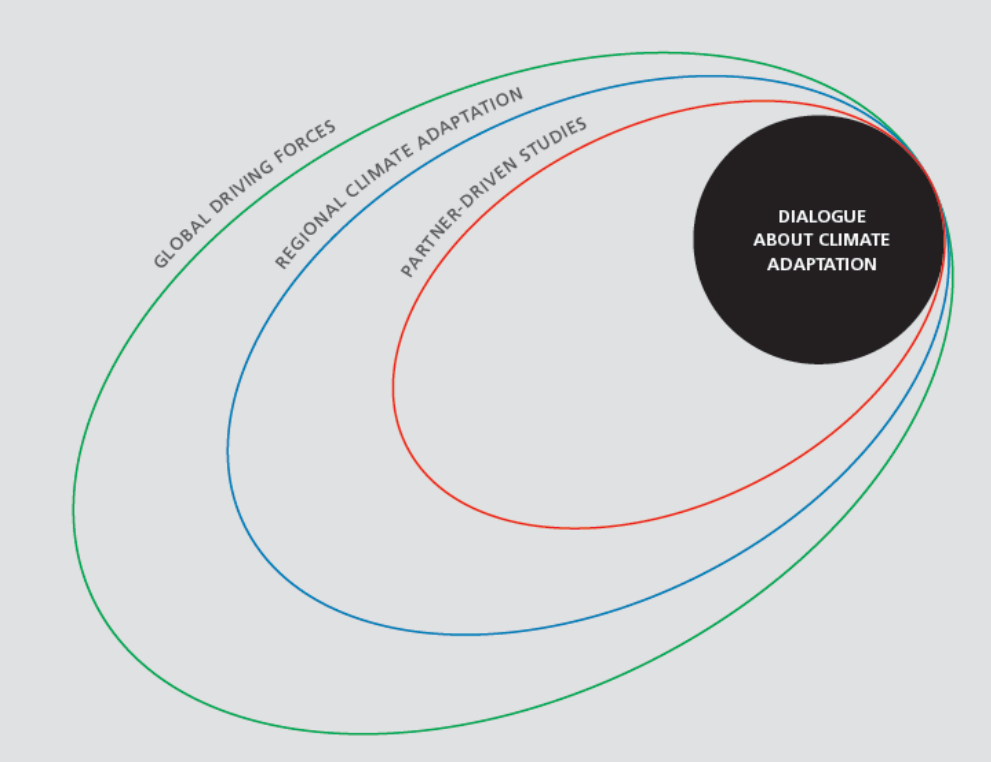
MISTRA SWECIA
CLIMATE, IMPACTS & ADAPTATION

Mistra-SWECIA 2008-2015

Impact Report

A summary of the main outcomes and payoff to society

15 September, 2015



Mistra-SWECIA's research dimensions.

Mistra-SWECIA IMPACT REPORT: A summary of the main outcomes and payoff to society

Contents

Annexes

Introduction

From the Phase II Programme Plan, Vision:

Mistra-SWECIA aims to provide high quality and salient scientific support for informing climate change adaptation, working with stakeholders within and across different sectors and at a range of scales. Stakeholders will benefit from focused decision-support and an enhanced capacity to translate scientific information into practical knowledge for underpinning decisions. Researchers are offered the promise of a long-term legacy of advanced interdisciplinary research on climate change adaptation across the fields of climate science, economics, life sciences and social sciences. For researchers and stakeholders alike, Mistra-SWECIA presents an ideal arena for science-policy dialogue and problem-based research. problem-based research that promotes relevance, synergy and scientific innovation.

Mistra-SWECIA – the Swedish research programme on climate, impacts and adaptation has been an eight-year collaborative effort between the Swedish Meteorological and Hydrological Institute (SMHI), Stockholm (MISU, IIES) and Lund Universities (ULUND) and the Stockholm Environment Institute (SEI). University of Edinburgh and the Swedish University of Agricultural Sciences (SLU) have collaborated as affiliates. In all, around 75 staff has contributed to Mistra-SWECIA during 2008-2015 as researchers, students, in outreach and others.

The aim in the programme has been to pursue new and interdisciplinary research on adaptation as a process (actors, processes, promoting factors, obstacles) and research on supporting knowledge for adaptation (climate scenarios, climate impacts, economic factors), including bridges between these two areas, new tools and engaging with stakeholders.

At its inception, Mistra-SWECIA gathered a team with expertise in climate modelling, policical sciences, ecosystem sciences, and economics. Whereas some of the teams had worked together already in the past, others had not. This implied both a potential for novel research and a risk on how the programme would develop.

In Phase I of the programme (2008-2011), the programme recorded notable successes and achievements relative to its original goals (see Mistra-SWECIA Phase I Progress report). At the same time, it was concluded that some of the research goals that had been set remained within basic research, and might not come to extensive use during the overall programme period. Rather, they would come to enable the next wave of generation of novel knowledge.

In Phase II of the programme (2012-2015), the research that had matured was further developed and applied, and there was considerable advancement of emphasis on stakeholder interaction and dissemination of results. Based on the work done so far, the evolution of relevant climate adaptation landscapes, the recommendations of the mid-term evaluation and the outcome of scoping with stakeholder communities, the Phase II focus was put on forests and forestry in Sweden, acknowledging the importance of multiple scales, actors and goals, and including relevant global driving forces (see illustration on the cover page of this report). The development of climate-economy modelling, Agent-Based-Modelling and very-high-resolution climate modelling continued as forward-looking research, but with significant input from the rest of the programme.

Phase II built on tools and interdisciplinary insights from Phase I. Reflecting the maturation of the collaborations, the programme was realigned from the earlier disciplinary structure to two thematic interdisciplinary research components. A third component was dedicated to activities for bridging science, policy and practice through partner-driven studies and synthesis. Including the subcomponents, the Phase II programme organization thus became:

Component I: Regional adaptation

1. Research on climate change adaptation processes
2. Research on regional climate modelling: high resolution climate projections, impact modelling and risk assessment

Component II: Global drivers

3. Climate-economy modelling
4. Global Climate Projections
5. Land use narratives

Component III: Partner-driven studies and synthesis

Main outcomes and payoff to society

By the end of the second programme phase, Mistra-SWECIA will have delivered eight years of increasingly integrated and user-oriented advanced research of relevance to climate adaptation challenges and possibilities. The three main outcomes that were foreseen will be delivered, which is described in the subsequent sections of this report:

- Forging a core group of interdisciplinary Swedish climate scientists with established collaboration and a demonstrated ability to produce top-class research.
- Contributions to the development of solid Swedish capacity for integrated model-based analysis of climate change, related impacts and economic assessments of such change, combined with deepened understanding of sector-related climate change adaptation processes, institutions and interactions.
- Development and demonstration of the utility of a sustained interactive model for outreach, decision-support and communication on climate change and adaptation.

In the rest of this report, only a selection of key references is explicitly cited. A fuller account of the programme's societal value, research outcomes and other contributions is available in the annual reports and in the wealth of published briefs, reports, working papers, scientific articles, presentations, users' reflections and organized events.

Phase I activities and outcomes are documented in the mid-term programme report and evaluation, and not described below.

Value to stakeholders and societal impact

While Phase I of the programme was focused on building up the interdisciplinary collaboration and research, in the second phase, larger emphasis has been on dialogue and collaborative efforts with stakeholders. The researcher-stakeholder platform developed within Component III has been the main vehicle for this. The participatory research activities, joint outreach activities and communication have further leveraged the research efforts. The full value and impact of the programme will of course continue unfolding over the coming years, but there are already now clear and identifiable impacts in addition to "normal" outreach activities. Prominent examples are highlighted below.

Science-policy interface

In phase II, specific resources were dedicated for interaction between the research done within Mistra-SWECIA and stakeholders who in one way or another are present in the Swedish forest sector. A working group of Mistra-SWECIA researchers and stakeholders was formed as the platform for this work. Stakeholders were represented by three county administrative boards (Uppsala, Gävle, Västmanland), the Swedish Forest Agency, the Federation of Swedish Family Forest Owners (LRF Skogsägarna), Holmen Skog (the forest management branch of the forest industry concern Holmen Group) and the Swedish National Knowledge Centre for Climate Change Adaptation, at SMHI.

The group has had bi-annual meetings during which common areas of interests have been identified. Subsequent decisions have been made to highlight or investigate specific topics in more detail, either by organizing events (seminars, workshops, excursions) or by carrying out research studies. The "events" component was more in demand among the stakeholders, and for this reason hosted the majority of the activities:

Seminar/workshop (November 2012, Stockholm): a seminar with 60 participants from academia, the forest sector and climate change adaptation professionals. Focus was on the need for decision support systems in the forest sector. Insights were that the sector is not so much in need of new tools, but these aspects need to be incorporated in already existing tools and that information and advice need to better highlight adaptation. Insights were fed into ongoing Mistra-SWECIA research on climate change adaptation strategies and climate change communication.

Excursion (September 2013, Västmanland County): A two-day forest excursion in Västmanland. Climate change impacts and adaptation strategies were discussed in the field with 50 participants from academia, government agencies and the private sector. See the article "Climate adaptation in Swedish forestry" in Annual Report 2013 and the Mistra-SWECIA Swedish homepage.

Guidelines for sustainable forestry (2014-2015): In the study "Climate effects and adaptation strategies in Swedish forestry: the example of Holmen Skog", results from Mistra-SWECIA's research on climate change adaptation strategies for Swedish forestry was applied to Holmen Skog's forest holdings throughout Sweden. Regional climate change and expected impacts were assessed and adaptation strategies were suggested. This work was carried out in cooperation with Holmen Skog and it fed into the work in updating Holmen Skog's *Guidelines for Sustainable Forestry*. A first version of a decision support tool was also developed.

