impacts on human welfare and health. Objectives are:

- To develop a statistical methodology, which exploits available historical data on weather variability and outcome variables of interest regarding human welfare, health and mortality in order, to better quantify direct climate impacts on the human and economic system.

- To use such quantifications to specify the damage mechanisms embedded in climate-economy models, for improved modelling of the changes in the economy under a different future climate.

- To begin exploring the potential future impacts of climate changes on human beings, via a set of pilot studies regarding human health.

*Research questions*

- How can we best exploit the randomness of short-run weather fluctuations as quasi-experiments to infer the causal impacts of weather events on outcome variables such as human health, agricultural productivity, and so on?

- How have heat waves and cold spells affected mortality within different age and gender groups in a number of southern European countries over the last few decades?

- How have heat waves, droughts and extreme rainfall events affected infant mortality and other measures of health in a number of African countries in the last few decades?

- How do culture, living standards, availability of government assistance, and political systems interact with weather-related factors in their effect on, *e.g.*, infant mortality?

*Methods and approach*

Statistical techniques (multiple regression, panel-data methods, semi-parametric methods, etc.) will be used to relate outcome variables (*e.g.*, incidence of disease, mortality within different age/gender/social categories) to postulated driver variables including climate factors and modifying factors such as infrastructure. It is essential that the statistical analysis isolates causal effects (rather than mere correlations). This may be more convincingly achieved by using large data sets which assemble high-quality weather data and outcome data in a panel (longitudinal) form: *i.e.*, combining data for a large number of time periods and a very large number of regions at the same small grid scale.

The panel data set on weather outcomes will be obtained from existing large scale data sets, such as the CRU 0.5°, 10' and country-based surface analyses based on station data (Mitchell *et al.* 2002, 2003, New *et al.* 1999, 2000, 2002) and such global reanalyses as the ECMWF Re-Analysis ERA-40 data set (Uppala *et al.* 2005) that covers the period from 1958 to 2001 with a resolution of around 150 km[39]. The latter may be further refined by means of regional climate modelling (Project 1, WP1.3), for example for studies in Africa, where availability of long-term weather data is otherwise poor. Successful studies require that the outcome variable of interest is also available for the same time period and at the same level of resolution. Mortality data by region in Europe over the last 40 years will be available from national sources. Infant mortality in Africa over the last 30 years, and the current health of people born at different times over these 30 years, will be measured through so-called Demography and Health Surveys, where GPS data on the location of the respondents are available for as many as 25 African countries. As European and African populations live in different climates and at different levels of economic well-being, different weather events will be of interest, given the different drivers of health and mortaility (*e.g.,* chronic *vs.* infectious diseases).

Once the analysis of the historical data are completed, scenarios from Projects 1 and 2 with projected future climate and economic conditions can be used to assess the possible impacts of future climate change on mortality and health considering, of course, future trendwise improvements related to economic and medical progress.

It should be underlined that to a large degree, these initial studies will serve to develop and refine methodology. The research design (see further below) will require the resolution of a number of non-trivial issues in statistical specification and data-base management. Once these initial hurdles have been overcome, however, a similar research design can be used to gauge the impacts on a variety of variables from weather related disease in the tropics to weather related sick-leave absence in various parts of Sweden. This will be of great value when cali-

[39] and the follow-up project ERA-inter.

brating the damages of future weather outcomes in the climate-economy models to be developed in Project 2.

*Integration with other SWECIA projects*

Historical weather data, statistically downscaled to a fine spatial grid, will be provided from Project 1 and will be used to construct statistical models of the impacts of weather-related phenomena. Given the statistical analysis of historical data on some variable of interest, projections from Projects 1 and 2 will provide input data for the evaluation of the effects of future climate change and economic growth on that variable of interest. Impacts substantial enough to propagate to the global economy (*e.g.* via changes in regional affluence, economic development and demand for food) will be incorporated in integrated assessment modelling in Project 2.

**Work package 3.2: Global impacts and feedbacks**

*Objectives*

This work package will form part of a cross-cutting activity with Project 1 and Project 2 focusing on the implications of large-scale ecosystem changes on climate, economics, policy and adaptation choices. The specific objectives are:

- To improve or where necessary develop new models of large-scale climate impacts, of relevance for the modelling of global climatic and socio-economic change.

- To identify syndromes and thresholds that may possibly trigger sudden or major changes, both globally and within particular regions, with significant consequences for climate development or society.

- To contribute to describing the global context in which climate adaptation will take place and which will affect the available options by estimating major future impacts on environmental systems and ecosystem services at regional to global scales and communicating these to stakeholders in the context of the SWECIA case studies.

*Research questions*

- Can plausible changes in climate and economic activity over the next 20-100 years lead to major changes in ecosystems and land use that would significantly feed back to climate via atmospheric composition, regional energy balance, albedo or radiation forcing?

- How should nutrient constraints on primary productivity be incorporated in global ecosystem models, and to what extent might they moderate changes in agricultural and forest production, carbon sequestration and biospheric feedbacks to the climate system?

- What is the potential for changes in soil respiration and the liberation of frozen carbon in arctic and boreal soils over the coming century to accentuate greenhouse forcing and climate change?

- How may the representation of climate-driven changes in fire regimes be improved in global models, and what are the consequences of such changes for ecosystem services and the communities that depend on them, for example in the dry tropics?

*Methods and approach*

A global-scale analysis focusing on a few key sectors will generate information on potential changes in supplies of natural resources (food, fuel, water), land use, vegetation patterns and ecosystem carbon storage under a representative range of driving scenarios (climate, emissions, global demography) compatible with the CSF. This information, in regionally disaggregated form where appropriate, will be delivered to the models in Projects 1 and 2 where they will provide boundary conditions or input data (*i.e.* descriptions of factors influencing the modelled systems but not simulated internally by the models) for scenario generation and model development. The analysis will also help describe the global context, with the economic and policy constraints it implies, defining adaptation needs and constraints at the regional scale. This will be part of the stakeholder dialogue within the case studies.

For the simulations of large-scale ecosystem changes in the present work package we will initially adopt LPJ-DGVM, a widely-used global terrestrial ecosystem model that in various current incarnations is suitable for simulating the dynamics of potential natural vegetation (Hickler *et al.* 2006) but also managed forests (Zaehle *et al.* 2006) and agroecosystems (Bondeau *et al.* 2007).

An existing version of the model will be used for the first set of global impact scenarios to be prepared in the Programme (as outlined above) but the model will also be further developed by adding or improving representations of nutrient feedbacks, arctic/boreal carbon cycling and fire disturbance as well as generalised management schemes for crops and managed forests. Part of this development will be done within SWECIA, but related work within partner projects will also be utilised.

The revised model will be used in a subsequent round of scenario generation focusing particularly on biospheric changes associated with critical thresholds or major potential feedbacks to global climate or economic systems; for example, major changes in carbon cycling, vegetation patterns, food supply or global commodity prices. It will also form the basis for a vegetation and carbon cycle module to be incorporated as a dynamic component in the climate-economy model systems being developed in Projects 1 and 2.

*Integration with other SWECIA projects*

Climate data and socio-economic assumptions used for impact scenario generation will come from Projects 1 and 2. Generated impact scenarios and proposed adaptation strategies will be delivered to Project 4 for use in studies of the adaptation process. Suitably generalised formulations of ecosystem impacts will be provided to Project 1 for inclusion in ESM development and to Project 2 for inclusion in climate-economy model development. Descriptions of biospheric changes with major consequences for climate and the economic system will guide model development and scenario choices in Projects 1 and 2.

**Work Package 3.3: Regional impacts and adaptation**

*Objectives*

This work package will contribute to the regional and sectorial case studies, each comprising an integrated assessment of impacts, vulnerability, adaptive capacity and the adaptation process, focusing on a particular region and one or more of its key sectors. The contribution of Project 3 to the case studies is to:

- develop and refine a general methodology for integrated impacts assessments at the regional scale, moving beyond the limitations of current approaches (*e.g.*, by a more comprehensive treatment of uncertainties, not missing extreme/worst-case impacts).

- identify robust general patterns independent of regional diversity as a step towards defining conceptual models applicable at larger scales, particularly in the context of global climate-economy model development in Project 2.

