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Climate, water and renewable energy in the Nordic countries

ÁRNI SNORRASON & JÓNA FINNDÍS JÓNSDÓTTIR
NEA Hydrological Service, Grensásvegur 9, IS-108 Reykjavík, Iceland
asn@os.is

Abstract Climate and Energy (CE, www.os.is/ce) is a new Nordic research project (2003–2006) with funding from the Nordic Energy Research programme (NEFP, www.nefp.info) and the Nordic energy sector. The main objective of the project is to make a comprehensive assessment of the impact of climate change on renewable energy resources in the Nordic area including hydropower, wind power, bio-fuels and solar energy. This study will include the evaluation of power production and its sensitivity and vulnerability to climate change on both temporal and spatial scales, and the assessment of the impacts of extremes including floods, droughts, storms, seasonal patterns and variability.

Key words bio-fuels; climate change; hydropower; renewable energy; solar energy; wind power

BACKGROUND AND SCOPE

In each of the Nordic countries, there are active and ongoing national projects in the field of climate research and climate impact assessment. Many of these projects were initiated in light of the importance of renewable energy sources in the Nordic countries that will play an ever increasing role in the quest for reducing the anthropogenic impact on climate (Snorrason & Jónsdóttir, 2004). The Climate and Energy (CE) project extends from 2003 to 2006 and focuses on the four renewable energy sources: hydropower, wind power, bio-fuels and solar energy. The CE project benefits from the national projects and extends and integrates their work both on a regional scale and for cross-cutting subjects. The projected climate changes will influence both the energy requirements and the possibilities of energy production. Furthermore, extreme weather events could impact the planning, design and operation of the energy system (Snorrason *et al.*, 2000). An important objective of the project is to establish a research network creating the critical mass that is necessary for a comprehensive regional assessment of the scope described here.

PROJECT ORGANIZATION

The project organization is based on a matrix structure (Fig. 1). The project manager is responsible for the overall management of the project with the assistance of the steering group. The project consists of five thematic working groups and five working groups whose tasks will cut across the thematic groups. For each of the four renewable energy sources the following issues must be addressed: production potential in various climate scenarios (long-term, seasonal and regional), and sensitivity to extreme events.

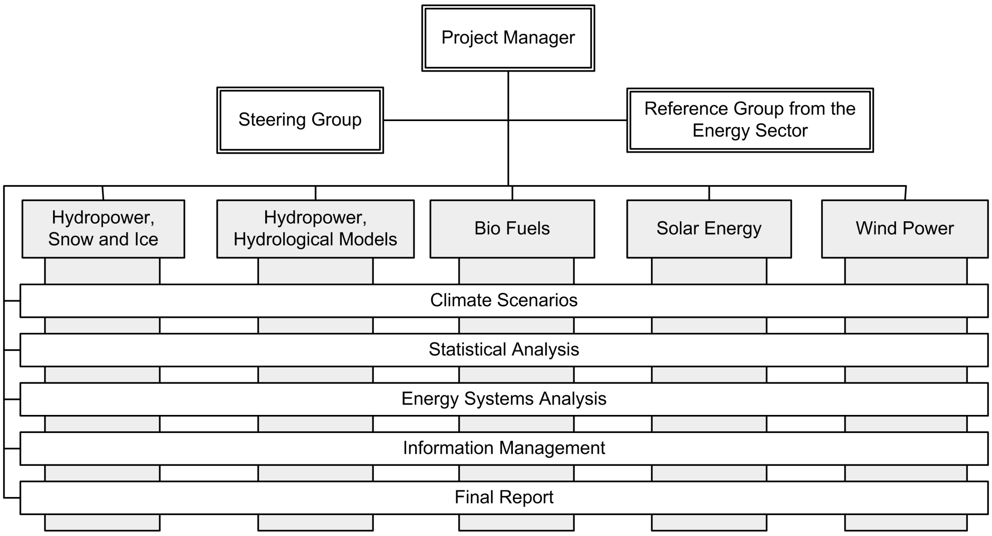

Fig. 1 The CE organizational chart.

Fig. 2 Rossby Centre regional modelling domain applicable in the context of CE. In a previous project a composite scenario of the whole Nordic region was developed (Rummukainen *et al.*, 2003).

Climate scenarios

Within CE, the Climate Group (CG) prepares input data for impact modelling by the CE renewables groups, in the form of regional climate scenarios. The basic data set refers to a small set of plausible projections from the 30-year-period of 1961–1990, to the period of 2071–2100, on a resolution of approximately 50 km. This basic data set is based on recent Nordic regional climate projections, which were originally prepared in other projects. The geographical extent of the data set is shown in Fig. 2.