Erik Normark, Research and development director, Holmen:

The review of the guidelines [for sustainable forestry] has given me more confidence. I have given a talk on climate adaptation at the Royal Swedish Academy of Agriculture and Forestry. The review has also contributed to Holmen's positioning, we show what we think and are not without answers regarding the climate issue anymore. The review was a useful exercise in how to act [regarding climate change].

Roundtable (September 2014, Stockholm) "Conservation and protection of forest landscapes in a changing climate" brought together 20 participants from academia, government agencies, forest owners associations and forest certification schemes. For example representatives from the Ministry of the Environment and from the Environmental Protection Agency professed that the discussions provided important input into ongoing policy processes regarding biodiversity conservation and establishment of nature reserves. See the article "Climate-friendly forest conservation" in the Annual Report 2014.

Måns Enander, responsible for climate adaptation, County administrative board Västmanland:

Mistra SWECIA has highly guided me in how I should adjust my climate adaptation work. For example, I want to look at the planned land use in forestry in our county, and I have also become aware of landscape planning in forestry. I have also realized the importance of understanding that actors have different motivations: some might be driven by pure idealism and passion, others by sentimentality, a third group by profit and the fourth is perhaps totally indifferent, and so on. These properties mix to completely different skills among the forest owners. I had not earlier really realized the depth and breadth of these differences.

Forest excursion (September 2015, Västmanland) was organized in cooperation with Föreningen Skogen (The Swedish Forestry Association). The excursion ventured into the area that was affected by the 2014 forest fire, which was the largest one in Sweden in recorded history. More than 120 participants from the forest sector, academia, insurance industry as well as members of the parliament partook. The excursion focused on how to deal with strategic risks in forestry and society, especially those related to climate change.

In addition to these activities, the work within Mistra-SWECIA has also yielded spinoff projects, directly or indirectly building on the work done within the programme.

Projects with specific relevance for stakeholders

During the programme Mistra-SWECIA developed tools for professionals, inspired by the science/practitioner/policy interactions, and based on the research within the programme.

Plantval is a tool developed by Skogforsk to optimise forest regeneration material. It was originally based on current climate information. In collaboration with Skogforsk the tool has been complemented with climate scenario data based on state-of-the-art regional climate scenarios. (See [in Swedish]: www.skogforsk.se).

A changing climate for businesses. One part of this project was to cooperate with the business incubator KRINOVA on how companies within the land use sector will be affected by climate change and how they can meet the new risks and possibilities. Together with companies the topic was investigated and a method for addressing climate-related risks and possibilities in a strategic way was developed. See the articles "Climate related risks and opportunities for agriculture and forestry businesses" and "Warmer climate increases opportunities for commercial vegetable farming" in the Annual Report 2014.

Evaluation of a climate change communication project of the Swedish Forest Agency provided a quantitative assessment of the effectiveness of professional Climate Change Communication (CCC) in engaging people with adaptation. The CCC project in question had been run by the Swedish Forestry Agency. The empirical data for the evaluation came from a survey sent out to 6000 forestry owners in Sweden (see Annexes: Case Study 1). Half of these forest owners had taken part in the CCC project. The other half was randomly sampled and formed a control group. The analysis looked into whether perceptions and attitudes about climate risks and adaptation measures differed significantly between the two groups of forest owners. The results will have been presented in three of the forest journals in Sweden by the end of 2015 and they provide

valuable insights for particularly the Swedish Forest Agency but also others into how CCC can become more successful in engaging certain target groups with climate change. See the article "National survey of forestry professionals in Sweden" in the Annual Report 2014.

Annette Arvidsson, the Forest Agency:

Very many of us have been working with climate projects. Now, based on an independent study, we can provide them with feedback and affirm that the work was successful,. It is a result of the cooperation with Mistra-SWECIA. The most important is that we can influence large forest owners attitude for climate adaptation, but for us it is really important to also know that we can achieve that outcome and show to those who worked on the issue here. The results have a high credibility because we did not do the study ourselves, but it was done externally by someone who also has a broader perspective.

Participatory research on climate adaptation decision-making among private forest owners in Sweden is actually part of the Mistra-SWECIA research efforts, but it also had tangible societal impact outcomes. It was based on a participatory process with private forest owners in Sweden during 2013-2014. All in all, seven focus groups, with a total of 49 private forest owners from four counties met at three separate occasions to discuss forestry and forestry management, climate change, and adaptation.

The process was highly valuable to both the forest owners and the involved researchers. The dialogues stimulated learning and exchange of knowledge between all those engaged. In follow-up interviews with forest owners several of them mentioned that the discussions led to new perspectives, and increased interest for issues related to climate change. Several forest owners have also expressed an interest in keeping the acquired network of forest owners alive and that they are keen on taking part of the results of Mistra-SWECIA.

Excerpts from the forest owners' reflections on the experience:

It was really positive to participate, a pause for thought that made you think in a different way.

I thought it was worthwhile [to participate], first to confirm a bit what you've been thinking about but at the same becoming a bit adjusted in your [way of thinking]. You've got a little more flesh on the bones of things you [have already] thought about.

I think it has been a positive experience to discuss these issues with other forest owners that also are operative in the practical reality. That means a lot. The question is maybe not something you always think of but through your presence it became structured. To raise these different issues and discuss them, together with this alternation with new knowledge […] and my previous experience and so on… this is a good way…

I think it's been interesting to think about issues I haven't heard about earlier when it comes to forest management. One the one hand to receive comments from the other participants and on the other the structure of the discussions that I think has been nice. All in all I think it was a positive experience.

I think that it has been very rewarding to sit and talk with other forest owners. To hear how they think and how they look at different things and their experiences and so on. It's not something you might do every day; it was like a new forum that you could do it.

Also, see the article "Adaptation processes in forestry", describing the related research in Phase I, in the Annual Report 2013.

Climate adaptation of forestry: A new tool based on ecosystem modelling for climate adaptation has been developed (Annexes: Case Study 2). It identifies how common forest decisions and actions relate to short and long term aspects of weather and climate conditions that can cause damage to forest ecosystems. The work within Mistra-SWECIA has included interactions with stakeholders such as the Swedish Forestry Agency, the forestry company Holmen Skog, county administrative boards, the forest owner association LRF Forest, and individual forest owners.

The Swedish Forest Agency has shown interest in our research through invitation to various meetings, and Holmen Skog by requesting a report on climate change adaptation. See the article "Climate, decisions and strategies in forestry" in the Annual Report 2014.

Indirect impacts of climate change: A global index and the case of Sweden This research address a hitherto relatively little researched area of such impacts of climate change that will not be confined to some bounded region, but transfer between neighbouring regions and also across long distances. Mistra-SWECIA has leveraged other ongoing research efforts looking at the global scale, and initiated research focusing on indirect climate change impacts on Sweden and forestry in Sweden. The work has gained interest within the Foreign Ministry of Sweden.

Other outreach

News, results, events and some commentary was distributed over the programme's home pages in Swedish and English and in almost 200 public lectures and presentations, in addition to scientific presentations in research meetings and suchlike. A complete record of communication activities and presentations can be found in the successive Annual Reports.

In addition to activities and communication specifically by the programme, outreach activities have targeted communication vehicles and arenas already familiar to stakeholders, for example forestry journals and activities organized by other relevant organisations. For example, the programme's researchers have made presentations in activities organized by the Forest Agency (e.g. at The Forest Agency's forest owners days in 2012), seminars organized by the County Administrative Boards (e.g. in Jämtland 2013 and in Östergötland 2014), and a co-organised seminar at the Royal Swedish Academy of Agriculture and Forestry (see the article Forestry in a changing climate in the Annual Report 2013).

Researchers from the programme have also been interviewed and contributed with articles in the established forestry journals in Sweden, such as SkogsEko, SkogsAktuellt and Skogen, as well as other media.

Prominent examples or co-organisation or significant contributions in meetings that cater to both the researcher and stakeholder communities include:

- Mistra-SWECIA has presented at, and in years co-organized, the most influential annual Swedish climate adaptation conference Climate Adaptation Sweden, which gathers professionals from all sectors. (For the 2015 event, see http://miljoaktuellt.event.idg.se/event/klimatanpassning-sverige-2015/)
- Mistra-SWECIA co-organised, sponsored and presented at the Second and the Third Nordic International Conference on Climate Change Adaptation in 2012 and 2014, respectively. These targeted both researchers and stakeholders and enabled the programme to display its research findings, dialogue with research and stakeholder communities and networking. (See http://www.nordicadaptation2012.net ; http://nordicadaptation2014.net).
- During the European Climate Change Adaptation Conference (ECCA) 2015, Mistra-SWECIA hosted two sessions focusing on driving forces and forest owners' climate-related decisions. The conference gathered researchers, policy-makers and practitioners. One conclusion was that it is very important for both governmental authorities and researchers to be aware about different drivers for decision-making in order to communicate information and advice in an efficient way. (More information about the sessions can be found on the Mistra-SWECIA home page.)
- Mistra-SWECIA's research has also been presented to the Ministry of Finance, the Ministry of the Environment and the Foreign Ministry, at government agencies and in seminars for

the Swedish parliament (see, e.g., the article "International cooperation can mitigate climate change" in the Annual Report 2013).

Finally, the researchers in climate economy are now seen as key experts in this area. The Ministry of Finance has drawn on their knowledge and research for advice on specific climate-related questions in informal meetings (with Ministers and State Secretaries). The researchers were also invited to a private meeting with the Chinese Premier, to discuss desirable climate change policy for China. It was well received and they have been invited for a second, similar high-profile meeting in China. They also participated in the Caixin Summit on Reform. Their work has been covered in key media in China, like the China Central TV, CCTV and the business magazine Caixin.

Åsa Sterte, Desk officer, Ministry of Finance:

The knowledge from Mistra SWECIA's research gives [her] and her colleagues at the ministry a firmer ground when arguing for general policy instruments in the daily work, when briefing politicians and when preparing other materials. The carbon dioxide issue is complex, with aspects such as indirect effects and different emission sectors and policies. What the researchers have done has been made very pedagogic and easy to understand – even if the math is complicated, it is easy to find the arguments in their material.

