



Climate changes in the 21st century and their impacts on renewable energy resources

Final report from the Nordic-Baltic research project: Climate and Energy Systems

Summary. *The Nordic Council of Ministers (NCM) has published a new report on the impacts of 21st century climate changes on the development and use of renewable energy in the Nordic and Baltic countries. The report is the final product of a comprehensive research project, Climate and Energy Systems (CES), which involved 30 scientific institutes and companies in the eight countries during the years 2007-2011. Main emphasis was on the impacts of climate changes on the utilisation of hydropower, wind power and biomass energy. The results indicate mainly beneficial impacts of a warmer, wetter climate on renewable energy sources although safety aspects have to be considered further.*

Climate scenarios developed for the period 2021-2050 (in comparison with 1961-1990) indicate continuing atmospheric warming in the region. The largest warming (about 3°C) will take place during winter in the north-eastern part of Fennoscandia, while summertime warming will be about 1-2°C all over the Nordic and Baltic region. Precipitation is expected to increase moderately but little change is expected in mean wind speed. The volume of glaciers will be dramatically reduced during the 21st century, resulting in increased meltwater delivery during the middle part of the century. Winter snowfall is likely to decrease, as will snowmelt floods during spring. The size of extreme floods will become larger in some regions but smaller in others, depending on precipitation changes. Increased runoff in some regions will lead to greater inflow to hydropower reservoirs, allowing a potential 10% increase in hydropower production in the NordPool area by 2020. Even though mean wind speeds are unlikely to change greatly, the utilisation of the wind power resource will increase significantly through construction of new onshore and offshore wind farms. Faster growth rates of forests will enable a substantial increase in the production of biomass energy from forest products and increased levels of biofuel production from peat deposits are expected.

Power trade within the NordPool area and between the Nordic and Baltic countries will increase and the region will likely increase exports of electricity to continental Europe. The uncertainty in scenarios of future changes in climate, hydrology, glacier mass balance and forest growth has been assessed within the project, and risks and opportunities identified. The CES project has demonstrated the Nordic added value of collaborative research on renewable energy sources and spawned new collaborations within this field.

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Renewable energy in the Nordic countries. Fossil fuels, which accounted for 81% of the global energy consumption in 2009, are a finite resource and their exploitation is increasingly expensive and damaging to the natural environment. In contrast, renewable energy sources derive their energy directly from the Sun or from the heat in the Earth's interior and are thus constantly being replenished. Hydropower, wind power, bioenergy, geothermal energy, solar energy and ocean (tidal) energy are the most important renewable energy sources and their share in global energy consumption rose to 16% in 2009. In 2008, EU countries set themselves the target of increasing the share of renewable energy to 20% of total energy consumption by 2020. The Nordic countries have already reached this goal and the share of renewables is much higher in Norway and Iceland, due to extensive utilisation of hydropower (and geothermal energy in Iceland). See Table 1.

Table 1. The share (in %) of renewable energy in total energy consumption in the five Nordic and three Baltic countries in 2008 and target values for 2020. Sources: www.energy.eu; www.nordicenergysolutions.org

Country	2008	2020
Denmark	19	30
Finland	30	38
Iceland	81	85
Norway	62	66
Sweden	44	49
Estonia	19	25
Latvia	30	40
Lithuania	15	23

The CES project. The project *Climate and Energy Systems (CES)* involved 100 scientists at 30 research institutes in the Nordic and Baltic countries (Fig. 1). The aim of the project was to develop new climate scenarios for the region until the mid-21st century (and in some cases until 2100) and use projections of temperature, precipitation and runoff to estimate potential changes in the delivery of water to hydropower reservoirs, changes in wind strength in relation to wind energy harnessing and changes in the production of biomass energy from forests. Hydropower is extensively developed in Norway and Iceland, wind power in Denmark and bioenergy from forests and peat forms a significant part of the energy production in Finland and the Baltic states. The largest producer and user of energy in the Nordic region, Sweden, uses all above mentioned sources of renewable energy and currently leads EU countries in the share of renewables in total energy production.

