SCAC 2

Swedish Clean Air and Climate Research Programme

A proposal for Phase 2

In response to the call ”*Hemisfärisk transport av luftföroreningar och åtgärdsstrategier i Europa*”

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Purpose and questions raised

The overall aim, defined in SCAC 1 remains in phase 2:

To develop and improve the scientific basis for air pollution policies on national and international scales including relations to climate policy.

Specific objectives and research questions in phase 2 are:

1. Develop a better understanding of the hemispheric transport of air pollutants - with emphasis on ozone (formation, distribution and effects), particles, and their precursors. Evaluate how local and remote anthropogenic emission changes affect climate and ozone concentrations in the northern latitudes and how this can be taken into account in the development of international agreements on emission reductions.
2. Quantify health impacts from particles with different properties and sources, including different particle measures, in order to improve cost-effective abatement strategies, taking into account the role of ozone and NO_2 and potential confounding problems and/or interactions.
3. Quantify and analyse the risk for ozone effects on the growth and carbon sequestration of northern temperate and boreal forests as well as on vulnerable subarctic ecosystems.
4. Evaluate and synthesise scientific knowledge on long-term effects of nitrogen on biodiversity and ecosystem services in Northern areas.
5. Improve and further develop existing Integrated Assessment Models to take into account new knowledge on air pollution, climate effects and abatement options.
6. Develop and apply Integrated Assessment Models to evaluate combined abatement strategies for air pollution and climate including the evaluation of potential frameworks for IAM analysis of changes in transport and domestic heating behaviours.

The research will focus on providing scientific support to national and international policy development and abatement strategies. Main stakeholders are EU (air and climate issues), the UN-ECE Convention on Long Range Transboundary Air Pollution (CLRTAP) as well as national, regional and local authorities responsible for the Swedish Environmental Objectives and issues related to the impacts of air pollution and climate on environment and human health. Finally, the Arctic Monitoring Assessment Program (AMAP) under the Arctic Council is identified as a stakeholder for the research focussing on hemispheric and Arctic issues.

Theory and methods

The research will be organised in four Work Packages described below. A time plan and list of expected main deliverables for all activities is presented in Table 1.

WP 1 Hemispheric transport and international agreements.

Main research questions (specific objective 1 above):

- How and how much does hemispheric transport of air pollutants, especially particles and ozone affect the Swedish, European and Arctic air quality and climate? Are the effects on climate mainly local (i.e. a direct response to a local change in radiative forcing) or remote (i.e. a result of changes in heat transport to and from the region)?
- How can we improve the simulation of long-range transport of air pollutants to the Arctic including transformation and precipitation scavenging of aerosols and chemical production/loss of ozone?

Approach and activities

Large modelling efforts on hemispheric transport have been made in the framework of the CLRTAP Task Force on Hemispheric Transport of Air Pollutants (HTAP), AMAP and through our own modelling activities in SCAC Phase 1. Results from HTAP are currently under evaluation and this work will continue under 2017. The results of these efforts will help respond to the first research question defined above concerning the air quality effects while the climate effects will be based on global climate modelling efforts and international collaboration initiated in SCAC. The second question will be tackled through a combination of synthesis of previous modelling studies including results from HTAP and AMAP and targeted modelling work where existing and new hypotheses regarding processes involved in long-range transport are tested. The results from this activity will in addition inform the impact assessment performed in WP3. Potential knowledge gaps and necessary complementary research connected to the research of this WP will also be identified during the course of the project.

Planned activities:

- **1.1** Evaluation and assessment of results from HTAP modelling activities in relation to hemispheric source-receptor relationships relevant for air pollution in Sweden and Northern Europe (SMHI).
- **1.2** Active participation in HTAP-meetings to maximize the use of HTAP results and to contribute to the evaluation of HTAP conclusions with regard to policy and abatement strategies. Identify gaps in knowledge and additional research needs, and contribute to follow up modelling efforts where possible. This will be done in cooperation with WP4 where the focus is on future abatement strategies. (SMHI, IVL (WP4))
- **1.3** Improve the simulation of transport of aerosol particles from lower latitudes to the Arctic region in NorESM and MATCH and simulation of ozone in the northern hemisphere in MATCH following recommendations put forward in the AMAP report. (SMHI, SU MISU, SU ACES)
- **1.4** Investigate how future aerosol emission changes in different regions, according to different scenarios developed within HTAP and by e.g. JRC and IIASA within the ECLIPSE and PEGASOS projects as well as different emerging scenarios as result of the COP21 climate abatement agreement, will affect hemispheric transport of aerosol particles, in particular to the Arctic region (SU MISU, SU ACES).
- **1.5** Examine the climate and aerosol impact of the above-mentioned aerosol emission changes, in particular for the Arctic region, and whether the climate impact is mainly due to local changes in aerosol forcing or due to modified heat transport caused by changes in aerosol forcing in other regions into the Arctic region. (SU MISU, SU ACES)

WP 2 Air pollution and health

Main research questions (specific objective 2 above):

- To what extent do particle characteristics such as source, size and chemical composition influence health impacts, and how should the effects of co-pollutants such as NO_2 and ozone be judged?
- How sensitive are the cost-effectiveness calculations to the choice of particle measures and co-pollutants to represent exposure and health outcomes included in the health impact assessment. I.e. does inclusion of particle characteristics in health impact assessment affect predicted health outcomes such as cardiovascular and respiratory effects or different groups such as elderly and infants?
- How can more cost-efficient abatement strategies be developed when based on robust information on health effects determined by particle characteristics and sources such as wood smoke, road wear (dust) and motor vehicle exhaust?