Two important outreach products will be added by the end of 2015. One of these is a synthesis report on the programme's collected research and dialogues. It targets Swedish forest professionals and it is written in Swedish. The second is an extended Annual Report that will present the programme's outcomes and updates the outlined research agenda and research questions that were posed at the start of the programme. The final Annual Report will be written in English with the science community as its principal target group.

Participation in other forums and panels

Programme participants have had prominent roles in different forums and panels, which has provided further leverage for outreach, as well as collecting input for programme planning and activities. Examples include the following:

- Mistra-SWECIA researchers have contributed to the IPCC's Fifth Assessment Report (AR5). Markku Rummukainen as Lead Author, and Anders Ahlström as a Contributing Author in WGI based on his dissertation. Richard Klein was Coordinating Lead Author in WGII.
- SEI was invited to be in the programme council for the Swedish Government's National Forest Program, led by the Minister for Rural Affairs. The objective of the programme is to develop a long-term forest strategy for Sweden.
- During 2014, a study of the Swedish climate adaptation efforts was undertaken in anticipation of the [Climate Policy] Control Station 2015. The investigation of climate adaptation was coordinated by the SMHI. Mistra-SWECIA researchers' participated in the workshops and provided material.
- John Hassler, IIES, has been commissioned a member of the scientific council regarding the programme for climate and environment at the Swedish think tank FORES. The researchers from IIES are also active in a number of other forums, where their knowledge on climate economy comes to use (e.g., John Hassler is Chair of the Swedish Fiscal Policy Council).

Scientific value and cutting edge-research

The scientific value and standing of the programme's research during 2012-2015 (Phase II) is discussed below. For the earlier programme years, we refer to the mid-term evaluation materials, and for the research questions and other framing of Phase II, to the Phase II programme plan.

A full account of the scientific value is found in the published research and presentations. The two programme periods have resulted in more than 100 scientific articles and more than 40 reports as well as a number of popular science publications and presentations over 2008-2014, and details are available in the annual reports. Publications in 2015 have not yet been summarized.

The first two sections below highlight Mistra-SWECIA's components I and II. The third section highlights new research opportunities that result from the Mistra-SWECIA developments. A common theme in the research is increasing interdisciplinarity, with natural and social sciences collaboration on one hand and economists and natural scientists on the other. These links have resulted in new understanding of pertinent issues, new research tools and new collaboration potential also in the long term. This would hardly have developed without Mistra-SWECIA.

Regional adaptation

Climate change adaptation processes

The research on regional adaptation in Phase II of the programme builds on the advances from Phase I on regional climate scenarios, impact studies, and case studies on adaptation processes. Work during Phase II followed an interdisciplinary science-stakeholder research process shaped by both new scientific insights and stakeholders' perspectives. A core objective has been to advance the understanding of the subjective factors and processes behind emerging adaptation processes and provide deeper insights into the complex realities of stakeholder decision-making strategies and behaviour.

For the purpose of the research, an interdisciplinary and integrative methodology was developed, combining social sciences on adaptation, climate scenarios and impact research. This unique participatory methodology builds on the concept of science-based stakeholder dialogues. The methodology comprises qualitative (André et al. 2012) as well as quantitative methods (see Figure 1). The main research component has been a vertical case study of the Swedish forestry sector. The planning, execution and evaluation of the research was led by SEI (adaptation process etc.) with support from researchers from SMHI (climate) and ULUND (climate impacts).

The qualitative research comprised focus groups, individual interviews and workshops. The research took place in four representative counties of Sweden (Skåne, Västerbotten, Gävleborg, Jämtland), with contrasting climatic and societal conditions for forestry, focusing particularly on private forest owners and their attitudes, needs and concerns. In addition to research outcomes, the participatory exercises also provided opportunities for stakeholders' and researchers' knowledge exchange and collaborative learning.

The quantitative research encompassed a survey of 6000 forest owners and 1000 forestry professionals. The study grew out of recognition of a lack of quantitative studies in the existing literature and an ambition to target a larger number of forest owners. The survey included questions about perceptions and attitudes of climate change risks and adaptation measures and a social network analysis (Vulturius et al. forthcoming A). The response rates were 43 percent and 32 percent, respectively. The survey ranks amongst the most comprehensive studies on forest managers ever conducted in the Nordic countries. Data from this survey also supports the development of the Agent Based Model (see below). In addition a social network analysis (André et al. forthcoming) was conducted that combined qualitative and quantitative insights.

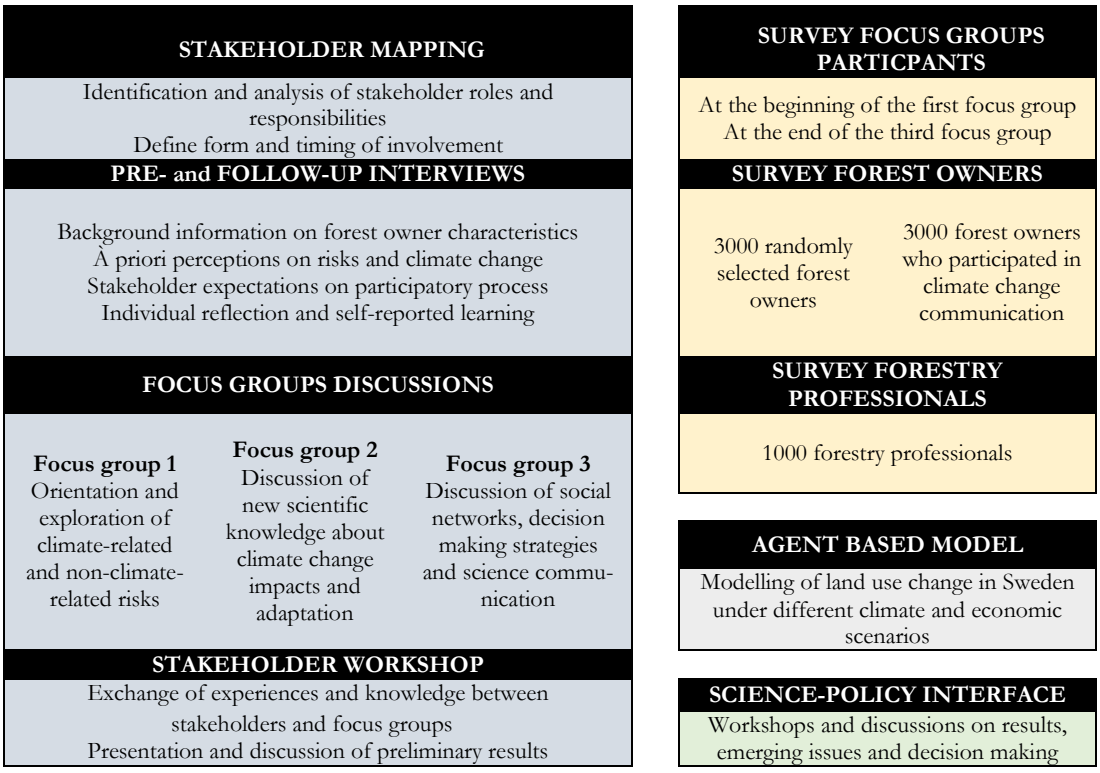


Figure 1. The methodological framework showing the combination of qualitative and quantitative methods. The left hand column represents the different methods used as part of the participatory process and the right hand column quantitative methods as part of both the participatory process and the national survey. The grey box represents the work with an agent-based model that is informed by the qualitative and quantitative studies. The green box illustrates the science-policy interface that has been supported by the research.

The mixed approach enabled a combination of in-depth qualitative insights and broad quantitative information, and provided a basis for cross-validation and contextualization of the findings. Results from the research point to different challenges, opportunities and motivations facing the forestry sector from the perspective of Swedish forest owners (André and Jonsson 2015, André 2013, André et al forthcoming, Gerger Swartling et al. 2015, Vulturius and Gerger Swartling 2015, Vulturius et al. forthcoming A). Climate change is one factor amongst others that affects the stakeholders' preferences and capacity to adapt. Findings show that there exists a relatively high level of practical knowledge and experience with risk mitigation and that these two factors, together with trust in climate science, risk awareness and experience with extreme events are key drivers behind adaptation processes. Coordination and collaboration among forest owners and between forest owners and authorities, stakeholder organisations and commercial companies is another critical issue. Results also show that there is a gap between scientific information on climate change and forest owners' practical needs that this gap can overcome with more targeted science communication (Vulturius et al. forthcoming B). Taken together, the study advances research on climate change adaptation by leveraging insights from social and natural sciences into adaptation processes with a comprehensive methodological design (Gerger Swartling et al., forthcoming).

Agent-based modelling

An agent-based model (ABM) has been developed within Mistra-SWECIA, to be applied to exploration and improved understanding of structural changes in socio-ecological systems associated with forestry, and the adaptation of this sector to climate change in Sweden. The model, CRAFTY-Sweden, is underpinned by a typology describing the decision-making responses of forest managers in response to internal (e.g. forest productivity) and external (e.g. global prices, policy, culture and norms) factors affecting their estate. The model also builds on a generalised

mapping of the institutional networks affecting the forest sector, the interactions between institutions and between institutions and land users. CRAFTY-Sweden is novel in that it allows exploration of land-use change at national scales, and to study adaptation to climate change by incorporating the decision-making strategies and management preferences of forest owners, and their effects on land-use and ecosystem service provision at such large scales (Blanco et al. 2015). Furthermore, it is state-of-the-art in that it will allow simulating the actions and interactions of different types of institutions with land and land owners. The findings will have academic value in that they advance the research in land-use simulation and provide new knowledge about the Swedish land-use system. The findings are also meant to have a value in informing and engaging in dialogue with forestry stakeholders around the implications of alternative actions in response to biophysical and socio-economic factors affecting forest growth.