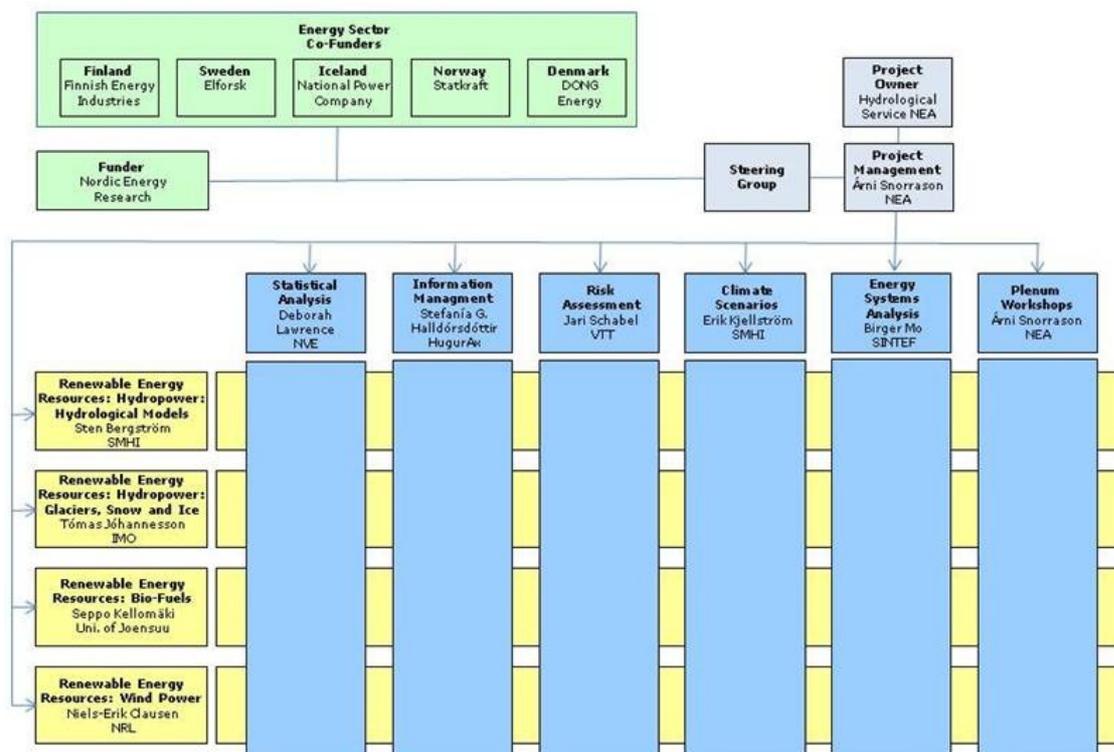


Figure 1. Structure of the project *Climate and Energy Systems*. The project was financed by Nordic Energy Research (a coordinating body operated by the Nordic Council of Ministers), Nordic energy companies and the participating institutes. The project was coordinated by the Icelandic Meteorological Office (and by the National Energy Authority, NEA, in the initial stages). Project homepage: <http://en.vedur.is/ces>

Climate scenarios. The production of climate scenarios for the CES working groups was led by the Rossby Centre of the Swedish Meteorological and Hydrological Institute. Climate scientists participating in the project used output from a number of high-resolution regional climate models to calculate likely development of air temperature, precipitation and wind speed in a region of N-Europe that encompasses the Nordic and Baltic countries. Fig. 2 shows that the largest increase in temperature in the period 2021-2050 (up to 3°C) is expected to occur in Finland and the northern part of Scandinavia during the winter season, according to these models. A temperature increase of 1-2°C is expected over the entire region during the summer season. Part of this warming (relative to mean temperature during the period 1961-1990) has already been observed. Precipitation will probably increase by 5-15% over most of the region and greater increase is expected in winter than during summer. Large changes in mean wind speed are not expected. The regional climate change scenarios were put in a wider perspective by comparing to a larger ensemble of global climate model scenarios as used in the 4th assessment report on climate change by the IPCC in 2007. This comparison shows that the regional climate model scenarios mostly fall within the range of the global climate model scenarios and add relevant information at the regional scale.