Recent Nordic regional climate projections from the Rossby Centre of SMHI (Räisänen *et al.*, 2004), DMI (Kiilsholm *et al.*, 2003) and met. no (Haugen & Ødegaard, 2003) that have been prepared by using the respective regional climate models, will be made available to CE. In addition to differences due to different regional climate models (RCMs), differences between these climate projections arise from the choice of emission scenario; both the A2 and the B2 IPCC SRES scenarios have been used (Nakićenović *et al.*, 2000), from which global climate model the large-scale boundary conditions are imported (HadAM3H, and ECHAM4/OPYC3). Two sets of additional simulations are planned: re-analysis simulations using the ERA-40 as the large-scale boundary conditions, and transient climate projections from about 1950 to 2050.

As the CE scenarios comprise only a small subset of plausible future evolutions, the CG will also utilize additional data and techniques to place the CE results in a greater perspective. The main objective is to assess aspects of uncertainty ranges inherent in climate change across the Nordic region arising from four sources: emissions scenarios, model formulation, natural variability and resolution of the scenario technique. In addition, differences between results from dynamical and empirical downscaling techniques will be addressed.

Hydropower: snow and ice

Snow and glacier studies are important for the assessment of the long-term variability of climate in the Nordic countries. Furthermore, the effect of climate change on snow cover and glacier mass balance is important in connection with changes in average river runoff and seasonality and thus on production of hydropower in the near future (Jóhannesson, 1997). In addition, an analysis of the impact of climate change on the snow and ice cover of lakes and rivers is relevant since they may have large impacts on the operation of the hydropower industry. The results from mass balance and dynamic ice flow models on the future shape of the glaciers will be used for water resources scenarios of the future.

Hydropower: hydrological models

Hydrological models serve primarily the role of a link between climate scenarios and water power production simulations as well as for estimating the magnitude and risk of floods and drought. Two main topic areas of research are on one hand, an analysis of the hydrological processes and their relationship to changes in climate, and on the other, the integration and coupling of climate and hydrological models.

Comprehensive hydrological climate change maps of the Nordic region The intention is to provide maps that show climate change impacts on the most important hydrological components and on water resources in the Nordic region. The maps will be based on the climate scenarios and the delta change approach as provided by the CG. They will show annual and seasonal average runoff maps for the 30-year periods 1961–1990 and 2071–2100, annual average of maximum snow water equivalent and number of days with snow cover as well as annual and seasonal average of maximum soil moisture deficit for the same periods. The maps will be as consistent as possible, but for practical and economical reasons it will have to rely upon existing national work. The climate scenarios will be the same but there will be differences in details of hydrological modelling and sub-division of the landscape.

A major issue within the project is the comparison of the delta change approach with the use of direct data from the scenarios. Methods will be developed to enable the use of direct data from the scenarios as an input to the hydrological model. As a first approach, simple scaling of the precipitation will be applied. The effects of different regional climate model resolutions will be a part of the comparison of the delta change approach and direct use of data from the scenarios. Comparisons will be carried out for the resolutions 49 and 25 km^2.

Climate change effect on dam safety Watershed simulation and forecasting system catchment models will be used to evaluate the design floods of large dams in Finland in present and future climate change conditions (2071–2100). Design precipitation and 40 years of weather data are combined to find the design flood in the present and changed conditions. The change of design precipitation due to climate change has already been evaluated using the HadCM2 IS92a climate scenario. The change in the average precipitation and temperature will be evaluated using climate scenarios from the CE climate group. The work will include sensitivity analysis of a design flood to changes in design precipitation, temperature and model parameters. Statistical and model-based methods of design flood assessment will be compared and evaluated.

Statistical analysis

Statistical analysis of long time series of hydrological and meteorological time series, and other long time series reflecting the renewable energy sources, is a key area of research. As a first approximation, past data are useful in clarifying the background of natural variability to which the forced change adds to. Both aspects are relevant for the energy sector. The work needs to focus on studies of trends in both annual and seasonal values, and the magnitude and timing of extremes. Furthermore, an analysis of which processes relate the variability of the atmospheric circulation to the variability of the Nordic rivers will be performed (Snorrason *et al.*, 2003; Jónsdóttir *et al.*, 2004). This will reveal the options for predicting the hydrological conditions in the region based on indices, e.g. NAO, and information from the prevalent general circulation patterns.