The ABM is still being finalised but will ultimately used to predict different levels of ecosystem service provision across Sweden, given the assumed behaviour of forest agents and institutions in response to climate change and its impacts on forests. Also, they will provide quantifications of possible future land-use and of forest owner type distribution. From these, identification of the most successful owner objectives and management strategies in adapting to climate change and changing service demands during a 90 year period (2010-2100) can be pursued.

Indirect effects

During Phase II, work has also been initiated on indirect impacts of climate change. In recent years there has been an increased recognition that impacts of climate change are not generally confined with e.g. administrative borders. It is obvious that a small, highly globalised, and export dependent country like Sweden will be impacted by climate change in Sweden, but also by impacts outside Sweden. Surprisingly little attention has been paid to this aspect of climate change. The work within Mistra-SWECIA has focused on developing a conceptual model of indirect impacts, a model that can be applied to regions (e.g. Sweden) or sectors of society (e.g. forestry). Preliminary results for Sweden indicate that Sweden's connections to climate vulnerable countries lies mostly within food imports and migrations flows.

Regional climate modelling: high resolution climate projections, impact modelling and risk assessment

Knowledge of climate change, its expected impacts and evolving and new risks is provided by climate science. Such scientific knowledge does not by itself enable adaptation, but it frames the challenge and also can be forged into practical tools and information to stakeholders. Mistra-SWECIA's research has considered global and regional modelling of climate, land use and impacts on natural and managed ecosystems, with a particular focus on croplands, managed forests and Arctic ecosystems. This provides a powerful basis for addressing impacts of climate and socio-economic projections on forestry, nature conservation and other land uses. Such information may seem "theoretical" to users; research within the programme has endeavoured to interpret, discuss and bring such knowledge closer to users' experiences for example through the focus group interactions outlined above. Additionally, science-based tools have been developed together with users (see above the Section "Value to stakeholders and societal impact").

High-resolution climate projections

Mistra-SWECIA has supported the development of a state-of-the-art high-resolution RCM, HARMONIE-Climate (HCLIM, Lindstedt et al. 2015, Lind et al. 2015). Based on past experiences, users desire high-resolution climate change information both for the local connection and in terms of expectations on changing climate extremes. Cutting edge very-high resolution models (temporal resolution of minutes, spatial resolution of 1-3 km) are very computer resource demanding, and only a limited number of institutes invest serious research efforts in this area. The contribution from Mistra-SWECIA has made it possible for Sweden to attain a leading position

in these developments. Nevertheless, HCLIM will not be ready for extensive use before the end of the programme. The development of HCLIM is planned to continue well beyond the end of Mistra-SWECIA. RCM-based research has in other ways well served the overall programme, as is detailed below. The HCLIM is further described as a case study (Annexes: Case Study 3).

Within the framework of CORDEX, Rossby Centre has produced more than 100 downscalings of CMIP5 climate scenarios, the largest downscaling effort by any climate centre worldwide. A large number of scenarios is important because it is the only well-established way to quantify uncertainties due to different climate models and emission scenarios.

That the utility of climate scenarios to user's benefits from dialogue between them and scientists has been recognised in Mistra-SWECIA's participatory research. This is evidenced by comments by participants in our focus groups and the follow up interview. In addition, Mistra-SWECIA has developed objective methods for getting beyond the general recommendation to users which that as many scenarios as possible should be used to encompass uncertainty. With respect to this research focus of the programme, the work has culminated in the "Ensemble reduction method" for selecting an optimal subset of scenarios, representative of uncertainty, taking into account the specific demands of the study in question (Wilcke and Bärring, submitted). The method has been successfully applied and is currently evaluated in combination with various categories of impact models.

"Plantval" is a tool originally developed by Skogforsk based on current climate observations to optimise forest regeneration material. Since trees have a life span comparable to the period into the future for which we expect a significant change in climate, an adaptation of the tool is warranted for taking into account climate change. Together with Skogforsk, the tool has been complemented with regional climate scenarios (Berlin et al. 2014). The development of the tool itself initiated parallel development which has been useful in similar applications.

Impact modelling and risk assessment

During Mistra-SWECIA, state-of-the-art descriptions of biosphere-climate response for regional and global climate/Earth System Models (ESM) have been developed, ultimately enabling more realistic future projections and more coherent assessments of the impacts of future climate. Reflections from users have been taken aboard in the model development. The research has engaged several of Mistra-SWECIA's partners and has thus had an interdisciplinary flavour.

The model-based analysis of impacts and risks has fed into empirical research on decision making and adaptation of forest sector actors (see above), and the outcome links to interdisciplinary analysis of ecosystem services, socio-economic interactions and policy for sustainable forest management. The work has also led to international cooperation on a review on modelling of natural disturbances in forest ecosystems (Seidl et al. 2011), with further research being under way in the EU-project EUPORIAS.

The Mistra-SWECIA research on climate impacts and adaptation options in forestry in Sweden has been based on ecosystem modelling as a tool to understand how climate change can influence tree phenology and growth (Jönsson and Bärring, 2011a, Jönsson et al. 2015), risk of damage (e.g. storm damage (Lagergren et al. 2012), frost damage (Jönsson and Bärring 2011a) and attack by spruce bark beetle (Jönsson and Bärring 2011b, Jönsson et al. 2012, Marini et al. 2013), and economic outcomes and forest biodiversity (Jönsson et al. 2015, Laurent et al. submitted). Scenarios based on climate modelling and ecosystem modelling have been used to characterise factors influencing forest management choices and economic and ecological outcomes to highlight needs and opportunities for adaptation on Swedish forestry. One important research area has been development of forest management, storm damage and bark beetle modules in the regionally-optimised ecosystem model LPJ-GUESS (Lagergren et al. 2012, Jönsson et al. 2012) and studies on how climate change and forest management can influence the risk of spruce bark beetle out-

breaks at the landscape level (Bergh et al. 2012, Marini et al. 2013, Bentz and Jönsson 2015). Another area has concerned development of strategies for climate adaptation within the forestry sector (Jönsson 2013). Science-stakeholder interactions with regard to forest sector adaptation have elicited land owners' preferences for alternative adaptation strategies and management options. The assessments include aspects related to the need for knowledge- based decision support (Jönsson and Gerger Swartling 2014). This line of research within Mistra-SWECIA has culminated in an analysis of adaptation strategies for Swedish forestry in the face of climate change, the first such assessment built on process-based forest growth modelling and accounting for economic implications of climate-related changes in growth, disturbance-related risks and management costs (Jönsson et al. 2015).

An overall finding is that climate change will affect the likelihood of climate and weather events that can cause damage to forest ecosystems. Exposure and sensitivity are two aspects of risk that can be influenced by forest management, for example, by climate-adapted management, landscape planning, and to minimize the losses by being prepared to take action if damage occurs. Planning for the future also concerns the development of new methods for forest management, wood products and plant material. The goal should be to strive for a long-term sustainable forestry that can produce a variety of ecosystem services. A better understanding of the role of biodiversity in production forests may lead to the development of forest management strategies to promote forests with a high resistance and resilience.

Global drivers

Climate-economy modelling

The Mistra-SWECIA research on climate-economy opened up a new research area in Sweden, involving economists and natural scientists. The aim has been to build integrated assessment models, IAMs, jointly describing the economy and the climate, that both break new ground on the international research frontier and are useful for policymakers as well as for other stakeholders. Excellent progress has been made both in model development, gaining new scientific insights and establishing new interdisciplinary collaborations. The programme's economists did not have prior background in either climate research or environmental economics in general (rather, on topics including macroeconomics and economic growth). Significant investments had to be made to share macroeconomics and growth and the natural-science elements of climate change, respectively, for progress in model development.

The programme's IAM modelling has two novelties. First, the IAM's economics build firmly on structures that are amenable to welfare and policy analysis (allowing one to trace out and quantify the effects of different interventions such as carbon taxes, regulation, etc.). Second, it has high resolution and global scope. The climate and carbon cycle in these IAMs are simple enough to feasibly merge with dynamic stochastic general equilibrium (DSGE) models. One of the key requirements for the latter is the forward-looking of economic agents: to allow them to react today – in their consumption, investment, and energy use behaviour – to what is expected to occur in the future (e.g., climate change, future taxes, and so on). Forward-looking is unique to economic models and is challenging to combine with natural-science models. Economic models can therefore only contain a handful of dynamic climate variables (such as the global mean temperature and the atmospheric CO_2-concentration). The programme's strategy has been to find simple but robust representations of key processes that only use these variables. This has been achieved both for the terrestrial biosphere, and for the ocean carbon cycle. Relative to the previous research frontier in IAM modelling the work has proceeded on two fronts; a simplified one-region model and a multi-region high resolution one described in brief below, followed by short accounts of new components.

A simplified one-region model

The first of the two fronts was about simplifying existing structures and develop them into regular DSGE models. Golosov et al. (2014) documents the resulting streamlined, and from an analytical point of view, pure DSGE version of Nordhaus's leading DICE model. The results are already widely cited, which implies that the issue of climate change is taken into main-stream macroeconomics, in contrast to the previous large literature on climate change and economic in specialized journals and with less attention from more general macroeconomists.

A multiregional model with high resolution

The second front has been to develop a high-resolution global model (one-degree resolution). The work is ground-breaking compared to any other multi-region IAM in the world. The work has taken a much longer time than expected, and there is still some calibration work to be done. Nevertheless, it has now advanced to near the submission stage for a set of papers.