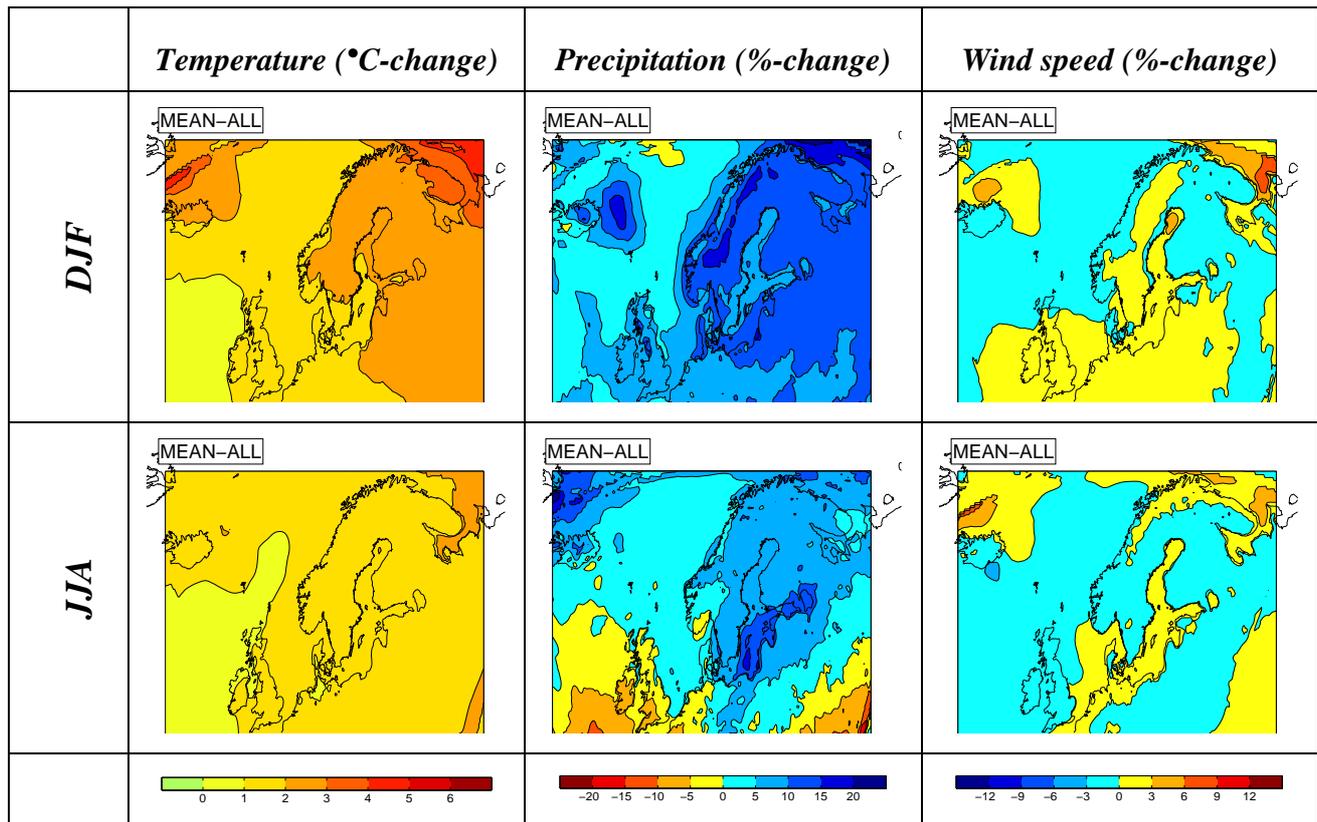


Figure 2. Projected change in temperature, precipitation and wind speed in Northern Europe between the periods 1961-1990 and 2021-2050. Averaged results from 15 climate models are presented in this scenario. See colour codes below the figures. Upper panels show winter mean values (DJF) and lower panels summer mean values (JJA).

Glacier changes. Modelling studies on the response of glaciers and ice caps in Iceland, Norway and Sweden to global warming were conducted in the CES project. The results indicate that the volumes of the large ice caps in the central highlands of Iceland will have diminished by 20-30% by 2050 (Fig. 3) and by 40-80% by 2100 (differences resulting mainly from elevation). Similar results are obtained for glaciers in Norway and Sweden. Meltwater discharge from the glaciers will increase during the downwasting period and reach a maximum in the period 2040-2070.