- deliver concrete decision support in terms of impacts and adaptation options to regional and sectorial stakeholders engaged in adaptation, taking into account insights from bottom-up adaptation studies in Project 4 (*e.g.,* with regard to communication bottlenecks, institutional barriers to adaptation etc) and users' knowledge of risks, consequences, thresholds and reported needs for climate impacts information.

*Research questions*

The specific questions to be addressed will vary depending on the region and sector(s) covered by the case study. General questions to be addressed in different case studies include:

- What are the likely and possible impacts of future changes in regional climate and other environmental and socio-economic factors – as described in the case study CSF – on resources and conditions of a sector, its actors and institutions at various scales and levels of organisation?

- What are the "worst case" outcomes from the point of view of the sector and how likely are these to be realised? What does this imply for risk (in the economist's sense of expected utility: the sum of the possible outcomes multiplied by their probability) as perceived by stakeholders?

- How might the endogenous behaviour of sectorial actors in response to perceived risks and opportunities affect the impacts (*e.g.,* via management and land use decisions)?

- Taking into account the broader regional and global context, what adaptation strategies are possible and how will they affect the impacts?

*Methods and approach*

The first case studies will focus on Sweden and the Nordic countries. Relevant impacts will be modelled or, where suitable models do not exist, estimated based on best available knowledge. For some such impact types, climatic indices, defined in a dialogue with users, may be used as first-order empirical/conceptual "parameterisations" of the climate response. Input climate data will come from downscaled or reanalysis weather data (for baseline climate) and regional climate modelling (WP1.2). A database of auxiliary data relevant for some impact types (*e.g.,* N-deposition, tree species and age class distributions, soil types), will be compiled from the literature, existing databases (*e.g.* the National Forest Inventory[40]; FLUXNET[41]) or obtained via links to other projects (*e.g.* N deposition, available from ALARM).

For modelling of ecosystem services we will use the regional dynamic vegetation model LPJ-GUESS (Smith *et al.* 2001) as the baseline model. For hydrology, the baseline model will be HBV (Graham 1999). For some impact types, complementary approaches with different strengths and weaknesses are available to the project team (*e.g.* forest production). Resources allowing, we will endeavour to adopt complementary approaches both to better encompass uncertainty and facilitate interpretation. Models will of course be carefully evaluated in comparison to observed data to confirm their validity and characterise their output uncertainty.

A few key areas of uncertainty will be addressed by focused model development effort in the present work package and WP1.2. An improved representation of nutrient feedbacks on production, particularly the effect of increased C:N ratios in litter on nitrogen mineralisation and plant uptake in cold climate ecosystems such as Scandinavian forests, will be implemented within LPJ-GUESS, taking advantage of recent improvements in theoretical understanding and results from field experiments (see Section 6.3.4). A number of processes and impact

[40] http://www-riksskogstaxeringen.slu.se/
[41] http://www-eosdis.ornl.gov/FLUXNET/

types of high regional relevance (*e.g.*, forest damage by insects, pathogens, storms and other extreme weather) are currently being addressed within partner collaborations and the wider research field. We will follow developments and hope to incorporate new findings in our models in a second phase of SWECIA.

For the modelling of urban storm runoff, the model of Amaguchi *et al.* (submitted) will be set up and validated for the Stockholm urban area. The model is based on a very detailed GIS-based description of the urban environment, which allows the complex flowpaths to be traced with high accuracy. It has been set up for an urban subcatchment in Tokyo and validated against flooding observations with a very good result (Amaguchi *et al.* submitted).

Future land use scenarios for the northern European case studies will be generated by the MOLUSC model (Rounsevell *et al.* 2005) at a spatial resolution of 10' lat/long for the EU25 (current EU countries plus Norway, Iceland and Switzerland). These will be downscaled to ~ 1 $km^2$ (the resolution of relevance to local decision-makers) using a pattern scaling approach and databases previously developed in partner projects (ALARM, EcoCHANGE). The scenario logic entering MOLUSC will be defined within the project, based on the CSF. The land use modelling will apply, as far as possible, the economic boundary conditions for Europe derived from global scale being developed in Projects 1 and 2. Pending the availability of operational global models, existing SRES or ALARM storylines will be used. For later case studies in a developing country, the development of an agent-based land use model will be considered.

Within each case study, available models will be used to generate impact projections (scenarios) relevant to the sector(s) and regional stakeholders at different organizational levels or scales. For example, in the case of the Swedish forest sector, impacts as perceived by individual forest owners, forestry companies and the national forest administration (Skogsstyrelsen) might be addressed. The projected impacts will be based on and employ consistent assumptions with the CSF. In addition to the deterministic scenarios, and where model structure allows, the impact models will be used to derive conditional probabilistic futures for the northern European and other case studies. This is achieved by deriving probability density functions (PDFs) of the key model input variables that are conditional on the scenario assumptions, and some form of sampling procedure of these PDFs (*e.g.*, Monte Carlo-based) to derive probabilistic outputs of *e.g.* land use change, forest and agricultural production or runoff. Such an approach – which is novel for environmental impact assessments – will attempt to represent some of the uncertainty inherent in constructing future scenarios of specific impacts.

Within each case study, adaptation strategies will be proposed and evaluated based on the projected impacts and their consequences with respect to the specific stakeholder goals. Goals and adaptation approaches will be explored through a dialogue with relevant stakeholders, taking on board knowledge they possess as to risks, consequences, thesholds and information needs. As an example, an individual forest owner in Sweden might have the goal of maximising the economic return from her forest, while avoiding too large a risk of extensive damages. The potential impacts of climate change for this forest owner might be an increased expected return through enhanced growth rates coupled with an increased vulnerability to damages due to wind storms, insect pests and other disturbances. Potential adaptation strategies to evaluate might include changes in the choice of tree species to plant, less frequent thinning and other adaptive management.

*Integration with other SWECIA projects*

Climate data and socio-economic assumptions used for impact scenario generation will come from Projects 1 (WP1.2) and 2. Climatic indices as proxies for certain impacts will be defined in cooperation with Project 1 (WP1.2) and in discussion with stakeholders (Project 4). Generated impact scenarios and proposed adaptation strategies will be delivered to Project 4 for use in studies of the adaptation process. Insights about adaptation information needs, bottlenecks, barriers to adaptation etc. emerging from Project 4 will influence the selection of subsequent case studies, impacts addressed, and adaptation strategies evaluated. Emerging patterns that extend beyond the regional scale, if important for global economic systems, may be incorporated in the climate-economy models in Project 2. Land use scenarios will feed into the ESM/EMIC and climate-economy modelling in Projects 1 and 2. At a later stage, the climate-economy models will incorporate mechanisms that capture the causes and climate effects of changes in land use.

### 6.3.4 Relationship to current international research and relevant theory, research design and methods

Climate impact assessments have been performed within various disciplines (biology, geography, hydrology, epidemiology, economics, etc.), and the sectors associated with their object of study (forestry, agriculture, water supply, human health, mortality, etc.). International efforts such as the Millennium Ecosystem Assessment (Reid *et al.* 2005) and Working Group II of the IPCC (IPCC 2001b, 2007b) have distilled the results of many available studies into syntheses for, *e.g.*, different sectors and regions.

Consolidated attempts to assess impacts on a range of sectors in a consistent and integrated way are more unusual. A pioneering study in this regard was the EU-FP5 project ATEAM[42] which assessed the vulnerability of ecosystem services to climate change on a spatially-explicit basis across Europe for multiple sectors and a range of climate, carbon and socio-economic futures. Changes in emissions, climate and land use were based on common assumptions of selected SRES socio-economic storylines. Results were synthesised by Schröter *et al.* (2005). Similar, but more sector-focused, approaches were adopted in, *e.g.*, SilviStrat (Kellomäki and Leinonen 2005) and ACCELERATES (Rounsevell *et al.* 2006a).