PRELIMINARY RESULTS

In a paper by Hisdal *et al.* (2004) a study of streamflow in the Nordic countries reveals that the streamflow has already changed. Even though the period analysed and the region studied influences the trend seen in the data, the conclusion is that the spring and winter streamflow has increased and that the snow melts earlier than before. Figure 3 shows trends in seasonal streamflow; the positive trend in winter and spring is regional, while trends during summer and fall (not shown) are more localized and regional patterns of change are not visible.

A study of climate change impacts on runoff in Sweden (Andréasson *et al.*, 2004) shows that annual runoff volumes will, according to the scenarios, decrease in southeastern Sweden, especially summer runoff. However, annual runoff volumes in

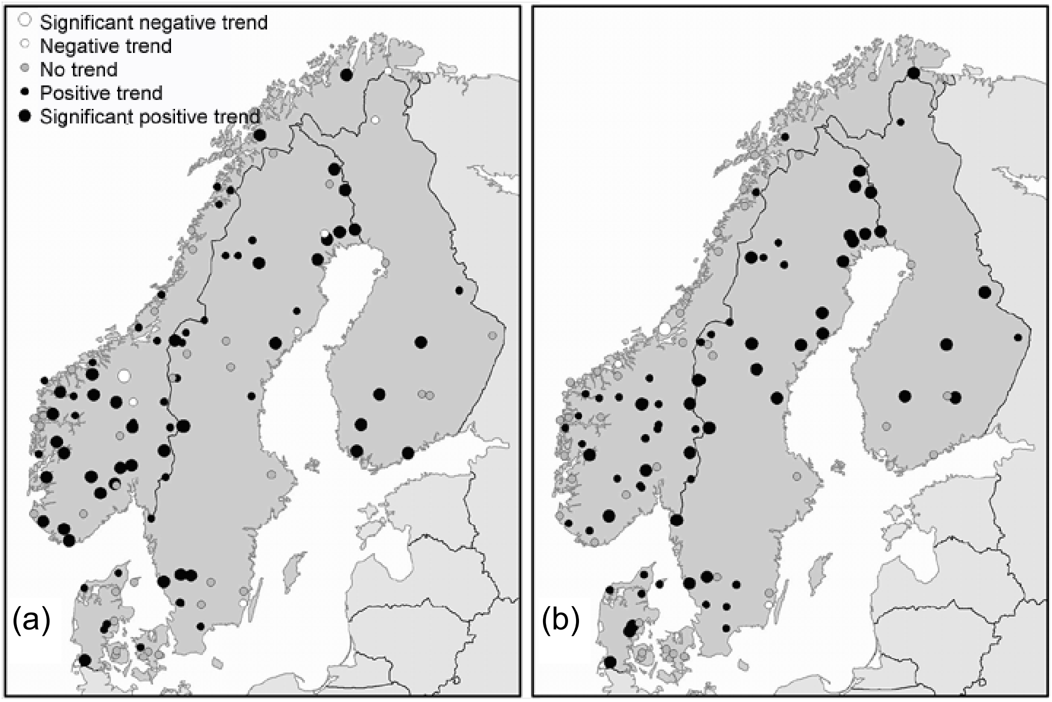

Fig. 3 Trends in seasonal streamflow: (a) winter, (b) spring (Hisdal *et al.*, 2004).

northern Sweden will increase, especially in the mountains. The estimated 100-year flood decreased in large parts of the country, but increased in the southwest and along the Norwegian border. Analysis of extremes are, however, very uncertain since the method of transferring the climate signal, the delta change approach, is questionable when dealing with frequency analyses since it does not include any special treatment of extremes. Trends in runoff records in Sweden for the period 1991–2002 do not contradict the scenario results.

A paper by Veijalainen & Vehviläinen (2004) discusses the effects of climate change on design floods in Finland. In northern Finland, the design floods remain spring floods, they stay unchanged or decrease since the increase in design precipitation is partly compensated by a decrease in snow accumulation. In central and southern Finland, however, the design floods in 2070–2099 are expected to occur during summer or fall (or winter) and these may intensify, some considerably.

CONCLUSIONS

The Nordic research project, Climate and Energy, has created an integrated network of institutes and scientists to carry out a comprehensive regional assessment of the impact of climate change on renewable energy resources in the Nordic region including hydropower, wind power, bio-fuels and solar energy. The project can serve as a regional base for a comprehensive global assessment at the scale and level that will be necessary in future work on climate change and its impact on water resources.

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