The CES project consolidated existing collaborations between Nordic glaciologists, who have now joined forces in a new centre of excellence supported by the NCM's Top-level Research Initiative; SVALI (= Stability and Variations of Arctic Land Ice). The main purpose of this project is to study the behaviour and variations of glaciers in the North Atlantic area, including Greenland and Svalbard, and estimate their contributions to future increase in sea level.

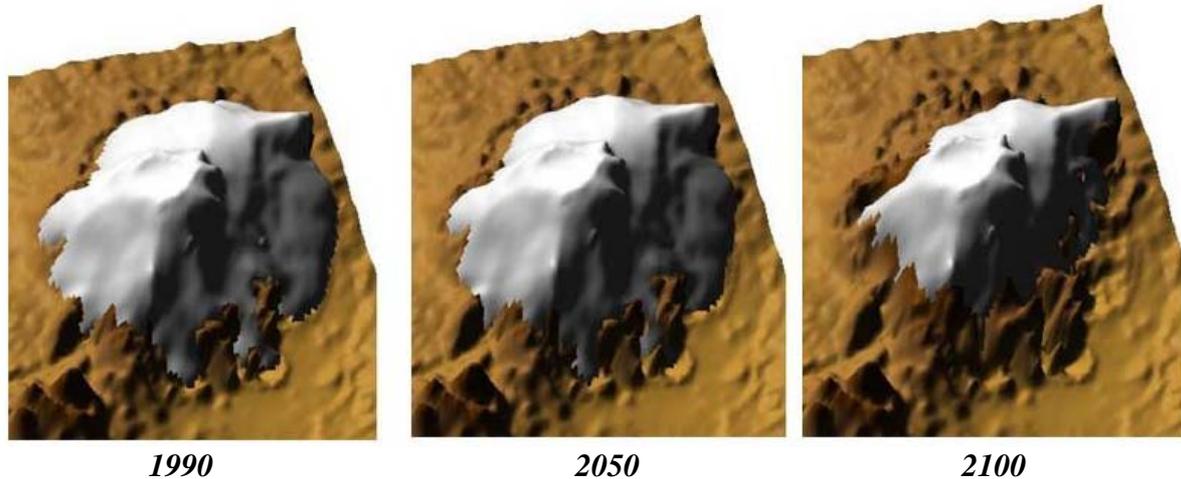


Figure 3. Modelled development of the Hofsjökull ice cap in central Iceland during the 21st century. Averaged projections of temperature and precipitation changes from 13 climate models are used as input to a glaciological model that computes changes in yearly mass balance and also accounts for the dynamic response of the ice cap to ongoing changes. The outline, shape and volume of Hofsjökull in 1990 are used as a starting condition in the calculations. Shown here is the extent of the ice cap in 2050 (20% volume loss) and 2100 (40% volume loss). The present diameter of Hofsjökull is 40 km, the area is 850 km² and the volume 200 km³.

Runoff changes and impacts on hydropower. Considerable changes are already occurring in climate parameters and runoff throughout the region, as exemplified by the data from the Baltic countries shown in Fig. 4. In a warmer and wetter climate, the seasonal variation in runoff and therefore the water delivery to hydropower reservoirs is likely to change (Fig. 5). A smaller percentage of the winter precipitation will fall as snow and spring snowmelt floods will decrease. Extreme floods that are expected to occur once every century (100-year floods) will diminish in some regions because of decreased snowfall. In other regions 100-year floods can become larger because of increased rainfall. Such an increase is f.ex. likely in Southern Sweden (Fig. 6). The CES project included a study of altered hydrological conditions in the future on dam safety in the Nordic countries, taking into account the uncertainties involved in the scenarios. Increased meltwater delivery from glaciers is expected in Iceland and Norway in the coming decades and more precipitation will probably lead to increased discharge to reservoirs in Sweden, Finland and Latvia. These changes imply a larger potential for hydropower production in the Nordic and Baltic region.