Climate, vegetation and carbon cycle integration in the IAMs

Several aspects of climate change affect the carbon balance of the terrestrial biosphere. The dynamic vegetation model (LPJ-GUESS) has been used to craft an emulator that captures the driver-response relationships of the full model in a simple enough way to be included in the IAMs. The terrestrial biosphere is relevant both in the description of how agriculture (as a part of the economy) is affected by the climate, and for the global carbon cycle and its interactions with greenhouse gas concentrations in the atmosphere. The emulator consists of a few analytic equations that describe how the productivity of main agricultural products depends on latitude, atmospheric CO_2 and the local climate. The latter is managed via pattern scaling of climate models to quantify how local temperature and precipitation change due to an increase of the global mean temperature. The pattern scaling was determined from a suite of climate scenarios from the CMIP5 archive. The pattern scaling together with the emulator provides an estimate of the change of the agricultural production under climate change.

The terrestrial biosphere is also an important part of the global carbon system. An emulator, consisting of a single dynamic equation, has been formulated with the help of climate models and LPJ-GUESS. It describes how the terrestrial part of the carbon cycle evolves with CO_2-concentration and the global mean temperature. The emulator also becomes a part of the IAM.

The ocean carbon system is a vital part of the coupled climate-economy model. The ocean carbonate chemistry also introduces the main nonlinearity of the climate system: the fraction of the emitted CO_2 that is eventually absorbed by the ocean decreases as the accumulated emissions increase. This is because the ocean's buffer system saturates at large emissions. A simple description of this effect is needed in the IAM. A simple nonlinear model of the ocean carbon system has therefore been derived and implemented in the IAM. Together with the emulator of the terrestrial carbon reservoir mentioned above, it forms a simple but complete description of the carbon cycle on relevant time scales. This is the first time such a nonlinear model of the carbon system has been coupled to a forward-looking macro-economic model.

Global Climate Projections

Research into global climate projections has been a part of Mistra-SWECIA, as an in kind effort, benefiting from the partners' networks and other research engagements. This has facilitated the provision of climate change information both directly (part of globally-developed narratives) and indirectly when global climate projections have been used as boundary conditions for regional climate scenarios and consequently as input to impact and risk assessments and other framing of dialogues with users. The main focus in global climate projections has been the development of the EC-Earth Earth system model in a European collaboration and its application in CMIP5. For the upcoming CMIP6 experiments, Mistra-SWECIA participants have incorporated dynamic

vegetation (based on LPJ-GUESS) into EC-Earth and made a wider range of studies on Earth system feedbacks possible. Climate prediction (decadal prediction) is another area where important advances have been made and groundwork laid for future research.

Land use narratives

Progress in the development of integrative scenarios describing potential future changes in socio-economic drivers, land use, greenhouse gases and climate has been one important aim, building on the different disciplinary models within Mistra-SWECIA and relevant international collaborations (Figure 2). These scenarios provide a basis for narratives; reasoning and analysis of future changes, uncertainty, risks and adaptation needs in a sector, that in turn can provide a basis for stakeholder reasoning about adaptation and facilitate knowledge exchange between users and researchers by providing explicit narratives of inter-related change in multiple factors of interest or concern. In addition, the integrative scenarios still being finalised will inform the Agent Based Model CRAFTY-Sweden with data on global drivers such as global demand and prices of land-based commodities as well as demand for areas for biodiversity conservation and recreation, thus explicitly taking into account some key aspects of the indirect impacts of climate change on a key economic sector of Sweden. An alignment (mapping) of fixed assumptions in the ABM with predicted outputs of the global land use models, and narrative assumptions, provides the key to these linkages and ensures an unprecedented degree of coherence between scenarios in terms of different socio-economic and biophysical factors and across scales.

This line of research within the programme takes full advantage of the new internationally-defined scenario framework, used inter alia as a basis for IPCC assessments from AR5 from 2013-2014, that combines alternative pathways of future radiative forcing (Representative Concentration Pathways, RCPs), socioeconomic development (Shared Socioeconomic Pathways, SSPs), and Shared climate Policy Assumptions (SPAs) in a scenario matrix. In theory, the three dimensions of the framework are independent, but in practice, only internally consistent combinations are relevant.

Global land use patterns are a key integrator of socio-economic and biophysical change fuelled by climate and other global change drivers. Mistra-SWECIA has contributed to the development of a global parsimonious model of land use change (PLUM) internalising aggregate land allocation choices in response to climate driven changes in crop yields, trade patterns, markets and demand for agricultural commodities (Baumanns et al. submitted). In a unique application, the model has been used to generate probabilistic global land use futures in relation to alternative socio-economic narratives (SSPs).

For specific global or country-level scenarios, some indicators may be used directly from the extended SSPs (e.g. population), while others (e.g. GDP) can be processed by global climate-economy models (as the IAMs discussed above) according to the influence of atmospheric CO_2 (from RCPs) or carbon taxes (from SPAs). The managed land version of the vegetation model LPJ-GUESS (Lindeskog et al. 2013), developed within the programme, provides biogeophysical variables, for example carbon sequestration, crop production, bioenergy production, forest production, damage risks (windfall, bark beetle), management costs, biodiversity (dead wood, old forest, broadleaved forest, continuous cover management), water runoff and proxies for aesthetic and recreational values. The Parsimonious Land Use Model (PLUM) (Hardacre et al. 2013) can produce SSP-specific land use futures. In some of these cases, a feedback of information between LPJ-GUESS (productivity) and PLUM (land use) over the modelled period is needed. In the development of scenarios of e.g. damage risks in the forest sector, global or country-level narratives and pathways will need to be downscaled to the regional level and used together with climate projections. This system is illustrated in Figure 2.

The dynamic vegetation-ecosystem model LPJ-GUESS that has been made specific use of in "Impact modelling and risk assessment" research in Mistra-SWECIA has also been further developed and used both on regional and global scales. Significant breakthroughs at the cutting edge of research internationally include implementation of nitrogen cycle feedbacks on ecosystem production and carbon cycling (Smith et al. 2014), which enabled an analysis that challenges results of earlier modelling studies by demonstrating that N-cycle feedbacks could enhance, rather than inhibit, biospheric sequestration of atmospheric CO_2 under high-carbon climate futures (Wårlind et al. 2014). Furthermore, the development of a cropland version of LPJ-GUESS (Lindeskog et al. 2013) is now one of few available tools for projecting impacts of climate and land use change on agricultural yields at continental to global scale, and provides crucial input to modelling of land use change. In addition to these advancements, the first regional Earth system model, internalising natural land cover dynamics and biogeophysical climate feedbacks within a physical climate model (Smith et al. 2011) was developed and it has now been applied to analyse the spatio-temporal role of land-atmosphere feedbacks in regional climate change for Europe, the Arctic and Africa as well as impacts on Arctic carbon balance. In-depth simulation studies of uncertainties as to future global carbon balance has been a further major development, which has demonstrated a critical role of global climate model (GCM) characteristics – especially inter-model divergence in circulation-related phenomena such as El Niño-Southern Oscillation (ENSO) – for projections of future productivity and carbon balance of the terrestrial biosphere (Ahlström et al. 2012, 2013). Results also reveal compelling new evidence that semi-arid ecosystems play a larger role than previously thought in variability and trends of the global carbon cycle (Ahlström et al. 2015).

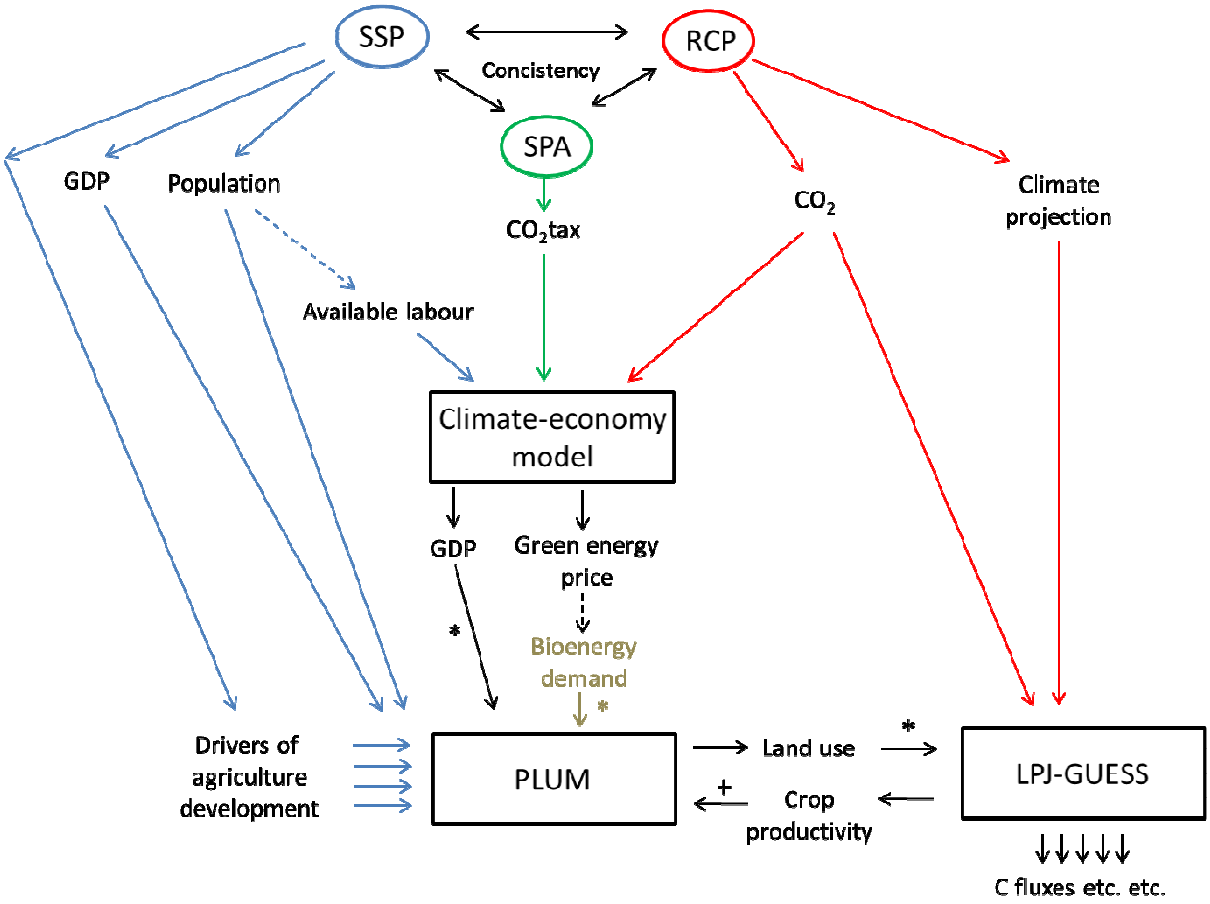


Figure 2. Schematic coupling of LPJ-GUESS, PLUM and the IAM with climate and economy to create integrated land use and biogeochemical scenarios for narratives. Dashed lines indicate data conversion methods, * indicates data disaggregation and + indicates data aggregation. "Climate projection" refers to 21st century climate projections simulated by GCMs including EC-Earth.