SWECIA's approach will be integrative, using scenarios of environmental and societal input factors that are consistent in terms of socio-economic assumptions. The key to the integration will be the "off-the-shelf" CSF in the beginning, and model-generated integrated scenarios once these become available in Year 3-4. Compared to earlier work, SWECIA will:

- address a wider range of impact types, including direct impacts on human beings (not via changing ecosystem services) and impacts that play a key role in controlling the dynamics of climate and socio-economic systems;
- use later-generation impact models that incorporate recent improvements in process understanding;
- improve on existing statistical studies of impacts by exploiting high-quality weather outcome data over long time periods and small grid scales;
- treat uncertainties, both in the input and output data from the impact models, in a more satisfactory way by paying particular attention to the possibility of extreme events of low probability but high impact, which may considerably amplify risks compared with projections based on "mean change" alone;
- pursue comprehensive case studies of particular regions, sectors etc. that provide information on impacts and risks tailored to the needs of the end-users engaged in adaptation.

The statistical impact studies in WP3.1 aim to improve on current approaches. Most previous such studies have been based on *either* cross-sectional (across different locations) *or* time-series variation. This carries a serious danger of the true weather-related response being con-

[42] http://www.pik-potsdam.de/ateam

cealed (or artificially amplified) by confounding factors. For example, if we wish to estimate the effect of extreme temperatures on human health or mortality (Patz *et al.* 2005) from variation across locations (*e.g.*, Martens 1998) we risk confounding the effects of factors such as differences in affluence or infrastructure with differences in climates. Further, both cross-sectional and time series studies tend to be based on relatively little data, so that strong functional-form assumptions have to be made without strong *a priori* knowledge. A final concern is that, if the time series are short, and measured at high frequencies, such as days or weeks, we may run into the problem of "harvesting": some individuals that were prone to die *a priori*, do die in a heat-wave but this does not affect permanent mortality.

We will avoid these statistical problems by using detailed panel data on weather outcomes at a very fine grid scale over several decades. These data will be cleaned from different grid-specific means and different time trends across broad locations (Deschenes and Greenstone 2007a,b). By the random property of weather, the residual variations in weather outcomes across years and locations can safely be assumed non-correlated with other non-weather determinants of mortality or other outcomes of interest. This means that the weather realizations can be seen as a gigantic set of quasi-experiments with realizations randomly allocated over years and grid-points, which gives us a credible framework for unbiased statistical inference. Moreover, the resulting data sets will be very large, allowing the estimation to be carried out non-parametrically or semi-parametrically. In other words, we will not have to make too many functional-form assumptions about the relation between, say, the number of days above certain temperature thresholds and mortality.

Established models and approaches exist for the ecosystem and hydrological impacts to be considered. We will use existing models initially, investing some effort in reducing uncertainties surrounding a few key processes.

Non-linear changes and the threshold-type adjustments in the global Earth system are potentially of great importance for adaptation decisions. Today these issues are discussed much based on inferences, qualitative reasoning, and models with reduced complexity. Process-based modelling is a foundation on which more balanced and informative studies and, consequently, user dialogue, can be conducted. For the global-scale impact studies in WP3.2, we will use the Lund-Potsdam-Jena dynamic global vegetation model (LPJ-DGVM; Sitch *et al.* 2003) as the main "workhorse". It is one of the most widely-used process models of terrestrial biosphere dynamics and has been applied previously in impact studies at scales from regions to the globe (*e.g.*, Cramer *et al.* 2001; Lucht *et al.* 2002; Schröter *et al.* 2005; Schaphoff *et al.* 2006; Scholze *et al.* 2006). It is also being applied or further developed in a number of partner projects of SWECIA (CarboNorth, ENSEMBLES; see Section 5.2). Model development activities in these projects are in several cases relevant for the planned applications within SWECIA (see below), and will be available to us. LPJ-DGVM has been benchmarked in comparison to a wide range of observational data types. Its performance generally compares well with other models (Cramer *et al.* 2001; Morales *et al.* 2005), including more "specialised" sectorial models (McGuire *et al.* 2001, Gerten *et al.* 2004). Recent developments have incorporated generic algorithms for agricultural (Bondeau *et al.* 2007) and forest (Zaehle *et al.* 2006) production that parameterise adaptive management by farmers and forest managers.

When it comes to the regional case studies, process-based modelling is likewise justified. For consistency between the regional analysis of impacts and the global context ("boundary conditions") in which they occur, models with common underlying assumptions as to physical and biological mechanisms will be adopted where practicable. For the regional scale, LPJ-GUESS (Smith *et al.* 2001) will be used as the baseline tool for modelling changes in ecosystem services: it shares the same formulations of plant physiology and ecosystem biogeochemistry as the global model LPJ-DGVM (see above), but has more detailed and mechanistic vegetation dynamics, distinguishing plant populations, age groups, vertical stand structure and patch-scale heterogeneity. Individual tree species can be simulated. It has been used to model climate effects on ecosystems in Sweden (Koca *et al.* 2006a,b), Europe (Gritti *et al.* 2005; Morales *et al.* 2007), North America (Hickler *et al.* 2004) and Africa (Hély *et al.* 2004). A forest management scheme that prognostically simulates silvicultural decisions (tree species choice, thinning and harvesting regimes) has been implemented and tested for Sweden (Koca *et al.* 2006b). LPJ-GUESS is being applied or further developed in a number of partner projects of SWECIA (ALARM, CarboAfrica; see Section 5.2), and is being coupled to a regional climate model (RCA3) in work that will continue in WP1.2. Where possible we will attempt to use alternative approaches to better characterise and reduce uncertainty in the regional studies. Various specialised sectorial models are available to and currently being used within the project team, *e.g.* BIOMASS (forest production; Bergh *et al.* 2003, Bergh *et al.* in press); TRIPLEX (forest growth, N feedbacks; Peng *et al.* 2002); and WINDA (storm damage; Olofsson and Blennow 2005; Blennow and Sallnäs 2004). Further improvements will be made in regional impact models based on emerging knowledge. Questions currently being addressed in the wider community include changing disturbance regimes in forests, *e.g.* insect pests, pathogens, large herbivores, wind storms. We hope to take results from current studies on board to further constrain model behaviour and reduce uncertainty in impact projections.

Understanding of ecosystem responses to global change has advanced substantially in recent years, thanks to experimental work (*e.g.,* Rustad *et al.* 2001; Ainsworth and Long 2005) and an upswing in the availability of observational data to validate models. A number of key uncertainties remain, however. Feedbacks on production of changes in nutrient (especially N) availability under climate and atmospheric [$CO_2$] change have been widely discussed (Hungate *et al.* 2003). In cold climates, warmer temperatures may increase N mineralisation rates and amplify the climate response of growth (Bergh *et al.* 1999). At the same time, higher C:N ratios in plants growing under high-$CO_2$ may propogate to soil carbon pools where they could immobilise nitrogen and inhibit growth (Luo *et al.* 2004). The proposed mechanisms are complex and different theoretical frameworks have been proposed (Ågren and Bosatta 1996, Luo *et al.* 2004). To improve the reliability of the ecosystem modelling within SWECIA, we will develop and test suitable formulations of nutrient feedbacks on production, taking as our starting point the concept of "progressive N limitation" of Luo *et al.* (2004) and a global parameterisation suggested by Krinner *et al.* (2005), utilising recent results from field experiments (*e.g.,* Ainsworth and Long 2005) for parameterisation and validation of the improved models. Another important uncertainty concerns the carbon balance of high-latitude ecosystems under climate warming and permafrost loss. We will cooperate with CarboNorth to develop an improved modelling capacity for this potentially important feedback to the Earth system.

Land use and land cover change, including conversions and modifications in association with climate change, are some of the primary drivers of global change (Vitousek *et al.* 1997, Betts 2000, Lambin *et al.* 2003). Human decisions concerning land use will change in response to a range of driving forces of socio-economics and climate change. Different land use models were developed in recent and current research projects (ATEAM, ACCELERATES, ALARM). The land use modelling within SWECIA builds on these state-of-the-art methodologies (Rounsevell *et al.* 2005, 2006a,b), generating land use change descriptions consistent with the climate (Project 1) and economic modelling (Project 2) and their underlying assumptions. Later, the land use model will also be incorporated as a dynamic component in the climate-economy and ESM models.