Approach and activities

Particles are responsible for a large fraction of the human health impacts from air pollution. The scientific knowledge on these health effects is growing and more attention is now focused on the relative importance of different characteristics of particles including size, chemical composition and sources. The approach taken to answer the research questions above is to evaluate the scientific literature (including health effects, emissions and characteristics of urban aerosols) and combining it with knowledge gained in SCAC phase 1 on health impacts, to provide new knowledge on these source-effect relationships. In addition to this, information on sources and effects will be used to evaluate potential impacts on the cost-efficiency of abatement options available in the GAINS model framework.

Planned activities:

- **2.1** Literature review on relationships between particle characteristics, sources and different types of health effects and integration with knowledge gained in SCAC phase 1. The focus will be on sources of high interest for Sweden such as wood smoke, road dust and vehicle exhausts. The efforts will be prioritised to complement on-going international research on e.g. vehicle exhaust and power plants. (KI, UmU)
- **2.2** Sensitivity-study with health impact assessment calculations for abatement options to assess how sensitive the cost-effectiveness results are to the choice of particle measures and co-pollutants (such as NO_2 and ozone) to represent exposure, and the health outcomes included in the health impact assessment (that will have relative-risk functions differently modified by particle characteristics). (UmU)
- **2.3** Estimation of exposure-response functions for specific particle measures and sources for specific particle measures and sources (e.g. local PM exhaust, local PM wood smoke, local Black Carbon, Long Range Transported-PM) and total mortality and cardiorespiratory mortality in the cohorts that were used in SCAC phase 1 to study stroke and IHD. (GU, KI, UmU)

WP 3 Air pollution and ecosystems – ozone and nitrogen

Main research questions (specific objective 3 above)

- What are the effects of ozone on the growth and carbon sequestration of temperate and boreal forests in northern Europe?
- Are there increasing risks for ozone impacts on sub-arctic vegetation due to high spring ozone concentrations in relation to the start of the growing season, which may be shifted by climate change?
- What are the long-term effects of nitrogen deposition on biodiversity and ecosystem services in northern Europe?

Approach and activities

Ozone

Increased forest growth rates and carbon sequestration as a result of reduced ozone exposure represent an important synergy between improved air quality and climate change mitigation. The research on ozone impacts on forests will build on previous results from SCAC phase 1, where a methodology and database for determining the impacts on forest growth and carbon sequestration was developed. The activities will be continued by further analysing the existing annual growth data with respect to the effect of environmental variables, primarily ozone exposure and nitrogen deposition, and meteorological drivers such as temperature, precipitation, humidity and solar radiation. We attempt to derive ozone dose-response functions for extrapolation to temperate and boreal forest regions in northern Europe.

The climate conditions at high northern latitudes represent a special case regarding ozone damage to vegetation, with high ozone concentrations during spring, short vegetation seasons and many daylight hours. We will analyse the impact of changes in biogenic emissions and dry deposition to vegetation on ground-level ozone concentrations/exposure at high latitudes. Further, we will investigate the latitude dependence on the ozone spring peak and whether the spring peak has shifted in timing and amplitude with a changing climate. We will further conduct source attributions of the ground-level ozone exposure partly based on results from WP1. Finally we will make use of the modelled ozone exposure including the source/process attribution in risks assessments, to describe the contribution of hemispheric processes (transport and chemical). The risk assessment for arctic and sub-arctic vegetation will be based on analysis of observed ozone concentrations, atmospheric modelling of ozone concentrations and fluxes including sensitivity studies of sources and sinks and literature studies of the vulnerability of arctic and sub-arctic vegetation for ozone damage as assessed from relevant literature data from different parts of the world.

Planned activities**:**

3.1 An assessment of ozone impacts on growth and carbon sequestration of European northern temperate and boreal forests. (IVL, GU-BioEnv, GU-GVC, UmU, SMHI)
- Expanding the SCAC-database with growth data for more tree species and with additional explanatory variables. (IVL)
- Analysis of tree ring data including statistics. (GU-BioEnv, GU-GVC, UmU)
- Calculations of impacts on carbon sequestration. (IVL, SMHI)
- Assessment and reporting. (IVL, GU-BioEnv, SMHI)

3.2 Risk assessments for ozone damage to arctic and subarctic ecosystems. (IVL, GU-BioEnv, GBT, SMHI)
- Analysis of observed ozone concentrations at northern latitudes, with a special focus on high spring ozone concentrations. (GU-BioEnv)
- Analysis of the causes behind a potential shift in spring peak through sensitivity modelling with special focus on the coupling to biogenic sources and sink processes to vegetation. (SMHI)
- Exposure assessment and source attribution to ground-level ozone exposure of the arctic and subarctic vegetation. (SMHI)
- Literature review of the vulnerability of arctic and subarctic vegetation for ozone damage. (IVL)
- Risk assessment. (IVL, GU, SMHI)