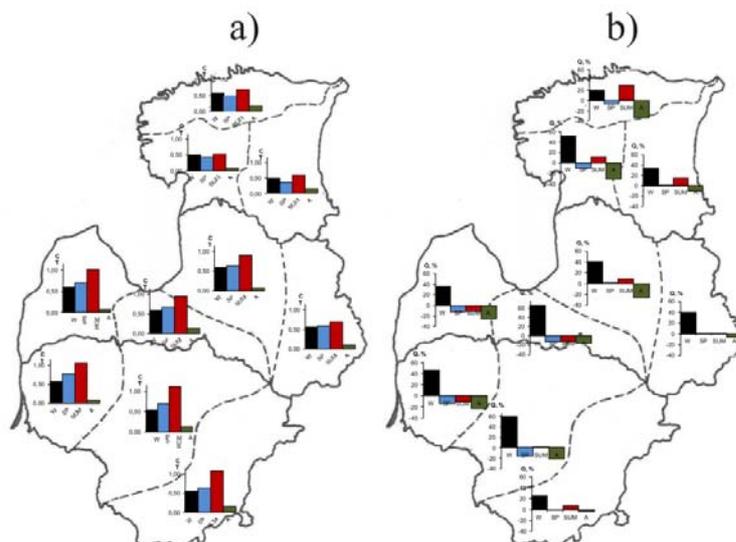


Figure 4. Seasonal anomalies in temperature and runoff in different parts of Estonia, Latvia and Lithuania in the period 1991-2007, relative to the 1961-1990 reference period. a) Temperature in °C, with the y-axis ranging from 0.00 to 1.00 °C. b) Runoff as a percentage, with the y-axis ranging from -40% to +60%. The seasons are indicated by colour: Dark blue – winter; light blue – spring; red – summer; green – autumn.

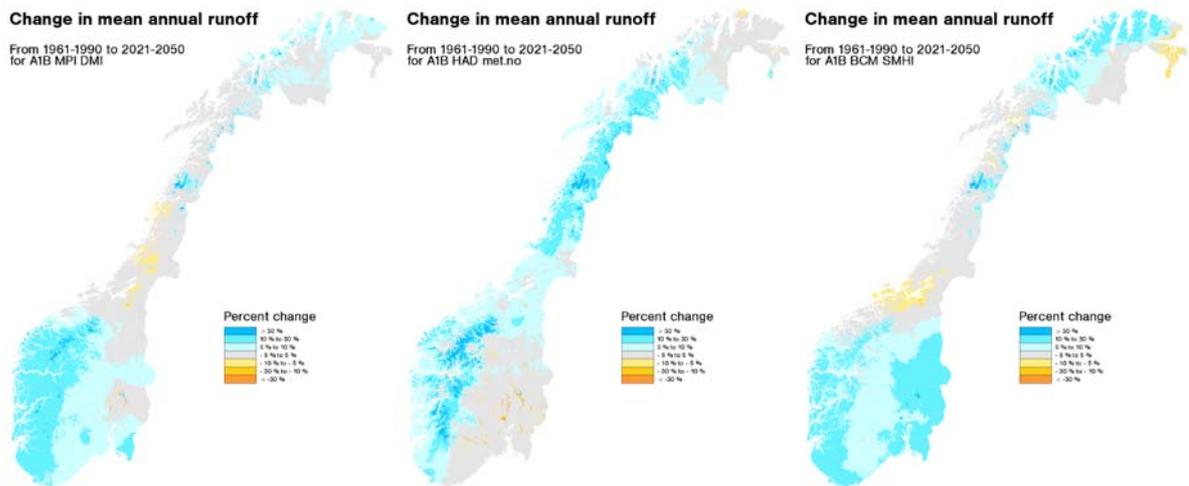


Figure 5. Percentage changes in runoff in Norway between the periods 1961-1990 and 2021-2050, according to three different models. Blue colours indicate increased runoff, in grey coloured regions little change is expected while yellowish colour indicates a runoff decrease. All three models forecast increased runoff in Western Norway whereas results differ for other parts of the country.