### 6.3.5 Value to users and details of the user groups involved

Non-science users of the results of Project 3 include user groups directly involved in the impact assessments in the regional case studies. By contributing Earth system knowledge to more accurate climate models (Project 1) and more consistent climate-economy models (Project 2), the project will benefit all stakeholders of climate scenario information. In principle, this includes all sectors of society with a need and ability to proactively adapt to climate change. Examples of specific user groups envisaged to benefit from Project 3 research:

- the Swedish energy and forestry sectors; policy makers, planners and other municipal decision makers of Stockholm and other urban case studies;
- development agencies, in prioritising among pro-active adaptation programs, *e.g.* in the areas of health and food production, in certain developing countries.

### 6.3.6 Planned scientific and user deliverables

DX.Y.Z; D=Deliverable, M=Milestone, X.Y = specific WP (3.0 signifies a deliverable that is common to all WPs of the project), Z = running number, or Programme Year

*Year 1*

**D3.1.1** Statistical impact studies of historical weather realizations on measurable health outcomes, in Africa. The important product is the development of a methodology that can be used to estimate impacts on other outcome variables of interest. Main recipients: researchers inside and outside SWECIA, members of the health and development communities.

**D3.2.1** Global vegetation patterns and terrestrial carbon storage for time slices 2000-2100 under CSF scenarios available for non-synchronous coupling of ecosystem changes to climate in ESM development and EMIC parameterisation. Main recipients: WP1.1, 1.2.

**D3.3.1** Database of input data to regional models for Sweden under CSF. Main recipients: WP3.3.

**D3.3.2** Land use scenarios for Europe (coarse resol) and Sweden (~1 $km^2$) under CSF. Main recipients: WP1.2, 3.3, 4.1-4.3, case studies.

**D3.3.3** Application of hydrological model to Lake Mälaren based on RCM input under CSF, required to determine boundary conditions for urban storm runoff model application for Stockholm case study (D3.3.4). Recipient: WP3.3, Case Study I, Stockholm region stakeholders.

*Year 2*

**D3.1.2** Parameterisations of weather impacts on production, human population and welfare for inclusion in global-economy models in WP2.1. Main recipients: researchers inside SWECIA.

**D3.2.2** Global vegetation/ecosystem model including robust generalised formulations of nutrient feedbacks, crop production and managed forests set up and validated. Main recipients: WP3.2, climate impacts modelling community.

**D3.2.3** Scenarios of ecosystem service supply for global regions for time slices 2000-2100 under CSF scenarios available to inform climate-economy model development. Main recipients: WP2.1, 4.1-4.3, sectorial stakeholders in case studies, climate impacts community.

**D3.3.4** Urban storm runoff model adapted and tested for application to urban catchment within Stockholm City. Scenarios of urban storm runoff consistent with CSF for urban catchment in Stockholm. Recipient Case Study I, Stockholm region stakeholders – urban planners, municipal representatives etc; urban hydrology community.

**D3.3.5** Nitrogen cycling scheme for regional vegetation model implemented and tested. Main recipients: WP3.3; ecosystem dynamics community.

**D3.3.6** Impact scenarios consistent with CSF for Swedish energy sector case study. Alternative adaptation pathways described and assessed based on projected impacts and stated stakeholder objectives. Main recipients: WP 4.1-4.3, Energy sector stakeholders, *e.g.* large energy companies, policymakers.

*Year 3*

**D3.2.4** Capacity for modelling climate effects on carbon storage in boreal/arctic ecosystems including hydrology changes, methane production and losses from permafrost soils implemented within global vegetation/ecosystem model. Main recipients: WP1.1, 3.2, ecosystem dynamics community.

**D3.2.5** Process formulations (generalised, parameterised or upscaled where appropriate) of feedback processes for incorporation in ESM and/or climate-economy models: vegetation, carbon cycle, land use, agricultural production, water supply. Main recipients: WP1.1, 1.2, 2.1, 2.3; Earth system modelling community.

**D3.3.7** Impact scenarios consistent with CSF for Swedish rural area case study. Alternative adaptation pathways described and assessed based on projected impacts and stated stakeholder objectives. Main recipients WP4.1-4.3, regional and sectorial stakeholders, *e.g.* municipal planners, forestry companies and forest owners, farmers.

**D3.3.8** Evaluation of hydrological climate change scenarios in Lake Mälaren with respect to multiple water uses (*e.g.* water supply), transport etc. including a sensitivity analysis of a new outlet and regulation strategy. Main recipients: Multiple sectors and administration in Stockholm and Mälaren region.

*Year 4*

**D3.1.3** Study of weather impacts on mortality in parts of Europe with an emphasis on temperature. Main recipients: researchers inside and outside SWECIA, members of the health community.

**D3.2.6** Improved understanding of feedback process, sensitivities, critical thresholds and analysis of impacts of change in the coupled environmental-societal Earth system based on scenarios from ESMs and climate-economy models; climate change and impacts community; IPCC; post-Kyoto process; global, regional and national climate, environmental and energy policymakers.

**D3.3.9** Impact scenarios consistent with CSF-based scenarios for a Swedish sector (to be decided, *e.g.* forestry, insurance). Alternative adaptation pathways described and assessed based on projected impacts and stated stakeholder objectives. Main recipients: WP4.1-4.3, sectorial stakeholders such as forestry companies, insurance companies, national forest administration.

**D3.3.10** Scoping of agent-based modelling on land use change in an African country. Main recipients: WP3.3; land use and land use change community.

**D3.3.11** A PhD with specialist knowledge on impact and adaptation science, thesis on environmental-change impacts and adaptation analysis of a Swedish region/sector. Main recipients: climate impacts and adaptation science community.

*Years 1-4:*

**D3.3.12** Relevant information (impact scenarios and assessment) to support adaptation decisions within the sectors/regions addressed in the case study context. Main recipients: local, regional and sectorial stakeholders involved in the case studies.

**D3.0.Yr** (Yr=1-4) Peer-reviewed articles will be produced throughout the Programme. Main recipients: global change science community.

*Years 5-10:*

Further improvements in impact models based on emerging knowledge, *e.g.* forest disturbance regimes, to further constrain model behaviour and reduce uncertainty in projections. Incorporation of adaptive management as a dynamic or prescribed process in impact models to account for autonomous adaptation and evaluate adaptation alternatives. Improved modelling of land use change regionally and globally, *e.g.*, agent-based approaches. Further case studies of regions or sectors in Sweden or Europe, benefiting from an improved description of the global context in which adaptation will occur, based on the ESM-climate-economy framework and its internally-consistent scenarios of change in climate and social systems. Case studies in developing countries, *e.g.*, in Africa. Contrasting environmental and social conditions compared to the European situation will offer both opportunities and challenges for process modelling and communication of impacts information; new insights are likely. An improved suite of impact models consistent with the ESM framework from Projects 1 and 2 (network of compatible tools for assessment of impacts and adaptation options). General methodology for studies that can be made available to users, *e.g.*, consulting companies on climate adaptation. Transfer of results from impact projections to databases and tools.

### 6.3.7 Project leader and participants

- *Associate Prof. Benjamin Smith,* LU (Project Leader)
- Prof. Torsten Persson, IIES (deputy project leader)
- Associate Prof. Almut Arneth, LU
- Prof. Martin Sykes, LU
- NN, PhD student, LU
- Dr. Jonas Olsson, SMHI
- Associate Prof. David Strömberg, IIES
- Assistant Prof. Masauyki Kudamatsu, IIES

External collaborators:

- Associate Prof. Johan Bergh, SLU/Alnarp
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- Associate Prof. Michael Greenstone, MIT
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## 6.4 Project 4: The process of adaptation to climate change

### 6.4.1 Significance for the Programme as a whole

Adaptation in the context of climate change refers to any adjustment that takes place in society in response to observed or expected impacts of climate change. These adjustments can be aimed at moderating harm or at exploiting beneficial opportunities. Planning for adaptation is becoming increasingly important: the IPCC (2007a) has established that it is very likely that human activities are responsible for the observed warming. Further impacts of climate change can no longer be avoided by reducing greenhouse-gas emissions alone. Adaptation can substantially reduce many of the projected impacts of climate change.

The science of adaptation is still young. Most of the recent work has focused on understanding the concept of adaptation. Research is now needed to understand the process of adaptation. Whilst methods exist to assess the potential of adaptation options to reduce adverse impacts and enhance beneficial ones, methods to assess the feasibility of implementing such options are only in the initial stages of development. The notion of “adaptive capacity” has been introduced (Burton 1996, Smit *et al.* 2001), reflecting an awareness that the mere existence of adaptation options does not mean that each exposed community, sector or country is in a position to implement them.