Nitrogen

Successful reductions in sulphur emissions throughout Europe have resulted in much improved air quality and less severe acidification problem in soils and waters of northern Europe. With nitrogen deposition, however, the situation is different. Nitrogen emissions and deposition did not decline nearly as much as those of sulphur. Translated into exceedance of critical loads, in year 2010 about 11% of Sweden had deposition of S above critical loads. For nitrogen as a nutrient, the area with exceedance is about three times as high, and also the decline in nitrogen deposition is slower and less extensive than that of sulphur. Nitrogen is an important nutrient that stimulates growth but it can have negative impact on biodiversity and it can cause eutrophication and acidification of both soils and waters. Oligotrophic ecosystems common in northern Europe are especially vulnerable to species losses due to N deposition. Within the CLRTAP the current focus is on several aspects of N deposition including impact of N on biodiversity and construction of national N budgets.

The research will be structured to reflect priorities of CLRTAP by focussing on long-term effects on biodiversity and the atmospheric part of the N cycle directly compatible with methodology proposed by Expert Panel on Nitrogen Budget, under the Convention’s Working Group on Strategies and Review, Task force on Reactive Nitrogen. The research will be a combination of compilation and synthesis of existing results and continuation of the existing experimental work. On the national level the N deposition will be assessed also from the point of view of ecosystem services.

The atmospheric part of a Swedish national N budget will be based on emission inventories and on modelling linking emissions to deposition on national level. Effects of N deposition on ecosystem functioning and biodiversity has been studied experimentally, by models and also based on regional monitoring. For example the Gårdsjön N-addition experiment, ongoing since 1991 including three complete vegetation surveys, repeated soil samplings, studies of tree growth and continuous monitoring of N leaching. Combing experimental results from existing long-term field scale N addition experiments in Sweden with monitoring data will provide knowledge to evaluate selected ecosystem services, to provide input for the hydrosphere part of Swedish national N budget, to provide input for assessment of N impact on biodiversity and to provide data to constrain modelling studies.

Planned activities

3.3 System study of long term N deposition impacts on soils, waters and biodiversity. (IVL, SMHI)

- Synthesis of emissions and deposition data from emission inventories, modelling and monitoring to provide input to the atmospheric part of Swedish N budget. (IVL, SMHI)
- Synthesis of existing ecosystem field experiments involving manipulation of N input focusing on N-leaching (contribution to national N-budget) and long term effects on plant biodiversity and selected ecosystem services (contribution to WGE). (IVL)

WP 4 Methods and models for identifying cost-effective abatement strategies

Overall research theme

How can policy decision support tools currently used today be further developed or complemented to provide a more complete support with regards to control of emissions, costs of emission control and impacts of specific policies?

Main research questions (specific objectives 5, 6 above)

- How will ambitious air pollution abatement strategies affect fossil CO_2 emissions and fuel use in Scandinavia?
- How will the proposed climate policy framework and a climate clean air strategy for Sweden (SOU 2016:47) affect air pollution emissions and abatement costs?
- How should policy measures including behavioural changes be analysed in IAM models? Which measures can be analysed with the RAINS approach?

Other IAM development activities

- Integration of WP1 – 3 results and ECLAIRE programme results into GAINS Scandinavia or Alpha RiskPoll Sweden.
- Introduction of intra-annual variation of SLCP emission into GAINS Scandinavia.

Approach and activities

The research performed within WP4 will be allocated between four activities. The last activity is divided into (a) and (b) sub-activities. The specific (b) activities to be carried out will be subject to decision by the programme management in coordination with NV depending on results of WP1-3 and the (a) activities described below. All activities will be performed by IVL, IIASA, Chalmers and SU ACES.

4.1 **Air pollution abatement and CO_2 emissions**. The current GAINS model data and setup allows for different types of analyses, e.g. how air pollution emission abatement affect the climate through SLCPs. Activity 1 will add analysis of how CO_2 emissions might change due to certain types of air pollution emission abatement technologies. The GAINS model database currently includes the risk of decreased fuel efficiency associated with certain technologies which will be converted to risk of impact on CO_2 emissions. The analysis will be done off line providing possibilities to include the full climate effect due to ambitious air pollution strategies into the analysis.

4.2 Greenhouse gas ambitions and air pollution emissions. In July 2016, The Swedish All-Party Committee on Environmental Objectives proposed new goals and measures to reduce emissions of greenhouse gases and air pollutants (including SLCPs). WP4 will convert the proposed climate strategy to GAINS model format and use GAINS Scandinavia to analyse the impact on emissions of air pollutants and air pollution emission abatement costs until 2045, building on previous activities reported in Åström et al., 2013 and on data collection activities in SCAC. This activity will also include temporal variations of SLCP emissions, which is reported as necessary to estimate climate impacts of SLCP emissions from European sources (Aamaas et al., 2016).