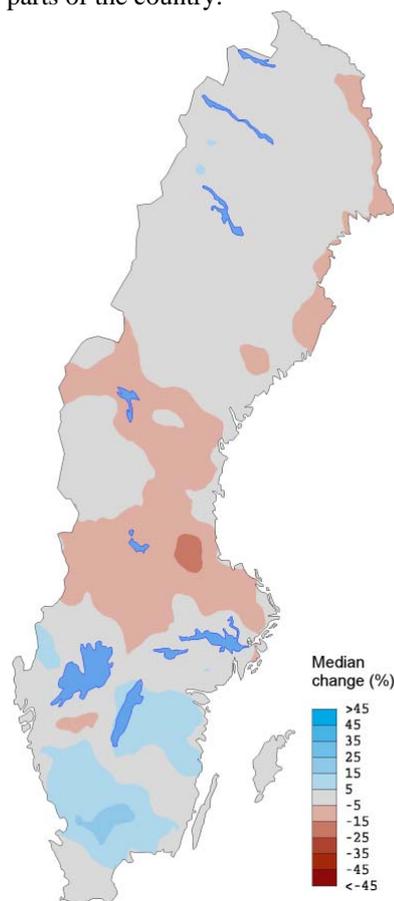


Figure 6. Results from an analysis of the most probable %-change in the size of 100-year floods in Sweden between the periods 1963-1992 and 2021-2050. The study made use of 16 regional climate scenarios and indicates that 100-year floods in the central part of the country will diminish in size, while they are likely to become larger in the southern part.



Wind power. Like many other countries around the world, the Nordic and Baltic countries are steadily increasing the exploitation of wind energy. Denmark has been leading in the development of onshore and offshore wind-power technology (Fig. 7) and by the end of 2010 Danish wind turbines produced 3800 MW electrical energy, i.e. more than 50% of the total production in the Nordic countries. Scenarios for wind velocity changes in the 21st century involve large uncertainties but major changes compared to baseline data from the period 1958-2000 are not expected. Participants in the wind-power working group within the CES project are leading in a new Nordic collaborative venture financed by the NCM's Top-level Research Initiative, ICEWIND. Among the main aims of this project is the mapping of wind-power potential in the Nordic countries in greater detail than before, development of improved forecasts of wind and ocean waves and studies of the occurrence of icing on wind turbines and resulting power losses.



Figure 7. The Middelgrunden offshore wind park on Øresund produces 4% of the electricity used in Copenhagen.

Production of forest biomass in a warmer climate. A Finnish research group within the CES project studied how projected 21st century warming will impact forest growth rates and thus the production of energy biomass (Fig. 8). The climate scenarios indicate that warming will be greater in Finland than in other parts of the region and thus a substantial increase in energy biomass and timber production is expected from modelling studies. For an unchanged forest thinning regime, the annual biomass energy production may increase by nearly 75% in the period 2071-2100 as compared with the baseline period 1961-1990. The Baltic countries will benefit in a similar way from increasing forest growth rates and they also aim for increased utilisation of peat resources for fuel production.



Figure 8. Left: A dense forest in Finland. Right: Briquettes from wood chips and sawdust, for energy production



Impacts on the Nordic power system. The NordPool market represents a single financial energy market for Denmark, Norway, Sweden and Finland. Scenarios for climate and runoff changes were used in the project to estimate likely changes in electricity production in the NordPool region, with special emphasis on hydropower. On the order of 10% increase in production potential is estimated by 2020 and changes are likely to occur in the power trade between the Nordpool countries. Exports to continental Europe are expected to increase and electricity prices are expected to decrease. In Iceland, the National Power Company assumes a nearly 20% increase in production potential in existing hydropower stations because of more meltwater delivery from glaciers. The current design of the stations will only be able to accommodate about 40% of this increase.

Uncertainty and risk estimates. Scientists modelling the future evolution of climate, runoff and glaciers emphasise that large uncertainties are involved in the scenarios. As an example, Figure 9 shows modelled changes in the size of 100-year extreme floods in the river Klarälven in northern Sweden. Results from 16 different climate models are employed to calculate discharge in the river and it can be seen that the range of results is very large (up to 50%). From these results it would not be possible to say with certainty whether a 100-year flood occurring in 2050 would be larger or smaller than a 1992 reference flood, even though the majority of models forecast smaller size.

The uncertainty concerning climate impacts on renewable energy resources is a key issue for the energy sector in the Nordic and Baltic countries, prompting a special study that assessed risks and opportunities for power and heat production systems during the upcoming 20-30 years. While recognising the benefits of increased power production potential, the study also highlighted disturbances in energy production that may occur due to extreme events such as floods, droughts, storms and increased wave heights. Uncertainty translates into riskier decisions at all levels within the energy sector including operational and market issues, short-term responses, and investments.