Adaptive capacity can be defined as the ability of stakeholders to plan, prepare for, facilitate and implement adaptation options. Factors that determine adaptive capacity to climate change include economic wealth, technology and infrastructure, information, knowledge and skills, institutions, equity and social capital. Most industrialised countries, including Sweden, have higher adaptive capacities than developing countries. On the other hand, having adaptive capacity is no guarantee that it is used effectively. The Central European floods of 2002 and the European heatwave of 2003 showed that successful adaptation cannot be taken for granted, even in the most developed societies.

Project 4 will study the process of adaptation in society, with the aim of understanding better the factors determining the success of adaptation, and what stakeholders can do to overcome barriers to adapting to full capacity. Its role in SWECIA includes research on stakeholders’ perceptions of risk and uncertainty, and their use of climate information. It also includes research into the opportunities and motivations for stakeholders to engage in a process of social learning leading to successful adaptation. In addition, it includes research on the role of policy in facilitating adaptation, and on the respective responsibilities of the various stakeholders involved in adaptation. Thus, Project 4 is explicitly about understanding the process of adaptation: it can be seen as conducting research *on* adaptation. It contributes to and complements the research *for* adaptation carried out in the other SWECIA projects. It will provide insights on how to facilitate adaptation through information and policy, benefiting Swedish decision making and policy formulation.

### 6.4.2 Specific tasks / research issues addressed

The increasing likelihood that human activities are the driving force behind climate change, and the knowledge that climate will continue to change have made many people and organisations aware of the need to prepare for the impacts of climate change. However, it is not always clear to them what is the best way to proceed when it comes to adaptation to climate change. Questions that are commonplace include “Which adaptation options are best?”, “How much damage can adaptation avoid?”, “How can we make decisions when things are so uncertain?”, “Doesn’t the market automatically take care of adaptation?”, “Is there such a thing as adaptation policy?” and “Aren’t many things more important than climate change?”

Questions such as these suggest a need for better information on and for adaptation. Project 4 starts from the premise that knowledge on climate change and its potential impacts, whilst important for raising awareness of the need for action, must be complemented with an understanding of how stakeholders make decisions for it to be used effectively (Jones 2001, Burton *et al.* 2002, Conde and Lonsdale 2005). Project 4 will conduct research on the process of adaptation, with results from Projects 1, 2 and 3 as input. Elucidated knowledge on user needs and perceptions will be returned to Projects 1-3. Project 4 will also make use of results from other recent or ongoing initiatives, most notably the Commission on climate and vulnerability and CLIMATOOLS.

The objective of Project 4 is to improve understanding of the factors that determine the success of adaptation, and to identify opportunities for stakeholders to overcome barriers to adapting to full capacity. It will build on similar research carried out in Norway, which found that whilst requirements for adaptation may be high at the local level (also when on a national scale climate change appears manageable), stakeholders may be complacent about their own roles and responsibilities (O'Brien *et al.* 2004, 2006). The research will place particular emphasis on the way stakeholders handle uncertainties in climate projections, and on how these uncertainties influence their perceptions of climate risks along with experiences of past weather events and real or perceived limits to adaptation. Thus, the overarching research questions are as follows:

- What factors promote or hinder adaptation to climate change?
- Which climate change information is required by end users/stakeholders, how is such information best communicated, and to whom?
- Who is responsible for ensuring that adaptation to climate change is successful and how should policy be formulated and implemented so as to support adaptation efforts?

The notion of adaptive capacity is fundamental to these research questions. There are three ways in which human behaviour can be studied to explain the emergence and use of adaptive capacity in society (Pelling and High 2005). The first one focuses on the social, political and economic structures that shape entitlements to assets and so determine adaptive capacity. The second one highlights unequal power relations and information asymmetries within organisations that shape decision-making and control the social and spatial distribution of adaptive capacity. The third one, which will be central to Project 4, sees adaptive capacity as arising out of social learning embedded in social relationships.

Social learning theory is being applied to many social issues and processes, and is not unique to adaptation to climate change. There are many different definitions and approaches to social learning. High (2002) defines social learning as a transformation in the potential for behaviour of an actor in response to experience, as seen from the viewpoint of an observer. This definition includes the possibility that an actor could adapt to a particular stressor without actually being challenged to it (*i.e.*, anticipatory adaptation). Project 4, as a contribution to the case studies, will engage with stakeholders with the aims of both analysing and supporting the process of social learning for adaptation (*cf.* Conde and Lonsdale 2005, Berkhout *et al.* 2006).

Project 4 will build on the work of the Commission on climate and vulnerability. Its conclusions will inform the research design in the work packages and case studies, and thus promote high end-user relevance. Project 4 will also draw on the professional networks developed as part of the Commission's work, particularly for organising stakeholder interaction and dissemination of research results.

The case studies will be supported by all Projects. While the in-depth studies of adaptation processes in Project 4 will much centre on these cases, the contribution of Project 1 will be to provide climate scenario inputs, of Project 2 to provide economic scenarios, and of Project 3 to provide input on impacts. SWECIA partners will take steps to ensure substantial and continued integration among the projects. The joint use of the same case studies will be an important mechanism for this. Specific resources will therefore be set aside for case study co-ordination (see Project 0). The case studies will be implemented in a sequential way, with the first, on Stockholm, primarily concentrated to the first and second years. The energy sector case study will be concentrated to years two and three. Additional regional and sector studies will be planned and their implementation commences during years three and four.

For SWECIA, case studies are one of a number of research methods. The purpose is not primarily to solve a particular sector's or region's adaptation. The case studies will be used as experiments to explore particular hypotheses and study real-world examples of general phenomena[43]. The results of the case studies will be both specific and general: useful for the regions and sectors under study, and applicable in other regions and sectors. Accordingly, the *users* of the research results will likely involve a larger set of actors than those directly involved in the SWECIA case studies (see Section 3).

Swedish energy sector and the Stockholm region will be subject to the first case studies. Each case study will rely on available models to generate impact projections (scenarios) relevant to the sector(s) and region(s) under study. The case studies are described in more detail in Box 1 further down.

#### 6.4.3 Work Packages

The work during the first four years of SWECIA is broken down into 3 complementary Work Packages (WP):

WP4.1 Stakeholder mapping and climate risk perception

WP4.2 Social learning on adaptation

WP4.3 Policy analysis and integration

The major part of the research activities will be centred around case studies.

**Work Package 4.1: Stakeholder mapping and climate risk perception**

*Objectives*

- To map the institutional and decision-making landscape in case study regions and sectors.

- To analyse how perceptions of climate risks and adaptation requirements are identified and prioritized in case studies. Results are compared to other ongoing Nordic/European studies in this field.

- To provide a basis for a dialogue and carry out a process of social learning in WP4.2-4.3.

*Research questions*

- Who are concerned with facilitation and implementation of adaptation to climate risks in the Swedish society at large and specifically within the case study sectors and regions?

- How are climate scenarios perceived and is that information causing any actions to be taken within the sectors and regions?

- How is adaptation to climate risks prioritised in relation to other stresses?

- How are climate scenarios interpreted and do they lead to action?

[43] *E.g.*, within the the energy sector substantive work exploring risks and opportunities arising from a changing climate is already underway, such as the CES project described in Section 5.2.1.

- What contributes to climate risk awareness and which key factors lead to the implementation of adaptive measures in sectors and regions?

- What are perceived barriers and opportunities to the implementation of adaptation measures to climate change within sectors and institutions across scales?