The global projections have provided important framing for the regional and local-scale research and dialogues, as well as connected both with the climate-economy IAM research and the push for land use narratives making use of the collected disciplinary model arsenal in the programme.

Additional cutting-edge work and future possibilities

The scientific research during Mistra-SWECIA will leave a legacy in terms of new knowledge, new methods and new research questions. Prominent examples of opportunities that have been created within Mistra-SWECIA include:

Participatory research, climate impacts

Experiences from Mistra-SWECIA strongly suggest that adaptation research needs to become more interactive and practice-orientated in order to create greater engagement among relevant stakeholders. Our findings also suggest that science-stakeholder based adaptation research needs to address social barriers to adaptation, namely factors affecting the perceptions of the severity of climate change risks and of the efficacy of adaptation measures. Work within the programme has initiated the development of user-oriented climate change communication strategies that build upon insights into these barriers and that convey a sense of self-efficacy to stakeholders.

The work on indirect impacts of climate change represents the first attempt to develop a coherent model of a novel perspective on climate risks. The work also represents the first attempt of quantifying an effect that only recently has gained interest in the scientific and policy communities. Effects of climate change are often seen as a local or regional issue, but in a globalized world this is a narrow-minded view that does not take into account ripple effects from the local to the global. Hence, one important future research question is how adaption planning could include both direct and indirect impacts of climate change. Insights about the globalised character of impacts must ultimately be transferred into adaptation-related decision-making. The work will be further developed in for example the EU-project IMPRESSIONS.

SEI together with SMHI has recently received funding from the Swedish Civil Contingencies Agency (MSB) for a project that aims to develop a new method for decision-makers and climate experts to tailor information about the impacts of climate change on natural hazards for adaptation decisions. SEIs contribution in the project draw on research results and methodological insights gained from Mistra-SWECIA.

Ecosystem modelling

Climate change impacts on forest biodiversity is a poorly-developed research area in Sweden, and there is a demand from policy actors for science to support policy development and stewardship. ULUND is building up expertise in this area, inter alia by having recruited a postdoctoral researcher to develop indicators of biodiversity value that can be used in a predictive system for forest biodiversity based on ecosystem model and climate information (Marquer et al. submitted, Pontarp et al. in prep). The research will continue in for example the EU-FP7 project EUPORIAS, and the Strategic Research Area BECC.

Integrated assessment models

There are still developments and improvements with the IAMs waiting to be done and the set of applications that are around the corner is large, for example incorporation of more sectors, as well as scientific analyses with the multi-region global climate-economy model.

High-resolution climate projections

Research indicates that the climate change signal for extreme events, especially precipitation, is model resolution dependent. High-resolution models simulate extreme events more realistically but they are also computationally still tremendously expensive. The European climate modelling

and weather prediction communities currently strive for a joint effort to tackle this problem. Resources are slowly brought together with respect to competence, models and computer facilities. Sweden, supported by Mistra-SWECIA, has a very active role in this process where the weather and climate high-resolution modelling system HARMONIE running at resolutions well below 10 km in climate simulation model will become increasingly available for more than 20 European countries over the next years to come.

Global land use modelling

Earth system modelling is a new research area that did not exist in Sweden a decade ago. Mistra-SWECIA has made an important role in supporting the development of expertise and international engagement in this area now at the forefront of climate research. The global Earth system model EC-Earth built by a European consortium, represented in Sweden by SMHI, ULUND and MISU, participates in the international climate model intercomparison project CMIP6 that will support the next-coming sixth assessment of the IPCC. Through work largely supported by Mistra-SWECIA, EC-Earth is being developed into a state-of-the-art tool for studies of the role of carbon cycle, land cover and land use change forcing of future climate.

Further plans to extend the land use scenarios are planned by using the global climate-economy IAM as it now passes the calibration phase. A modified GDP input to PLUM can then take into account climate damage (determined by the RCP-dependent CO_2 level input to the climate-economy model) and the effect of mitigation by CO_2 taxes (SPA dimension). Another PLUM parameter, bioenergy demand, may be modified by the climate-economy model (via output green energy price). Ultimately, models like PLUM may be coupled as integrated components into Earth system models, thus explicitly accounting for the feedbacks linking climate, ecosystems and human land use decision-making.

Agent-based modelling

The Agent-based model, CRAFTY-Sweden, developed to simulate the decision-making and adaptation behaviour of forest managers in Swedish will be finalised during the final months of the programme. Results and information deriving from the modelling exploration will be presented, at the final conference in November 2015, thus initiating a dialogue with forestry stakeholders about potentially most successful strategies to adapt to climate change. The ABM will be freely available online and thus will be used by a broad community of researchers.

Contribution to Sweden´s competitiveness

Forestry and forests

Mistra-SWECIA's contributions to Sweden's competitiveness weigh the heaviest within the broader forestry sector, but also other impacts are evident. The programme has contributed with new knowledge, new tools, fostered deepened insights on the significance of climate change adaptation for forest owners, companies, agencies and both regional and national government levels. Activities have also targeted independent forest advisors and "timber buyers". These latter two categories of actors on the forestry sector are significant intermediaries and have authority between the industry and authorities on one hand and private forest owners on the other.

The enhanced interdisciplinary research links as such enables a legacy of scientific knowledge production and the acquaintances among forest owners and professionals a legacy of other knowledge production. The new knowledge, recommendations and communication can help to improve the resilience and robustness of Swedish forests in a changing climate, which in turn will have a positive effect for the Swedish forestry sector in the future. Special efforts have been made to make the research results easily available for the forest sector through a synthesis report (Mistra-SWECIA, 2015). While some impacts are immediately visible, the full impact will of course unfold over time, at the pace of new decisions and developments in the field.

The research within Mistra-SWECIA has improved the understanding of how managed forests will be affected by a changing climate and how different management strategies affect management goals economy, biomass production, biodiversity, and carbon sequestration in the forests. The new tools and the results have the potential to support improved recommendations for forest management with both economical and societal benefits.

The insights from the evaluation of the Forest Agency's climate information, knowledge about from who forest owners gain their information and the experiences from the focus groups can help to improve the effectiveness in climate change communication, and hence increase knowledge and adaptive capacity of Swedish forest owners. They are a key target group as the private forest owners hold 50 percent of the Swedish forests.

PlantVal is a well-used tool among forest actors in Sweden when choosing which seedlings to plant in their forest. The cooperation with SkogForsk to incorporate climate change into the tool will contribute to more robust decisions on forests being planted today and in the future to meet new climate conditions.

The cooperation with Holmen has resulted in climate change aspects, both mitigation and adaptation, being further incorporated in the company's manual for forestry (Guidelines for sustainable forest management, new version from 2015 only available in Swedish). Holmen is a major forest sector actor in Sweden, and their choices can also influence other actors to look further in to the new conditions with a changing climate.

In addition, the programme has put a lot of effort on communication in established channels for the forest sector as well as organized a number of activities targeting different actors in the forestry sector. The cooperation with our science-policy interface group has resulted in both concrete activities but also built knowledge in different stakeholder groups. The specific impact on Sweden´s competitiveness is difficult to specify, although communication of research results is part of knowledge build up in order to increase the capacity to meet future challenges.

Additional initiatives which contribute to future competitiveness

The programme's work on supply chain risk management and companies' preparedness for a changing climate was the first of its kind in Sweden. It focused on companies in the land use sec-

tor in southern Sweden. However, the method developed can be used by any sector. Companies that are well prepared for the new risks and opportunities in a changing climate will have a greater possibility to be successful in the future.

The climate-economy research within Mistra-SWECIA has resulted in further knowledge on the effects and challenges of taxation and price on fossil fuels. As Sweden already has a carbon tax, the research has provided insights on how a global price on carbon can affect Swedish economy.

With the new insights from the research on indirect effects, it has become better demonstrated that also faraway climate impacts have tangible effects at home. Sweden, for instance, will be impacted by the local climate change impacts, but also by impacts outside Sweden; a small, highly globalised, and export dependent country. A case study is presently (when this report was being written) undertaken for the forest sector. Results are expected to be relevant both for Sweden and for the forestry sector.

Capacity building within academia and society

Within academia

The Mistra-SWECIA experience has as a whole built new capacity within academia. The joining of forces of economists (IIES), meteorologists (MISU) and ecosystem modellers (ULUND) underlies the new IAM. Mistra-SWECIA also introduced Swedish economists to climate change research, and they have gained great international recognition on the field. A master's course in climate economy is now also available at Stockholm University as an elective course within the economics master's program. There is a manuscript for a book to the course by now, but there is some distance to go before it can be submitted. The course has been given once a year for five years and attracts around 20 students every year, resulting in some master's thesis on climate-economy issues. The course will also be incorporated into a new Stockholm University master's program on environmental issues in the social sciences. A joint research school in climate and economy, based on the Mistra-SWECIA developments, is under scoping.