4.3 Analysing Behavioural change in IAM. This activity focus on analysing behavioural change (non-technical) measures, currently not represented in GAINS. Modelling concepts have been developed that at least partly allow analysis of some behavioural changes impacting emissions (Bunch et al., 2015 for transport measures & Giraudet et al., 2012 for household energy measures). However, these modelling concepts are developed primarily for analysis of greenhouse gas emission reduction and are not directly transferable to the GAINS modelling setup. Preliminary results from SCAC (currently under development) show, from a GAINS modelling perspective, that it is necessary to separate between behavioural changes that primarily affect pollution generating activities and those that primarily affect emission factors of the activities. In the cost optimization mode used today in GAINS Scandinavia, only the latter can be considered as suitable to analyse. In WP4 we will build upon the activities in SCAC and evaluate different model concepts given the modelling constraints existing in the GAINS model approach.

4.4 A. Other GAINS Scandinavia and Alpha RiskPoll developments. The IAM model development will be based on results from SCAC and from WP 1 to 3 by e.g. adding new effect-criteria parameterisation or new information on source-receptor relationships to the analysis in the GAINS and Alpha RiskPoll models. As an important first step of this work, the effect of new information on cost-effectiveness of abatement options will be compared to the existing cost-effectiveness result in the GAINS model. Some of the results, most likely health related, might be more suitable to introduce into the economic evaluation tool Alpha RiskPoll (Holland 2012).

4.5 B. Other GAINS Scandinavia and Alpha RiskPoll developments. There are other interesting developments within WP1-3 and elsewhere, that might be possible to implement in GAINS Scandinavia or Alpha RiskPoll. Currently the following development opportunities are under consideration; development of Alpha RiskPoll to include economic values of ecosystem impacts as developed within the EU programme ECLAIRE; introduction of ozone-carbon stock interactions into GAINS Scandinavia; or deepened analysis of co-benefits & trade-offs between NH_3 and CH_4 emission abatement options. This activity can also include an assessment of abatement options on the hemispherical scale, based on results of HTAP in cooperation with WP1.

Current knowledge

The Air Convention has recently published a scientific assessment report "Towards Cleaner Air", in which achievements and future challenges are presented and discussed (Maas and Grennfelt, 2016). Despite successful reductions in many emissions, the report points to the needs for further international efforts to improve human health and environment within the UN ECE region. Some issues are given particular attention;

- Particles and human health, for which there are still uncertainties with respect to dose-effect relationships as well as the contribution to PM exposure from various sources.

- Nitrogen deposition and threats to biodiversity, recent studies indicate that the damage costs significantly exceed the costs for control.
- Background ozone concentrations over the northern hemisphere, which is enough to decrease photosynthesis even in clean areas but also significantly contribute to the exceedance of threshold levels for human health and crop/forest production.
- Interlinks between air pollution and climate both with respect to effects and emissions control.

Intercontinental transport and effects

The intercontinental scale of air pollution has for more than 10 years been the focus for HTAP. Collaboration between many international institutions has resulted in a set of models by which future scenarios may be analysed. The models need however further consideration and refinements in order to be able to answer more concrete policy questions. In particular it is important that the outcome can form a basis for policy steps forward e.g. by the Air Convention.

Air pollution and human health

The European Union has recently agreed on a new directive on national emission ceilings, which will outline emission control in Europe up to 2030 (EU, 2016). The new directive will also take into account the European climate policies and the benefits from this with respect to air pollution. The directive will however not be enough to meet the challenge of clean air for European citizens and clean environment.

There is within the research community a focus on the different types of particles to reveal differences in their impacts on mortality. However the WHO REVIHAAP panel of experts has concluded that current knowledge does not allow precise quantification of the health effects of PM emissions from different sources (WHO, 2013a).

Only in a few projects have the different types of PM been assumed to influence mortality differently. For example; ExternE3 (2005) includes assumptions about the toxicity of other different types of PM, which reflect results that indicates a higher toxicity of combustion particles and especially of particles from internal combustion engines.

The effects of combustion-related particles have also been studied using black smoke, black carbon or elemental carbon as the exposure variable. The WHO Project REVIHAAP (WHO, 2013a) recommended that black carbon should be used as exposure variable in more studies, but did not recommend it to be used for the European impact calculations (WHO 2013b).

A recent review collected information on studies of mortality and long-term exposure to the combustion-related particle indicators (Hoek et al., 2013). The included studies used different methods, and their relation and conversion factors have been described before (Janssen et al., 2011) All-cause mortality was significantly associated with elemental carbon, the meta-analysis resulted in a RR of 1.061 per 1 μg m^{-3} EC (95% CI 1.049-1.073), with highly non-significant heterogeneity of effect estimates. Most of the included studies assessed EC exposure without accounting for small-scale variation related to proximity to major roads. These results suggest that using the common RR for long-term exposure to PM2.5 and mortality, may lead to an underestimation of impacts of particle mass from motor vehicle exhaust.