*Methods and approach*

Studies of adaptive capacity in Sweden indicate that the desired process of mainstreaming climate change considerations into social planning and developmental activities has not advanced far. Major challenges lie ahead in the interaction and learning of actors and organisations, as well as the distribution of their roles. A general awareness of the need to consider climate change is evident, but actors have been hesitant to discuss tangible climate adaptation measures, suggesting that awareness needs to be combined with the reorganisation of activities, reallocation of power, and new mobilisation of social support. Existing measures generally take recent climatic variability rather than climate change as their prime starting point. The need for guidance in outlining relevant local knowledge, consequences and necessary adaptive measures related to climate change has been called for (*e.g.,* Rummukainen *et al.* 2005, Storbjörk accepted). The process of adaptation comprises different activities, carried out by public and private actors. One can distinguish between two basic institutional roles in adaptation: facilitating and implementing adaptation. The former includes information and raising awareness, removing barriers to adaptation, making available resources for adaptation and otherwise enhancing adaptive capacity. The latter includes making changes in operational practices and behaviour, and installing and operating new technologies. Analysing processes of adaptation entails focusing on both adaptation to current climate variability and future change. The former is often seen as an important starting-point for the latter (Burton 2004). When going from the global to the local level, the responsibility of relevant stakeholders shifts from facilitating adaptation to implementing it. An analysis and identification of the stakeholders and how they relate to the Swedish "adaptation community" is our starting point.

*Perception of climate risks* by stakeholders will be explored. Stakeholders within the case studies will be the main informants. Stakeholder analysis will be used to identify and select informants (European Commission 2003, Bryson 2004). Qualitative individual and focus group interviews, using participatory research methods, will be conducted. To involve stakeholders in a participatory process requires that it maximises both opportunities and motives for them to engage (Jonsson and Alkan-Olsson 2006). Varying the design of different meetings and the use of a number of facilitation tools will produce most value added (Jonsson *et al.* 2005, Jöborn *et al.* 2005). Relevant documents will be analysed as a complement. To facilitate generalisations, comparisons will be made with other ongoing case studies.

*Facilitation of adaptation*. Several studies have investigated public perceptions of climate change (*e.g.,* Bostrom *et al.* 1994, O'Connor *et al.* 1999, Grothmann and Patt 2005, Grothmann and Reusswig 2006). Studies have been initiated on perspectives and strategies of climate adaptation within the field of risk-management and planning (*e.g.* Storbjörk accepted). Perceptions among different stakeholder groups in society will have a strong bearing on how stakeholders act in decision-making. Decisions on remedy implementation depend on the factors influencing their participation, their acceptance and the existing legal and economic incentives (Jonsson and Alkan-Olsson 2006). It is important to investigate how decision-makers and sectorial stakeholders perceive climate related information. These types of issues will be investigated through group interviews.

*Implementation of adaptation.* By investigating how climate related risks are ranked and prioritized in relation to other problems will reveal how adaptation is likely to occur under current circumstances (*i.e.* with available information, policies and incentives). Stakeholders' assessments of their capacity to adapt will be investigated. Analysis of cross-scale institutional and organisational gaps and mismatches provides information on how to address adaptation in an efficient manner (Berkhout *et al.* 2004, Naess *et al.* 2005, Tompkins 2005).

A structured identification and analysis of the barriers (Trudgill 2000) or institutional constrains (Belausteguigoitia 2004) to the implementation of vulnerability reducing measures will be addressed in the case studies. In the analysis of the perception of climate factors by decision-makers and sectorial stakeholders, the customized outputs from the Projects 1-3 will be used. A ranking and prioritisation of climate-related risks in relation to other problems will reveal how likely adaptation is to occur under current circumstances.

Different users have different perspectives on climate and what information is required to adapt to climate change. The Rossby Centre has experience of tailoring climate change scenarios into the needs of users (Bärring *et al.* 2007). A large set of various climate indices has been derived in co-operation with users. Additional and more complex indices, often combination of different variables, have been suggested. In WP4.1 the need for such user-oriented indices derived from climate scenarios (Project 1) will be investigated and produced.

*Integration with other SWECIA projects*

Projects 1-3 will provide climate, economic and impact scenarios that will be used in the interactions with stakeholders. Specific demands on climate change information explored in this work package will provide information for the scenarios in Projects 1-3. Scenarios, in turn, will be used as input to the case studies. Work within WP4.1 will be closely co-ordinated with WP4.2.

**Work Package 4.2: Social learning on adaptation**

*Objectives*

- To develop a social learning framework for adaptation to climate change.

- To analyse the adaptive capacity of social and economic actors and organisations that results from processes of social learning.

- To identify opportunities for social learning as a governance mechanism in responding to climate events.

- To explore climate change as an example of a complex, unbounded problem[44] and the implications of this for learning and organisational and social change.

*Research questions*

- What can the theory of social learning contribute to promoting adaptive capacity?

- What conditions facilitate learning in organisations and society on climate adaptation?

- How does social learning on adaptation happen and what effect does it have on risk perception?

*Methods and approach*

Much of the research on climate adaptation has so far focused on describing, categorising and analysing adaptive responses (Smit *et al.* 2000). Our research focuses on another strand of adaptation research, the understanding of human behaviour that underlies observed adapta-

[44] A problem is unbounded when there is no clear agreement about exactly what the problem is, there is uncertainty and ambiguity as to how improvements might be made, and the problem has no limits in terms of the time and resources it could absorb (Chapman 2002).

tions. The overall aim is to analyse the adaptive capacity of actors and organisations that results from processes of learning embedded in social contexts, and identify opportunities for social learning as a governance mechanism to future responses to climate change. By tracing where and how learning occurs in social networks and organisations, we can contribute to an understanding how to build adaptive capacity for climate change.

We will draw on existing theory and previous experiences of adaptation to climate change and natural hazards. This will include a review of theories of learning in social and organisational contexts. To analyse the adaptive capacity of social and economic actors and organisations as a result of social learning, we need to understand the role of organisations and institutions in adaptation. Climate change might alter the assumptions that drive organisations. They, in turn, shape the cultural norms and values of individuals and offer a space for internal dissent, offering a potentially positive force for local innovation and adaptation (Pelling and High 2005). The understanding of organisations will draw on the overall analysis made in WP4.1 on the institutional and decision-making landscape.

This framework will be applied in the case studies, in which key assumptions will be field tested through a series of focus groups and workshops. By using a participatory process that combines various tools and question guide, we will move from a superficial discussion (*e.g.* brainstorming technique to articulate problems and explore the issues) to a process of concretising and structuring the identified issues (*e.g.*, mapping, problem trees) and enable communities or sectors to set priorities among key issues and identify preferred actions (ranking and action planning). This process of reflection, analysis and formulation of new issues and questions can be very empowering as the local stakeholders themselves identify solutions.

The empirical research in WP4.2 will be closely linked with WP4.1 throughout the project. The majority of participatory exercises will be co-arranged to ensure coherence, integration, transparency and time efficiency across the both work packages. The particular design of the participatory exercises to be undertaken in WP4.2 will be developed by the project team during the first year.

By being relevant to stakeholders, and by developing knowledge and providing science support, SWECIA will facilitate adaptation in Sweden in the longer term.

*Integration with other SWECIA projects*

Outputs from Projects 1-3 (model scenarios and narratives on possible futures) will be used as input into stakeholder and community based workshops and focus groups. The learning dimension can be studied fruitfully if the participatory process is designed to elicit knowledge, perceptions and concerns before the scientific framing of the discussions, as well as after scientific information is provided, allowing for informed discussions.

**Work Package 4.3: Policy analysis and integration**
*Objectives*

- To identify barriers and opportunities for integrating climate adaptation concerns into economic sectors.

- To examine institutional requirements to achieve integration of climate adaptation concerns in sectored policy making.

- To explore the benefits of stakeholder involvement in promoting integration of adaptation policies into mainstream policy formation and decision making.

*Research questions*

- What is the current preparedness and ability of government and private actors to incorporate climate adaptation into their long term policies and strategies?

- To what institutional, cultural and policy factors can we attribute any variation found in climate adaptation capacity?

- What might be a generic set of policy and institutional requirements to manage the integration of adaptation to climatic stress?

*Methods and approach*

The purpose of developing and implementing policy for adaptation is to promote and facilitate actions that reduce vulnerability and enhance resilience. In everyday policymaking, however, reducing vulnerability to future climatic stress is one of many goals and decisions on adaptation that are bound to involve uncertainty and conflict. Poorly managed uncertainty and unresolved conflicts may result in "wrong" decisions being made, or simply no action being taken. Policy integration seeks to offer a process for addressing conflicts in the face of uncertainty; it depends on the ability to understand the reasons for conflicting views amongst stakeholders (Nilsson and Eckerberg 2007). Policy analysis is instrumental in informing this process, complementing WP4.1.