Not least in the course of the focus group studies, the collaboration of social scientists (SEI), climate scientists (SMHI) and ecosystem modellers (ULUND), has heightened the interdisciplinary readiness and interest. By the end of the programme, new collaborations had already been initiated.

The programme also fostered a new generation scientists. 12 PhD students and one licentiate student successfully defended their theses within Mistra-SWECIA, and a few are expected to shortly do so. The subject areas range from Climate Economy (4 PhDs) to Meteorology (4 PhDs and 1 lic), Physical Geography and Ecosystem Science (1 PhD), Social Sciences (2 PhDs) and Geography (1 PhD). Yet additional PhD students have been involved in Mistra-SWECIA, although they have not been directly financed by the programme.

PhD student		**Present position**
Karin André	PhD in Social Sciences	SEI
Jenny Hieronymus	PhD in Meteorology	At SMHI from Nov 2015
Anna Löwenschaal	PhD in Meteorology	Post-doc, Gwangju Institute of Science and Technology (GIST) South Korea, 2014. Post doc MISU, on-going
Johan Gars	PhD in Economy	Beijer Institute, Stockholm
Gustav Engström	PhD in Economy	Beijer Institute, Stockholm
David von Below	PhD in Economy	Oxcarre, Oxford University
Alexander Schmitt	PhD in Economy	Center for Energy, Climate and Exhaustible Resources, München
Anders Ahlström	PhD in Physical Geography and Ecosystem Science	Postdoc Lund University/Stanford University
Victor Blanco	PhD in Geography, on-going	On-going, University of Edinburgh
Gregor Vulturius	PhD in Social Sciences, on-going	On-going, SEI/University of Edinburgh
David Lindstedt	PhD in Meteorology, on-going	On-going, Stockholm University/SMHI
Petter Lind	PhD in Meteorology, on-going	On-going, Stockholm University/SMHI
Jonas Claesson	Lic in Meteorology	High school teacher in maths and physics

Within society

In addition to the efforts already highlighted in a previous section of this report; Value to stakeholders and societal impact, the programme reached out also to a wider audience. News, results, events and some commentary was distributed over the programme's home pages in Swedish and English and in almost 200 public lectures and presentations (the number does not include scientific meetings and conferences). The Annual Reports have been designed to provide informative material to sectorial stakeholders, written in a way that is accessible also for other interested actors. In addition to the Annual Report, a number of other professionally designed project reports and briefs were produced. One prominent example of wider outreach were three short briefs on each of the three IPCC AR5 Working Group reports. These were used inter alia in a seminar at the Swedish Parliament in 2013. Public events were also organised in conjunction with the publishing of the IPCC AR5 Working Group reports.

The programme Board gathered some key people from the society including from governmental authorities and bodies, a former Minster of the Environment, the finance sector and forest industries, as well as academia. They all brought their knowledge and contacts into the strategic planning and management of the programme, and in return had front row seats in the knowledge production.

Erik Normark, Research and development director, Holmen:

Previously, I felt a bit sceptical about climate change and it has as an issue been a little abstract for me. Then I met Markku Rummukainen during the [2013 Autumn Mistra-SWECIA] excursion. He explained how the UN climate panel IPCC does it work, how the world's elite meteorologists meet, how all objections are responded to in a transparent manner, and the responses are made available on the Internet. I was transformed. There was no real basis in questioning climate change anymore – we need to address it. It was very impressive to meet Markku. I had not been explicitly sceptical, but had in my head thought that climate varies naturally. But I surrendered, in my mind that discussion was over. It was rewarding for me and to Holmen to meet him.

Networks and international partnerships

Mistra-SWECIA has in itself created new and interdisciplinary networks in Sweden between the involved Swedish research teams. The climate-economy modelling (IIES, MISU, ULUND) and participatory research, as well as the research on climate risks and adaptation (SEI, SMHI, ULUND) are pure Mistra-SWECIA developments which hardly would have come about without the programme. The increased understanding and mutual respect for each other's scientific area has the potential to be utilized in a range of future research related to *inter alia* climate, development and communication. The programme has also led to new international networks and partnerships have developed and/or deepened within specific research areas. Some examples of development of networks and international partnerships related to Mistra-SWECIA are presented below, together with the partners directly affected.

The research undertaken at ULUND in areas of relevance to Mistra-SWECIA is well-connected internationally. Carbon cycle analysis based on the ULUND ecosystem and cropland models benefit international intercomparison and assessment projects such as the Global Carbon Project, AgMIP, and the Joint Programme Initiative for European agriculture FACCE/MACSUR. Regional Earth system modelling (ESM) studies are carried out in a dialogue within the international CORDEX. The EC-Earth global Earth System model development is carried out within an international consortium in which ULUND leads the working area on land-atmosphere interactions. Based on its leading expertise in biosphere-atmosphere coupling developed in part during Mistra-SWECIA, ULUND is a partner in the Horizon 2020 project CRESCENDO which underpins European ESM contributions to CMIP6. ULUND is also a partner in the EU-FP7 project EUPORIAS in which the potential use of seasonal predictions to support the operational planning of forest management in northern Europe is identified and evaluated. One PhD graduate has received a competitive international postdoc grant with a joint affiliation between ULUND and the prestigious Stanford University (USA), which strengthens the cooperation between the two universities.

The role of Rossby Centre, SMHI, the Swedish climate modelling data provider, connects Rossby Centre closely to the activities within the Modelling Theme of the World Climate Research Programme (WCRP) where SMHI is hoststhe international office of the Coordinated Regional Climate Downscaling Experiment (CORDEX) and coordinates overall the development of EC-Earth. EC-Earth contributed to the fifth Coupled Modelling Intercomparison Project (CMIP5) and is now about to also contribute with the Earth System model version (see above) to CMIP6.

The contribution through Mistra-SWECIA has made it possible for Rossby Centre to reach a leading role in the development of high-resolution RCMs in Europe. SMHI has the leading position in the HCLIM development that involves the European NWP community related to HARMONIE. SMHI arranges workshops and training and currently also coordinates the development. The development of HCLIM is a long term commitment and planned to continue well beyond the end of Mistra-SWECIA.

The economists at IIES have established themselves as broadly known to be among the leading macroeconomists in the world in the area of climate change analysis and integrated assessment modelling. The area of climate-economy has led to new collaborations and arenas for the researchers. They have been asked to write "handbook chapters", one on environmental aspects of macroeconomics for the Handbook of Macroeconomics and one on macroeconomic aspects of environmental economics for the Handbook of Environmental Economics. The handbooks are North-Holland issues that appear about every 15 years, summarise key research contributions, and are read by all economists (and particularly used for PhD teaching). In addition, the research within Mistra-SWECIA has strengthened networks with Yale University, and IIASA in Vienna.

MISU has in collaboration with other research networks developed descriptions of aerosol processes and their interaction with radiation, clouds and climate in Earth system models (NorESM, EC-Earth). As a continuation of their work in Mistra-SWECIA, and within the Swedish Clean Air and Climate Research programme, MISU-scientists are now evaluating different climate metrics to understand the underlying mechanisms behind remote responses in temperature and precipitation. This is done in collaboration with the Center for International Climate and Environmental Research (CICERO) in Norway and the Norwegian Meteorological Institute.

SEI's work on indirect impacts has led to a close collaboration with the Finnish Environment Institute SYKE. Joint work is ongoing, for example in the FP7 programme IMPRESSIONS. Over the course of Mistra-SWECIA, SEI has also developed close collaboration with the Environmental Sustainability Research Centre (ESRC) at Brock University, Canada. This initiative has resulted in multiple outcomes, including international workshops in Sweden and Canada. In 2011, SEI was commissioned by Environment Canada to conduct a study based on Mistra-SWECIA work. Drawing on experiences from Mistra-SWECIA, SEI has engaged in the initial phase of the CADWAGO project that aims to enable multi-level multi-stakeholder collective action in water governance, improving climate change adaptation responses from a water security perspective.

The earlier established collaboration between ULUND and University of Edinburgh has during Mistra-SWECIA also come to involve SEI in ABM-development. The collaboration has, among other forms, involved PhD students.

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ANNEX

Impact Case Study 1: Evaluation of a climate change communication project of the Swedish forest agency

Impact Case Study 2: Climate adaptation of forestry

Impact Case Study 3: Development of the HARMONIE-Climate high-resolution regional climate model

Impact Case Study 1

Case study: Evaluation of a climate change communication project of the Forest Agency

Organisation: Stockholm Environment Institute (SEI)

Presentation of the research which the impact is based on

This research concerns Climate Change Communication (CCC), i.e. efforts that disseminate scientific information about climate change, raise public awareness about climatic risks and adaptation measures, and encourage behaviour change for adaptation. Increasingly, governments, researchers and others actors are using CCC to promote adaptation. However, quantitative assessments of CCC are largely absent in the scientific literature at this point.

The objective was to provide a comprehensive, quantitative assessment of the effectiveness of CCC in engaging people with adaptation and promoting adaptive behaviour. We asked if CCC can lead to cognitive, affective and relational learning and changes in attitudes and behaviour regarding adaptation to climate change risks. The empirical data came from a survey of 6000 forestry owners in Sweden. Half of them took part in a CCC project run by the Swedish Forestry Agency, and had been given information and practical guidance about the risks of climate change and viable adaptation measures. The other set of 3000 forest owners was randomly sampled and formed a control group.

We compared if perceptions and attitudes about climate risks and adaptation measures differ significantly between these two groups of forest owners. We used multivariate regression, factor analysis and related statistical methods to estimate the effect of CCC on the perception of climate risks, perceived efficacy of adaptation measures, perceived self-efficacy and actual adaptive action of participants and non-participants of CCC. The study also examined the influence of preference for different forestry objectives, personal experience with extreme events, trust in climate science, gender, age, social capital, education and dependency on income from forestry activities as well as other factors on the perception of climate change risks, the efficacy of adaptive measures and their own ability to adapt to climate change.