However, the WHO REVIHAAP report also concludes that more studies have now been published showing associations between long-term exposure to NO_2 and mortality (WHO, 2013a). The potential confounding problem in studies of effects from NO_2 and PM2.5 on mortality was dealt with in a recent review paper focusing on 19 epidemiological long-term studies of mortality using both pollutants as exposure variable (Faustini et al. 2014). In their analysis, studies with bi-pollutant analyses (PM2.5 and NO_2) in the same models showed decrease in the effect estimates of NO_2, but still suggesting partly independent effects. The greatest effect on natural or total mortality was observed in Europe for both NO_2 and PM2.5. In Europe, there was a 7% increase in total mortality per

10 µg m^{-3} for both NO_2 and PM2.5. After judging the evidence less strong, the WHO HRAPIE project still recommend to calculate a long-term effect on mortality of NO_2 in the age category 30+, added to the impacts estimated using the common RR associated with all PM2.5 (WHO, 2013b). The UK Committee on the Medical Effects of Air Pollutants (COMEAP) has in an interim statement (December 2015) presented recommendations on how to estimate the mortality effects associated with long-term average concentrations of NO_2 in UK. The way to estimate long-term effects, especially on mortality, of source specific PM and of NO_2 (itself) will likely be modified during the next few years. SCAC 2 will match this process very timely.

Ozone and nitrogen

Ozone

The co-benefit of ozone concentrations reduction for air quality and climate change mitigation is well established at global (Sitch et al., 2007) and national scales (Subramanian et al., 2014). In Sweden and other Nordic countries, the main forest carbon sequestration is to the living biomass carbon stocks. This in turn depends on that forest growth (in Sweden ca 120 M m^3/yr) exceeds forest harvest rates (ca 100 M m^3/yr). A relatively small growth reduction can result in a proportionally large impact on carbon sequestration. Ozone impacts on tree growth have mainly been assessed based on experimental studies with young trees (e.g. Karlsson et al., 2009) and the transfer of these results to mature forest conditions remains uncertain. One way to validate and quantify ozone impacts on mature forest trees is to use an epidemiological approach (Karlsson et al., 2006; Braun et al., 2016). Due to the co-variation between high ozone levels and confounding factors, large sets of data are required for the statistical analysis including potential explanatory variables such as ozone exposure, nitrogen deposition and meteorology.

There are strong indications that the dynamics of ozone concentrations in north and central Europe are changing. While the levels of the highest ozone peaks are declining, the average ozone concentrations are constant or increasing (Karlsson et al 2016). Of particular importance at high latitudes is the so called spring peak or spring maximum in ozone, the mechanisms behind which are not fully understood (Monks 2003). This maximum represents a larger fraction of the yearly ozone exposure at higher latitudes. It is of large importance to understand the causes, the development of the spring peak and the extent to which it is likely to overlap with the growing season in the future. For the mountain regions of northern Scandinavia, the increase in ozone concentrations with altitude also has to be considered in risk assessment (Karlsson et al 2007; Klingberg et al 2009).

Nitrogen

Nitrogen deposition has major impact on biodiversity (DeVries et al., 2010) and over long term cause loss of oligotrophic species. It is a recognized threat to plant diversity in temperate and northern parts of Europe (Bobbink et al., 2010) and globally (Vitousek et al., 1997). Emissions and deposition of reactive nitrogen as a threat to biodiversity have been incorporated into work of CLRTAP and there has been considerable effort to develop scientific knowledge to incorporate this effect in setting critical loads for N as a nutrient (Slootveg et al., 2014). In Sweden in particular the northern part of the country is vulnerable (Nordin et al., 2005).

Nitrogen is circulated in the environment in several reactive forms which cause multiple and often interlinked effects with implications to climate, food security, energy security, human health and ecosystem functioning including alteration of biodiversity (Erisman et al., 2011). Within CLRTAP the Task Force on Reactive Nitrogen (TFRN) is making an effort to develop national nitrogen budgets using common methodology covering all important aspects of N flows and stores, ranging from atmosphere to hydrosphere and from energy production to waste management and agriculture (http://www.clrtap-tfrn.org/epnb). Compilation of national budgets will be powerful source of information needed to take evidence based decisions to form policy, nationally and internationally.

Abatement strategies

Studies of co-benefits and trade-offs between air pollution and greenhouse gases is currently mostly focused on the size of the climate impacts from emissions of certain air pollutants (Acosta Navarro et al. 2016), and how control of these pollutants can be executed to maximise co-benefits and avoid trade-offs with climate change (von Schneidemesser and Monks 2013, Schmale et al. 2014). However, the risks for decreased fuel efficiency from the pollution control technologies has not been given much attention but might lead to increased CO_2 emissions (Fino 2007, Bosch et al. 2009, Lloyd's register 2012). One reason for omission is high uncertainty but also fast development of technologies and policies that can reduce the problem, such as co-development of stricter Euro-standards and fuel efficiency standards in the European vehicle fleet. Regardless, analysis of possibilities to avoid risks for trade-offs between fuel penalties and air pollution control is needed.

There have been a number of scenario analyses of air pollution impacts of GHG strategies. McCollum et al. (2013) present that global climate policies could lead to substantial improvements in air pollution-related health impacts and improve energy security. Amann et al. (2014) present that for the EU an implementation of the revised EU climate policy package will reduce the costs of reaching the EU proposal for a revised NEC directive. Thompson et al. (2014) evaluate the air pollution impacts of US policies to reduce GHG emissions and find that the monetized air pollution impacts from climate policies would offset 26 – 1050% of the costs. Schucht et al. (2015) show that exposure to $PM_{2.5}$ in Europe mostly depend on European air quality policy with limited impact of global climate policy, while exposure to ozone is more dependent on global climate policy than European air pollution policy. However, studies also find that the potential for co-benefits decrease with increased climate policy ambition level (Thompson et al. 2014). Sweden, with large penetration of hydro and nuclear power as well as relatively strict climate policies since 1991, is therefore an interesting case for studies of future co-benefits and trade-offs between climate and air pollution policies.