This work package seeks to understand what the problems and barriers are for policy integration for social learning. Taking on a particular subset of these problems in further detail, it also aims to provide recommendations and prescriptions on how to enhance policy integration, specifically in the case studies as well as more generally. With respect to adaptation to climate change, it is crucial to understand what factors promote and hinder the integration of climate risks and uncertainties into policy processes and decision-making.

The same basic methodology will be used for all case studies. The first research component employs process tracing, and maps decisions and events in detail, along with arguments and positions taken by different actors. We will thus be able to follow several rounds of planning or management cycles, for which each round will be characterised by a certain sets of rules, actors, ideas, and agendas that dominate the process. Across rounds, there are differential patterns as issues move between levels and contexts. Variations are therefore observable both within and between cases. The second research component is a policy-analytical exercise with the purpose of understanding and discussing how generic principles for what makes policy analysis work for policy integration can play out in practice. In the analysis the social, legal, institutional and political contexts for adaptation, will be given special consideration.

Data will be collected through examination of official documentation and reports from local government and planning units (case study on Stockholm region) and actors at appropriate levels (case study Energy Sector). Researchers and interest groups; combined informant and respondent interviews, attending hearings and meetings, secondary sources of published studies, and articles in newspapers and journals will also be used as sources. Documents will be selected to represent perspectives of key actors in each policy round, as well as key policy decisions made.

*Integration with other SWECIA projects*

Output of this work package will serve as input in Projects 1-3 as "requests" for targeted and customized climate change scenarios that will fit better with the reality of decision-making and policy formulation as it has been conceptualized and studied in this work package.

In the search for “socially acceptable” solutions and levels of risk taking, the kind of results generated within Projects 1-3 will play a key role as input in the focus groups applications with stakeholders and decision makers.

**Box 1:** Case studies

**Case study I: Stockholm region**

The case study of the Stockholm region is proposed to illustrate and explore the deliberations, political interactions and formulations of co-ordinated adaptation measures at the regional level. The 26 municipalities of Stockholm County host around 21% of Sweden’s population within 2% of its land area. In the Swedish political system the regional level in Sweden is relatively weak (compared to other European countries): the system can be described as an hourglass, where the regional level is the waist (Pettersson 1998). Constraints on regional decision-making have been the subject of recent analysis (*e.g.*, Brynielsson 2003) and are clearly illustrated in the latest regional development plan for the Stockholm region, which states that “the region continues to lack efficient institutions for co-ordination and common decisions” (RTK 2002:74). The plan further argues that the division of planning and implementation responsibility amongst numerous stakeholders at different levels means that it is difficult to achieve common and joint action. Moreover, it is contended that joint action will require not only a change in institutional settings, but also better ways to reach agreement on resource allocation and investments.

The municipality of Stockholm has taken some initial steps on adaptation. Similar work may be going on in other of the region’s municipalities. However, the regions economic, social and technical infrasystems are all integrated, and for adaptation activities to be cost-effective and appropriate, local activities must be carried out bearing a regional perspective in mind.

Starting in 2006 the regional actors (the 26 municipalities, the rail track and road authorities, and the chamber of commerce among others) have jointly embarked on a process to produce a new regional development plan, due to be ready for political approval in 2010. The process is led and facilitated by the Office of Regional Planning and Urban Transportation (RTK)[45]. The plan will cover both spatial/physical and social and economic issues and thus have a truly integrative scope. Climate change impact assessment and adaptation studies will constitute some key elements of the planning process. The choice of Stockholm region as a key case study is thus particularly timely and relevant.

The Stockholm region is the only Swedish region in which a well developed, formalized and recurring regional planning process exists. The process is arguably the most advanced in the country, both in terms of scope, mandate and impact. However, as mentioned earlier, the implementation of the measures agreed upon in the planning process are largely subject to voluntary initiatives taken by individual actors, which brings attention to interesting research questions regarding why certain actions are taken and why not, and where bottlenecks and hurdles to implementation of adaptation activities exist (see below).

The Stockholm case study will focus on information needs and the institutional requirements for effective decision-making on adaptation. In practical terms the research will focus on the

[45] Over the last five years SEI has been increasingly involved in development and assessment work within the Stockholm region within the areas of environmental policy and sustainable development. The key client has been RTK. SEI continues to play a key role in the new planning process in the fields of environment and adaptation. SEI has a wide network among government and private actors in the region and is thus particularly well placed to activities such as the ones proposed here.

process of municipal structure planning[46] among the municipalities within Stockholm and how such planning has incorporated (or not) climate adaptation strategies and measures. Since municipal structure planning is something all municipalities in Sweden are concerned with, the case study will provide opportunities for drawing general conclusions applicable also elsewhere.

The results from the Stockholm case will feed into the other case studies (see below). Work in other city-regions might be pursued in the second phase of SWECIA (beyond Year 4), such as the Oslo region, which offers similar spatial and biophysical characteristics but a different legislative, political and institutional setting.

**Case study II: Energy sector**

Climate change will affect energy systems in several ways. Production, distribution and consumption of energy are all partly determined or influenced by climate. Increased frequency of extreme weather events or changing means of wind, precipitation or temperature will change the production or consumption patterns of energy. Renewable energy resources will likely become more productive and lucrative in the future, at the same time as new seasonal and geographical patterns of supply and demand need to be managed. The climate and societal conditions under which the systems operate will change and the expectation among the actors in this regard will shape the investments made and precautions taken. The system’s operational framework and conditions are in addition affected by climate policy decisions. The sum of these changes could substantially alter energy management and investment options for consumers, producers and national system operators. In order to provide a solid base for proactive and effective European and national policy making for adaptation, we have to improve our understanding of how adaptation work takes place within the energy sector and how the various actors look upon their own roles and responsibilities.

The energy sector has a long planning horizon where investments may be used for 30-100 years. Adaptation measures will therefore have to guard against substantial uncertainty, *e.g.*, regarding dam safety. The energy sector has a multi-layered structure going from global supply systems and world markets, through international and national policy and legislation, down to multinational and national companies that provide the energy to users of all sizes. The energy companies themselves are hierarchies with decision making power distributed throughout the organizations. As a case study the energy sector will provide ample room for studying how adaptation needs and opportunities are perceived and acted upon at these different operational levels. SWECIA will draw general conclusions about whether and how new information and insights are shared and acted upon within such hierarchies.

Some Programme partners are already involved in research directly connected to the energy sector. The delineation and narrowing down of the potentially vast scope of the energy case study will be an important first step in project 4, as well as exploration of various synergy opportunities with ongoing work.

**Additional case study work years 3 and 4**

Beginning in year three of SWECIA, research within Project 4 will be extended beyond the initial case studies, applying the experiences and results from the two first years of work on other regions and sectors. Most likely, one regional and one sector study will be defined, thus providing opportunities for comparisons with results from cases I and II. The final selection of those two case studies will also be informed by the results of Projects 1-3 to facilitate integration across the Programme. The selected region will be dominated by natural resource man-

[46] ”kommunal översiktsplanering”

agement (*i.e.* agriculture, forestry). A preliminary choice of second sector study would be forestry, an important sector in Sweden that will be affected by climate change.

### 6.4.4 Relationship to current international research and relevant theory, research design and methods

The Project will draw on the team's combined research experience, as well as on theory and recent practical experiences reported in the literature, the key features of which are summarised below.

*Stakeholder participation*

The past years have witnessed a growing recognition of the legitimate interest and meaningfulness of stakeholder involvement in environmental policy and resource management processes (Gerger Swartling 2002). Studies have shown that, if given the opportunity, lay publics are often capable of validating relatively technical facets of environmental issues in using their local knowledge, values and preferences (*ibid*, Wynne 1996). Indeed, studies advocate new forms of participation to cope with the new environmental challenges (Funtowicz and Ravetz 1991, Wynne 1996, Fischer 2000, Gerger Swartling 2002). There is an expanding toolbox of participatory approaches, aimed at understanding which of the variety of emerging methods is the most applicable in different contexts. By examining stakeholders' perspectives, one can get access to practical experience that is greatly needed to come to terms with the challenges discussed above.