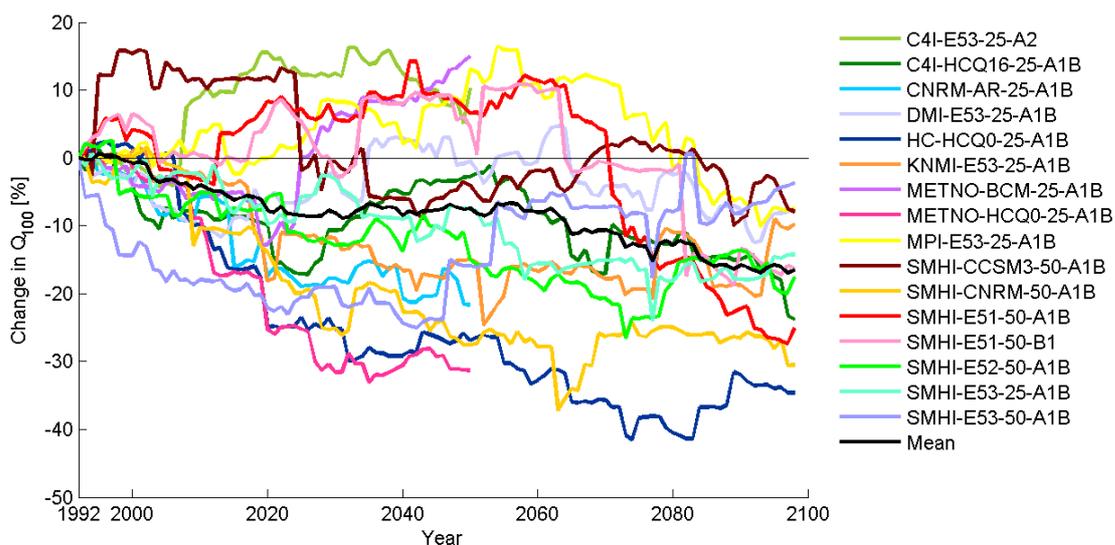


Figure 9. The vertical axis shows the percentage (%) change in the size of 100-year extreme floods in the river Klarälven in the 21st century. For the year 2050 two models indicate 10-15% discharge increase but one model yields a 30% decrease, the others lie in between. All models forecast smaller extreme floods by the end of the century, but the %-decrease varies between 5% and 35%.



Conclusions. The Nordic countries are leading in the exploitation of renewable energy resources and their share in total energy production in the region can be expected to rise further in the coming decades. The Baltic countries also aim to increase the use of renewables and bolster power trade with the Nordic countries, f.ex. through a new 700 MW submarine power link between Lithuania and Sweden, to be opened in 2015. Generally, all eight countries are well positioned and sufficiently prepared to handle the impacts of projected climate changes on the energy systems of the region in the first half of the 21st century, and important adaptation measures are already being taken. Improvement in climate scenarios and hydrological, glaciological and forest ecosystem models will reduce uncertainties in future forecasts and help minimize risks involved in decision making within the energy sector. The project *Climate and Energy Systems* has demonstrated the Nordic added value of collaborative research on renewable energy sources, not least due to the important differences in these countries' energy sectors.

Participating institutes

Icelandic Meteorological Office (IMO)
Danish Climate Centre, DMI
Danish Meteorological Institute (DMI)
Ea Energy Analyses, Copenhagen
Finnish Environment Institute (SYKE)
Finnish Meteorological Institute (FMI)
Geological Survey of Denmark and Greenland (GEUS)
HugurAx Software Solutions, Reykjavík
Institute for Meteorological Research, Reykjavík
Institute of Earth Sciences, University of Iceland
IVL Swedish Environmental Research Institute
Landsvirkjun (National Power Company), Iceland
Latvian Environment, Geology and Meteorology Centre
Lithuanian Energy Institute
National Environmental Research Institute, Denmark
Norwegian Meteorological Institute (NMI)
Norwegian Water Resources and Energy Directorate (NVE)
Risø DTU National Laboratory for Sustainable Energy
Rosby Centre of the Swedish Meteorological and Hydrological Institute
SINTEF Energy Research, Norway
Swedish Meteorological and Hydrological Institute (SMHI)
Tallinn University of Technology
University of Alaska
University of British Columbia
University of Eastern Finland
University of Helsinki
Uppsala University
Voeikov Main Geophysical Observatory, St. Petersburg
VTT Technical Research Centre of Finland