Behavioural change has been shown to have relatively large GHG abatement potential in the EU (Faber 2012), which also implies potential for air pollution emission reductions. Modelling of behavioural changes requires more complex functions than what is used in the linear optimization of the standard GAINS model (RAINS mode optimization), and seem to focus on modelling transport demand. Furthermore, there is a difference in what type of data that is considered as exogenous to the modelling. In the standard GAINS model analysis of transport, total vehicle demand, fuel consumption, as well as vehicle miles travelled are used as input to the modelling while when modelling behavioural changes, these parameters are often the output. There is however experience of how to integrate energy system models (slightly similar to GAINS) with more advanced models of behavioural change (Bunch et al. 2015). But these experiences have been collected for the TIMES model that has more degrees of freedom than currently available in the standard GAINS model, and it is unclear how to incorporate this knowledge into the GAINS model system, and which types of behavioural changes that could potentially be modelled with a GAINS approach.

Practical Relevance

The research activities under SCAC 2 are relevant for several national and international policy activities.

Nationally, The Swedish Environmental Quality Objectives (SEQOs), decided by the Swedish Parliament, define the wanted status for the Swedish environment (Miljömål, 2016). Of the 16 objectives, *Clean Air, Only Natural Acidification* and *Zero Eutrophication* are directly related to air pollution. There are also other objectives of importance for air pollution policies such as *Reduced Climate Impact*, *A Non-Toxic Environment* and *Good Built Environment*. Sweden is still far from achieving the air pollution-directed objectives. The largest improvements have been achieved for acidification which has been halted in many lakes and there are also signs of ecosystem recovery, thanks to the large reductions in sulphur deposition. The health-related air quality has also improved but the premature deaths due to air pollution are estimated to several thousand annually. Nitrogen deposition is still above the critical loads in large areas, in particular in the south of Sweden, causing changes in biodiversity and increasing risks for nitrogen leaching from forest soils.

The Swedish Environmental Objectives Council presented recently a strategy for air pollution and climate (SOU 2016). The strategy points to the problems Sweden is facing and discusses the needs for further measures to meet the SEQOs. The strategy estimates the socio-economic costs for air pollution to 30-42 billion SEK annually (Gustafsson et al., 2014). The Council proposes various instruments to achieve the long term objectives. There are however several areas, where the scientific understanding underpinning the strategy is weak, e.g. for the emissions and effects from small scale wood combustion. The strategy points in particular to the interactions between air pollution and climate change and to the co-benefits that can be obtained through considering air pollution and climate together.

The research in SCAC 2 will significantly contribute to underpin further actions with respect to defining environmental and health risks in relation to the SEQOs, and proposing optimal control strategies. It will also take into consideration various interactions between climate and air pollution.

The air quality in Sweden is to a significant level dependent on international air pollution and air quality related SEQOs cannot be achieved without emission reductions in areas outside Sweden. The two main bodies for international air pollution negotiations and regulations are CLRTAP or the Air Convention and the European Union. The research in SCAC-II has to a large extent been defined by priorities set in various bodies in the CLRTAP structure under EMEP (HTAP), WGE (JEG) and WGSR (TFIAM, TFRN) and results will be disseminated in these fora accordingly.

Organisation and management

The program organisation will be based on the structure and procedures successfully employed in SCAC phase 1. In brief, the organisation and management of the programme will be based on the following components:

- **The coordinator with support from the coordinating institute (IVL)** is responsible for the overall scientific, communicational and administrative management of the programme. This includes financial and administrative issues in relation to the funding agency (NV) and internally between partners (contracts, distribution of grants etc.) as well as overall scientific coordination. The latter includes establishing routines for regular internal reporting to ensure progress in each WP.
- The **program steering committee (PSC)** with representatives for program coordination, the four WP co-leads, communication officer and representatives for the Swedish Environmental Protection Agency will be responsible for all decisions concerning the program, for reporting of progress and taking any necessary action to solve problems and delays in the project. Communication activities will also be discussed and coordinated in the PSC. The PSC will meet (digitally) at least 4 times per year and more often if needs arise. Coordination and communication functions are responsible for convening meetings and preparing brief notes on decisions taken and information exchanged.
- The **WP co-leads** will be responsible for internal coordination of research activities and for reporting of progress and any problems detected to the coordinator and to the PSC. The co-leads will also support the coordinator with any issues regarding the overall scientific and administrative coordination of the program.
- Partners not represented as WP co-leads will appoint a **partner lead scientist** (for scientific issues) and **administrative contact** (for administrative and financial issues).
- **Annual internal program meetings** will be arranged to report on progress and discuss cooperation and coordination between WPs. All partners and involved scientists as well as

representatives from NV will be invited to these meetings. In total three program meetings are planned.

Competence and external networks

The program participants represent a broad scientific competence and experience on air pollution and related areas. Program participants are active in a large number of networks and international research programs related to research and policy issues on air pollution and climate. A summary of the main competences, roles and networks program participants are involved in is given below. Additional information can be found in the CV:s enclosed to this proposal as well as on the programme website www.scac.se.