Stakeholder participation in environmental decision-making in Sweden has traditionally been limited to consultations and *ad hoc* working groups (*e.g.*, Lundqvist 1997). However, stakeholder input into planning and decision-making is not guaranteed with conventional approaches (*e.g.*, Federal Ministry of Agriculture, Forestry, Environment and Water Management 2000). Bearing this in mind, SWECIA will investigate the potential usefulness of a particular participatory technique, the focus group method (Krueger 1994, Morgan 1988) in research on climate adaptation processes. The method has been employed worldwide since the 1950's, but is relatively unexplored in the field of sustainability assessments for policy support (Kasemir *et al.* 2003). Participatory approaches are particularly relevant in Project 4 of SWECIA, as stakeholders are the principal resource for responding to climate change impacts, and they have the current and past experience of coping with, and adapting to climate variability and extremes (Conde and Lonsdale 2005). SWECIA will draw on recent EU-wide research initiatives on participatory integrated assessment (Dürrenberger *et al.* 1997, Pahl-Wostl 2002) and focus groups.

*Social learning*

Social learning has become a popular area of research in the sustainability science and policy debate. The concept of social learning can be viewed as a participatory process designed to elucidate the nature and importance of stakeholder goals; reach democratic environmental solutions; encourage the implementation of consensus-based goals; and improve management of conflicts over, for example, natural resources (Pahl-Wostl 2002). Social learning is important in achieving sustainable resource management in complex situations with many stakeholders (SLIM 2004). Further, social learning is considered to be one of the main avenues to social change and therefore key to attaining a sustainable society (Pachet 1999).

The process of social learning is intimately linked with participatory, bottom-up approaches. It is thought to occur through the sharing of knowledge between individuals, groups and organisations in society (Social Learning Group 2001). In interacting and exchanging their views with others, stakeholders can build a shared understanding of the issues and work out co-ordinated action. An environment conducive to learning can help develop adaptive capacity through a process of mutual strengthening of knowledge, networks, resources, and willingness to find collective solutions (*cf.* Conde and Lonsdale 2005, Siebenhüner 2006). As social learning requires shifts in understanding, it has great potential for exploring the process of adaptation as this is a situation where no single person has the full answer and there is a pressing need to come up with some imaginative solutions “out of the box”. SWECIA will both study and facilitate the process of social learning on adaptation in the case studies.

*Policy integration*

Policy integration is a vibrant field of policy research. It is concerned with the ways in which climate and other sustainability-related issues become part of mainstream sectorial decision-making processes. Integration of environmental policy within public organisations, specific public policies or the central government at large has been the focus of scrutiny in several studies, and in Sweden most prominently in the Policy Integration for Sustainability project (PIntS, Nilsson and Eckerberg 2007). Academic discussions concerning integration of environmental policy has tended to focus on formal, regulative processes (Lafferty and Hovden 2003, Lenschow 2002). Some recent work explores the role of governance and social learning for policy integration (Gerger Swartling and Nilsson 2007, Nilsson 2005), taking into account both analysis of cultural understandings and power structures in policy integration (*ibid*). The results of these studies call for a merger of participatory assessment approaches with more traditional forms of decision analysis in specific policy-learning arenas (Nilsson 2006). SWECIA will explore the possible constitution of such arenas for policy learning in the context of adaptation to climate change.

### 6.4.5 Value to users and details of the user groups involved

Results of the research in Project 4 will be of direct use to those who stand to benefit from an improved understanding of adaptation processes, in particular policymakers at all levels.

Tangible outcomes will include documented increased understanding of and ability to deal effectively with climate change adaptation among case study stakeholders. In terms of documentation, assessment reports aimed directly at the stakeholders (WP4.1) and a manual/toolbox for social learning (WP4.2) will ensure that the capacity built during the course of the project will be sustained once the research activities are over.

Work within WP4.3 will directly aim at understanding the relevant policy processes and the ways in which they may address adaptation challenges more effectively. Recommendations will be made both with regard to the content and process of policy formulation in this field.

### 6.4.6 Planned scientific and user deliverables

DX.Y.Z; D=Deliverable, M=Milestone, X.Y = specific WP (4.0 signifies a deliverable that is common to all WPs of the project), Z = running number, or Programme Year.

*Year 1*

**M4.1.1** Relevant stakeholders for Stockholm region case study identified and approached. Plan for stakeholder analysis developed in consultation with stakeholders and Programme partners.

**M4.1.2** Decision on materials/results needed from Projects 1-3 for climate risk perception analysis.

**D4.1.1** Report describing stakeholder landscape for Stockholm region case study, including roles and responsibilities concerning adaptation and climate risk reduction. This report is mainly for internal purposes and is submitted to Mistra.

**M4.1.3** Detailed analysis of climate scenarios for the Stockholm region (with WP1.3).

**M4.2.1** First round of focus groups and other participatory methods completed for Stockholm region case study.

*Year 2*

**D4.3.1** Report describing policy processes and their effects on adaptation as regards municipal planning, aimed at relevant stakeholders.

**D4.0.5** Working papers summarizing results from risk perception work, social learning and policy integration work in Stockholm region case study (input to final case study report in Project 0). The final case study reports target the stakeholder community in each case study.

**M4.1.4** Relevant stakeholders for Energy case study identified and approached. Plan for stakeholder analysis developed in consultation with stakeholders and Programme partners.

**M4.1.5** Decision on materials/results needed from Projects 1-3 for climate risk perception analysis.

**D4.1.2** Report describing stakeholder landscape for Energy case study, including roles and responsibilities concerning adaptation and climate risk reduction. This report is mainly for internal purposes and submitted to Mistra.

**M4.0.6** Detailed analysis of climate scenarios for the Energy sector (with WP1.3)

**M4.2.2** First round of focus groups and other participatory methods completed for Energy case study.

**M4.0.7** International workshop convening experts on risk perception, social learning and policy integration in the context of climate adaptation.

**D4.2.1** Draft report on framework for social learning on adaptation (theory and concepts applicable in the Swecia context), for internal research purposes, to be submitted to Mistra.

*Year 3*

**D4.3.2** Report describing policy processes and their effects on adaptation as regards the energy sector, aimed at relevant stakeholders.

**D4.0.8** Working papers summarizing results from risk perception work, social learning and policy integration work in energy case study (input to final case study report in Project 0). The final case study reports target the stakeholder community in each case study.

**D4.1.3** Analytical comparison of results from the case studies with other national and international studies on climate risk perception, and adaptation. This deliverable will either be in the form of a report or a journal article manuscript, targeted at both interested stakeholders and the academic community.

**M4.0.9** Analysis and planning of suitable complementary case studies. Agreement on scope and approach coordinated with Projects 1-3.

**D4.0.10** Report describing stakeholder landscape for subsequent case studies, including roles and responsibilities concerning adaptation and climate risk reduction.

*Year 4*

**D4.0.11** Synthesis reports on climate risk perception, social learning and policy integration for all case studies.

**D4.3.3** Synthesis report and popular report on research findings for stakeholders and the public.

**D4.0.12 Working papers** summarizing results from risk perception work, social learning and policy integration work in subsequent case studies (input to final case study reports in Project 0). The final case study reports target the stakeholder community in each case study.

*Years 1-4*

**D4.0.Yr** (Yr=1-4) Peer-reviewed articles, relevant to national and international scientific communities.

*Years 5-10*

The long-term outcome of Project 4 will be an improved ability to consider climate risks not only in policy and decision-making but also in sector research (*e.g.*, forestry, health, water). In addition, Project 4 should be able to provide a template for linking modeling research and participatory research. Such a template would make it possible to extend the methodology of SWECIA beyond the case studies to all of Sweden, as well as to other countries.

### 6.4.7 Project leader and participants

- *Dr. Richard Klein,* SEI (Project Leader)
- Associate Prof. Ben Smith, Lund University (deputy project leader)
- Prof. Katarina Eckerberg, SEI
- Dr. Åsa Gerger Swartling, SEI
- Dr. Måns Nilsson, SEI
- Oskar Wallgren, SEI PhD candidate
- Associate Prof. Lars Bärring, SMHI

Collaborators

- Assistant Prof. Louise Simonsson Forsberg, Linköping University

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