The results offer valuable insights for particular for the Forest Agency but also others into how CCC can become more successful in engaging target groups. Key insights suggest that CCC can be improved if it more purposively addresses the varying objectives, needs, experiences and decision making processes of different user groups.

The research was conducted by SEI, Lund University, University of Edinburgh, and Gothenburg University (external to Mistra-SWECIA).

Describe the impact of the research and the societal value

The idea for this research was born out of a conversation between the researchers and Forest Agency officials during the Mistra-SWECIA field trip in 2013. Both sides recognized the need for a comprehensive and quantitative survey of opinions of Swedish forest owners regarding climate change risks and adaptation. The research team convinced the forest agency of the value of assessing the effectiveness of a climate change communication project that had been recently finalized. It had been implemented by the Forest Agency with co-financing from the European Commission, and focused on building knowledge and capacity among thousands of Swedish forest owners to deal with climate change.

In late 2013, the research team and the Forest Agency signed an agreement outlining the scope of research, sharing of results and handling of sensitive information about the participants of the CCC project. It was agreed that the Forest Agency would not interfere in the research process and that the research team would provide information and assistance to the Forest Agen-

cy during and after the research if needed. This also happened at two occasions so far; in 2014 when the research team provided information to the Forest Agency that was used at a presentation for forestry professionals in Poland, and when results of the research were presented to officers at the Forest Agency who have been in charge of the communication project.

At the end of research, officials of the Forest Agency will be given more detailed information about the success of the CCC project and how similar projects in the future could become more successful in engaging forest owners with adaptation. This includes practical guidelines for knowledge dissemination and stakeholder engagement.

The results were also met with a high level of attention from the forestry related media. After the largest forest fire in recorded history in Sweden in summer 2014, we were approached by "Skogsaktuellt", one of the three main forestry related trade magazines in Sweden, to summarize our research on adaptation. In the subsequent article, we presented preliminary findings on forest owners' perception of climate risks and attitudes towards adaptation measures. We also argued that effective knowledge dissemination and stakeholder engagement are key issues in order to raise awareness about climate risks and promote adaptive behaviour.

In August 2015, a second forestry magazine, "Tidningen Skogen", wrote about our insights on how to effectively communication climate change related information and how perceptions and attitudes among forest owners and forestry professionals differ. This article will be published in connection with the field trip that Mistra-SWECIA and Föreningen Skogen jointly organize in September 2015.

Lastly, results of this research will also feature in the December 2015 edition of "Skogseko", the magazine of the Swedish forest agency. We will summarize our results about the effectiveness of the CCC project in disseminating information, raising awareness and promoting adaptive behaviour. We will also include insights into how climate scientists and governmental authorities can build trust and how information about climate change can be made more accessible and relatable.

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Impact Case Study 2

Case study: Climate adaptation of forestry

Organisation: Lund University

Presentation of the research which the impact is based on

The Mistra-SWECIA research on climate adaptation of forestry in Sweden uses ecosystem modelling as a tool to understand how climate change can influence tree phenology and growth, risk of damage and forest biodiversity. The goal has been to develop a tool for adaptive forest management in relation to multiple management goals and options, such as sustainable timber production, bioenergy, carbon sequestration and non-tangibles like environmental services and biodiversity. Contacts with stakeholders such as forest owners, advisers and officials in the forestry sector have been an integrated part of the research in order to be able to focus on stakeholder relevant issues, to inform about new results and to get feedback on our research and ways to present the results. Specifically, the research work has included (i) Developing the ecosystem model LPJ-GUESS for analysing the impact of temperature, precipitation and storm frequency on *Ips typographus* outbreak dynamics at landscape level. The aim has been to analyse how climate change and forest management can influence the risk for major outbreaks throughout the 21st century. (ii) Developing phenological models for climate change impacts on forest growth and natural distribution of tree species, of relevance for forest management regarding selection of species and provenances, estimation of future changes in productivity and risk of frost damage. (iii) Analysing how uncertainties associated with climate models influence the result of biological impact assessments.

The research has been carried out at Lund University in close co-operation with Mistra-SWECIA partners at SMHI and SEI. Our model-based analysis of impacts and risks has fed into the programme's empirical research on decision making and adaptation. The outcome will link to analysis of ecosystem services, socio-economic interactions and policy for sustainable forest management. Collaboration has also been carried out with the strategic research area BECC (Biodiversity and Ecosystem services in a Changing Climate, at Lund University and the University of Gothenburg,), and with researchers from the Mistra-programme Future Forests. The work has also led to international cooperation on a review on modelling of natural disturbances in forest ecosystems. Further research is underway in the EU-project EUPORIAS on evaluating the usability of seasonal projections for operational forest management planning.

The impact of the research and the societal value

Climate adaptation is of strategic importance to the forestry sector, as climate change is expected to lead to more extreme weather events, which increases the risk of damage to production forests and has impacts on biodiversity. Risks include tree drought stress, water logging, forest fires and attacks by pests and pathogens. Changes in storms are still uncertain, but the risk of storm felling of trees will in any case be influenced by the generally warmer climate leading to shorter periods or frozen ground, and lowered tree root anchorage capacity. Many of these negative impacts can, at least in part, be alleviated by adaptation.

Mistra-SWECIA has developed a tool for climate adaptation that identifies how common forest decisions and actions relate to short and long term aspects of weather and climate conditions. Our conclusions and recommendations are that climate change will affect the likelihood of climate and weather events that can cause damage to forest ecosystems. Exposure and sensitivity are two aspects of risk that can be affected by forest management, for example, by climate-adapted management and landscape planning. The losses can be minimised by being

prepared to take action if damage occurs. Planning for the future also includes the development of new methods for forest management, wood products and plant material. The goal is to strive for a long-term sustainable forestry that can produce a variety of ecosystem services. A better understanding of the role of biodiversity in production forests may lead to the development of management strategies to promote forests with a high resistance and resilience.

This work has included interactions with stakeholders such as the Swedish Forest Agency, the forestry company Holmen Skog, county administrative boards, the forest owner association LRF forest, and individual forest owners. The aim has been not only to convey results via popular texts, sectors-specific journals, and workshops, but also to get feedback and input to through surveys, interviews and focus group studies. We presented our work at an early stage for forestry policy makers who provided input to the modelling process from their point of view. The Forest Agency has shown interest through invitations to various meetings, and Holmen Skog by requesting a report on climate change adaptation. Meetings between scientists and foresters have been a useful forum for the exchange of information, practical knowledge and perspectives, with great potential to improve both the research process and decision making processes. Our goal is to reach deeper understanding of stakeholder relevant issues, and stakeholder interaction has therefore been documented and published scientifically.

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Impact Case Study 3

Case study: HARMONIE-Climate high-resolution regional climate model

Organisation: Swedish Meteorological and Hydrological Institute (SMHI)

Presentation of the research which the impact is based on

Climate model development is a very long-term commitment. The regional climate model (RCM) development at Rossby Centre, SMHI, was initiated in 1997 by the development of the RCM named RCA. Until 2011 five versions of RCA were released. The latest version, RCA4, has been used for downscalings of CMIP5 model data within the CORDEX project. Rossby Centre has produced well more than 100 CORDEX downscalings which puts us in a world leading position as a RCM group. The publishing of RCA4 data in open international data bases has had a big impact on the scientific climate research community by allowing unlimited amount of applications based on RCM data. Research development within the RCM community has now one main focus on high-resolution RCMs operating on a horizontal mesh size of a few kilometres. This responds to the societal requests on information on return periods and intensity of extreme events. RCA is not suited for high resolution modelling and a few years ago the decision was taken to invest resources into the European Numerical Weather Prediction (NWP) system HARMONIE. HARMONIE consists of a well-established network of scientists at European meteorological institutes. In 2011, with support from Mistra-SWECIA, SMHI took the initiative to start to develop and apply HARMONIE-Climate (HCLIM). Now, four years later, its first official version has been released within the network. Non-official development versions of HCLIM have been published during this period as well. A few high-resolution downscaling over Europe are ongoing and planned for 2015.

The main difference between NWP and climate applications is that physical processes with long time scales need to be considered in climate while they can be omitted in NWP. However, short event extremes change with the slower climate processes, such as deep soil conditions, lake processes and snow conditions. Much of the research in the development of HCLIM has been devoted to these processes. HCLIM consists of a multi-layer soil scheme with respect to thermal energy, water and ice. A multi-layer snow scheme is applied and a physical lake model is activated. In addition, important technical development has been invested to solve issues related to data formats and limited data storage space.

The impact of the research and the societal value

By the development of HCLIM, Mistra-SWECIA contributes to the continuous need of climate model development. The future climate information used by many partners in Mistra-SWECIA has been produced by climate model systems that were developed with support from projects running years ago. Thus, the efforts made in Mistra-SWECIA on model development will support future projects with climate information. Being part of this process is to take responsibility for the needs in the society on a long term basis.

The actual impact of HCLIM cannot yet be measured. Based on the impact that RCM activities at Rossby Centre has had over the last 18 years we can estimate the expected impact of HCLIM. Two examples with important societal value of RCM activities at Rossby Centre during Mistra-SWECIA are (i) over the period 2010-2014 "Länsvisa klimat- och sårbarhetsanalyser" ("climate and vulnerability analyses for counties") have been published which describe climate change impacts in 19 Swedish counties, along with identified needs for adaptation. (ii) Since 2011 Rossby Centre has produced more than 100 future scenarios within the context of CORDEX. 30% of these scenarios are for Europe but the other ones are for other regions of

the world. The CORDEX data is being used in many different national and international projects and the societal value of these RCM activities now also goes beyond Europe.

References for the research

(HCLIM is very recently released as model system and therefore very few publications have appeared.)

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