Examples of external networks and international projects where SCAC participants are involved

Name and function	Competence, experience and networks
John Munthe, IVL Applicant, and coordinator	PhD in Chemistry with 25 years experience of environmental research and science-policy interactions. Currently vice president, research, at IVL with responsibility for internal coordination and development of research activities. Coordinator or co-lead of several national programmes on air pollution and climate research (ASTA, SCARP, SCAC, CLEO) and EU program on mercury and chemical pollutions (GMOS, SOLUTIONS). Experiences from contributing to work in CLRTAP bodies e.g. EMEP, WGE. Board member of GAC – the Gothenburg Air and Climate Centre –since 2004.
Annica Ekman, SU WP 1 co-lead	PhD in meteorology with 20 years' experience of climate research with particular emphasis on modelling studies of aerosol particles and their effect on clouds and climate. Principal investigator and co-investigator of several national and international research projects funded by e.g. the EU, NordForsk, Swedish Science Council, Swedish Space Board, FORMAS, and Vinnova. President of the Atmospheric Sciences Division of the European Geosciences Union and member of several international steering committees related to atmospheric research.
Joakim Langner, SMHI, WP 1 co-lead	PhD in meteorology with >25 years of experience of environmental research with emphasis on the interaction between air pollution and climate. Principal investigator in or leader of several national, Nordic and European projects and networks. Long record of research management at institute level. Coordination of support to Swedish government on SLCF issues and member of AMAP expert group on black carbon and tropospheric ozone.
Bertil Forsberg, UmU, WP 2 co-lead	Professor of Environmental Medicine, Director of Division of Occupational and Environmental Medicine, Umeå University. PI for the Umeå centre in EU funded projects on air pollution and health such as PEACE, APHEA2, APHEIS, ENHIS, APHEKOM, ECRHS and ESCAPE. Coordinator of the ERANET project ACCEPTED (2013-2015) with 11 partners. WP leader for health in the ongoing Nordforsk program NordicWelfAir. WHO temporal advisor on air pollution and health.
Olena Gruzieva, KI WP 2 co-lead	MD, PhD, Postdoc, Institute of Environmental Medicine, Karolinska Institutet. Large experience from epidemiological studies of air pollution effects, 24 published papers in scientific journals.
Camilla Andersson, SMHI, WP 3 co-lead	PhD in applied environmental science, with 15 years of experience in air pollution dispersion modelling, including aerosols, tropospheric ozone and atmospheric deposition and effects. Research leader at the SMHI research department. Work package leader in international research programmes (ACCEPTED and Nordic WelfAir). Contributing to CLRTAP working groups, such as TFMM.
Per Erik Karlsson, IVL, WP3 co-lead	PhD in plant physiology. >25 years experience with research and science-policy interactions regarding ozone impacts on forests as well as changes in forest carbon stocks for climate change mitigation. Adjunct professor at Göteborg University in plants physiology with a focus on air pollution impacts on vegetation. Long experience with methods used to describe vegetation ozone exposure within CLRTAP, ICP Vegetation.
HC Hansson, SU, WP 1 co-lead	Hans-Christen Hansson is professor in Air pollution at SU with a 35 year long carrier in science. The research has mostly been within larger projects directed towards investigations of the life cycle of the atmospheric particles, later especially how they influence climate. Influence on health is also a concern, which drives his involvement connecting urban research with the regional focused research. He has active in the leadership of about 10 large EU-projects, Nordic and national projects.
Stefan Åström, IVL,	Ph.D.-student at Chalmers and researcher at IVL with over 10 years of experience with

WP 4 co-lead	integrated assessment of economic and environmental impacts of air pollutants. Work package leader in the SCARP, SCAC, and CLEO research programmes. Stefan is since 2013 co-chair in the UNECE CLRTAP Task Force on Integrated Assessment Modelling.
Maria Kardborn, IVL, Communication manager	Bachelors' degree in media- and communicational science from the University of Gothenburg. Ten years of experience from research communication and strategic communication at IVL and Volvo Cars.

Open access – data and publications

The results of this program will be published in publically accessible reports on in scientific journals with open access options. We will strive to publish with green open access if the journals' policy fits the NV requirements, if not we will publish with standard open access fees and have reserved budget for this cost. Environmental data collected in this project will be made available to the scientific community and other interested parties after results have been published via existing databases at the participating institutes.

Information on individuals in the mortality study is restricted for ethical reasons and will not be made public.

Communication

The primary objective and purpose of the SCAC communication is to support the program by communicating the research results to national and international stakeholders and to make results usable for policy and decision makers within the research field of SCACII, in addition to relevant professionals within the SEPA organisation. The SCAC program already has an established website, logotype and an email send-list for news items that will continue to be used for all communication activities within the program; presenting news, publications, events and contact details to management. **Target groups for the program are:**

Nationally

- Involved partners for the environmental objectives, with specific focus towards Clean air, Natural Acidification Only, Zero Eutrophication and Reduced Climate Impact - reached primarily through the researchers own contacts and affiliations, as well as targeted communicational efforts.
- Swedish municipalities - reached primarily through the researchers own contacts and affiliations, as well as targeted communicational efforts.
- The Swedish Environmental Protection Agency – reached primarily through recurring meetings and contact with the management team.
- Other researchers within the field – reached primarily through the researchers own contacts and affiliations.
- The general public and media – will be targeted with news of general interest, if applicable.

Internationally

- The results will be communicated to relevant bodies within CLRTAP - primarily HTAP, Task Force on Reactive Nitrogen (TFRN), ICP Vegetation and Task Force on Integrated Assessment Modelling (TFIAM).
- Expert groups under AMAP and in its extension the Arctic council - reached primarily through the researchers own contacts and affiliations.

As results are completed and/or published according to the activity plan below they will be spread through one or several of the following ways:

- Website – both on the publication site and as news.

- News items spread through partner networks (for example through IVL's own newsletter with 22 000 readers and their social media channels) and through the SCAC send list.
- Media presence when appropriate and relevant based on the results from the program.
- Arrangement of workshops, meetings and seminars as needed, requested or planned in the activity list.
- Arrangement of workshops and seminars as needed and requested, including a final conference.

Activity plan

WP 1 Hemispheric transport and international agreements. Budget 2 650 kSEK.			
Activity	*Month*	*Description*	*Partners*
1.1 and 1.2	16	Report on HTAP modelling activities in relation to hemispheric source-receptor relationships relevant for air pollution in Sweden and Northern Europe.	SMHI
1.3	24	Report/paper on sensitivity simulations using updated versions of NorESM and MATCH according to AMAP recommendations	SU+SMHI
1.4 and 1.5	36	Report/paper on the impact of future aerosol emission changes on the transport of aerosols, in particular to the Arctic, and how these aerosol emission changes affect climate.t	SU+SMHI
WP 2 Air pollution and health. Budget 2 350 kSEK.			
Activity	*Month*	*Description*	*Partners*
2.1	24	Journal manuscripts (or reports) on relationships between particle characteristics, sources and different types of health effects (at least two deliverables)	KI, UmU
2.2	36	Journal manuscript (or report) on sensitivity of health impact assessment calculations for selection of abatement options based on choice of particle measures and co-pollutants	UmU
2.3	18	Journal manuscript on exposure-response functions for mortality and specific particle measures and sources	GU, KI, UmU
WP 3 Air pollution and ecosystems – ozone and nitrogen. Budget 2 900 kSEK.			
Activity	*Month*	*Description*	*Partners*
3.1	12 24 30 36	-Completed database with growth and explanatory variables -Completed statistical analysis of the database, including possible dose-response relationships -Completed calculations of ozone impacts on C-sequestration in temperate and boreal forests in northern Europe -Assessment report: On the impact of ground level ozone on C-sequestration. "	IVL, GU-BioEnv, GU-GVC, UmU, SMHI
3.2	18 18 24 30 36	- Scientific manuscript: analysis of observed ozone concentrations at northern latitudes, with a special focus on high spring ozone concentrations - Report: literature review of the vulnerability of Arctic and Subarctic vegetation for ozone damage - Data delivery: Ozone exposure estimates for northern European temperate and boreal forests with source attribution - Scientific manuscript: analysis of the causes behind a potential shift in spring peak through sensitivity modelling - Assessment report on the risk for ozone damage to Arctic and Subarctic vegetation in northern Europe	IVL, GU-BioEnv,GBT, SMHI
3.3	24 36	Report on Swedish national nitrogen budget - Atmosphere and Hydrosphere Review report/paper on effects of N deposition on biodiversity based on experimental results and review of published studies	IVL, SMHI IVL
WP 4 Methods and models for identifying cost-effective abatement strategies Budget 2 900 kSEK.			
Activity	*Month*	*Description*	*Partners*
4.1	9	Report/paper on the risk of increased CO2 emissions from increased AP control. Report based on fuel penalty estimates from the literature and from the GAINS database.	IVL, IIASA, Chalmers, SU ACES

4.2	24	Report on the co-benefits on Swedish AP emissions from the climate ambition proposed in SOU 2016:47	IVL, IIASA, Chalmers, SU ACES
4.3	16	Submitted paper on which behavioural changes that could be modelled in a GAINS model setting, and how.	IVL, IIASA, Chalmers, SU ACES
4.4A, B	36	Report on which SCAC results that have been incorporated into GAINS Scandinavia or ARP-Sweden.	IVL, IIASA, Chalmers, SU ACES
Strategic Communication. Budget 600 kSEK.			
Activity	*Month*	*Description*	*Partners*
Kick-off meeting	1	Kick-off with all partners for planning purposes.	IVL, all
Yearly program meeting	12, 24 etc.	Presentation and discussions of results, plan integration and communication.	IVL, all
Final synthesis	35-36	Synthesis report focussing on main scientific results and policy relevance.	IVL, all
Final conference	36	Conference for dissemination of final results	IVL, all
Coordination. Budget 600 kSEK.			
Activity	*Month*	*Description*	*Partners*
Administrative and financial	1-36	Contracts, distribution of funds, contacts with SEPA and partners.	IVL
Steering group meetings	1-36	At least 4/year for progress reporting, adjustment of plans (if necessary) and internal communication.	IVL, all

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