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Impacts on the energy sector and adaptation of the electricity network business under a changing climate in Finland

Johanna Kirkinen, Antti Martikainen, Hannele Holttinen, Ilkka Savolainen, Osmo Auvinen and Sanna Syri

FINADAPT Working Paper 10

FINNISH ENVIRONMENT INSTITUTE

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Preface

The Intergovernmental Panel on Climate Change (IPCC) defines adaptation as "Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities"[1]. The IPCC lists two reasons why adaptation is important in the climate change issue. First, an understanding of expected adaptation is fundamental in evaluating the costs or risks of climate change. Second, adaptation is a key response option or strategy, along with mitigation. Even with reductions in greenhouse gas emissions, some climate change is regarded as inevitable, and it will be necessary to develop planned adaptation strategies to deal with the associated risks as a complement to mitigation actions.

In Finland, there has been substantial progress during the past decade in investigating the potential impacts of climate change on natural and human systems. In contrast, there has been much less attention paid to adaptation. This was recognised by the Finnish Parliament as early as 2001, when it recommended that a separate programme for adaptation to climate change be initiated. As a result, a task force co-ordinated by the Ministry of Agriculture and Forestry completed Finland's first National Strategy for Adaptation to Climate Change in 2005.[2]

At about the same time as the Strategy document was being drafted, a research consortium named FINADAPT also began its work. The goal of the consortium, involving 11 partner institutions co-ordinated by the Finnish Environment Institute, was to undertake an in-depth study of the capacity of the Finnish environment and society to adapt to the potential impacts of climate change. FINADAPT was funded for the period 2004-2005 as part of the Finnish Environmental Cluster Research Programme, co-ordinated by the Ministry of the Environment. It comprised 14 work packages (WP) covering: 1) co-ordination, 2) climate data and scenarios, 3) biodiversity, 4) forests, 5) agriculture, 6) water resources, 7) human health, 8) the built environment, 9) transport, 10) energy infrastructure, 11) tourism and recreation, 12) economic assessment, 13) urban planning, and 14) a stakeholder questionnaire. The primary objective of FINADAPT was to produce a scoping report based on literature reviews, interactions with stakeholders, seminars, and targeted research.

This report presents the findings of work package 10, describing adaptation to climate change in the energy sector, with special reference to the electricity distribution network.

Timothy Carter, Consortium Leader
Helsinki, December 2005

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[1] IPCC, 2001. *Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change* [McCarthy, J.J., O.F. Canziani, N.A. Leary, D.J. Dokken, and K.S. White (eds)]. Cambridge University Press, Cambridge and New York, p. 982.
[2] MMM, 2005. *Ilmastomuutoksen kansallinen sopeutumisstrategia* (Finland's National Strategy for Adaptation to Climate Change) [Marttila, V., Granholm, H., Laanikari, J., Yrjölä, T., Aalto, A., Heikinheimo, P., Honkatuki, J., Järvinen, H., Liski, J., Merivirta, R. and Paunio, M. (eds)], Ministry of Agriculture and Forestry, Helsinki (available in Finnish, 276 pp. and English, 280 pp.) http://www.mmm.fi/sopeutumisstrategia/

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Executive summary

Future climate change is expected to have impacts on the energy sector in different parts of the world. This can be concluded from many studies of the sector, though few of these have been very detailed. In Finland, two of the most relevant recent assessments are the ILMAVA project (Tekes technology programme CLIMTECH), and Finland's national strategy for adaptation to climate change (Ministry of Agriculture and Forestry). Globally, the impacts of climate change on the energy sector have been mostly studied at a quite general level with the exception of hydropower, which has some more detailed studies. The current review has revealed research in the following areas: climate change impacts on energy resources, on the exploitation of energy resources, on energy conversion, on demand of energy and the on the reliability of energy supply.

The energy resources considered in this literature review are hydropower, wind power, bioenergy, peat, solar power, fossil fuels and nuclear power. Under a changing climate, hydropower resources are estimated to increase in the Nordic countries, whereas in some parts of the world they may decrease. Wind energy potential is also estimated to increase in Finland. There was very little information about how climate change will affect solar energy, though some estimates suggest that solar energy may be reduced as a consequence of increased cloudiness. Biomass supply is estimated to increase due to a lengthening growing season and improved potential productivity, hence increasing the amount of available bioenergy. The amount of potential peat production is also estimated to increase in Finland, mainly due to a longer harvesting period. Climate change has only minor impacts on the exploitation of fossil fuel and nuclear energy resources.

Climate change affects the demand for electricity and heating. Climate warming can be expected to decrease heating demand but increase cooling demand. The production of combined heat and power may be reduced because of decreased demand for district heating. For energy conversion, climate change affects the temperature of cooling water reducing the efficiency of condensing power plants. The reliability of energy distribution and transmission will probably weaken, because climate change is likely to increase the frequency of extreme weather conditions.

Climate change has a large effect on the electricity network business in Finland at longer period. Climate change should be taken into account in the design of the networks, so that the harmful effects can be reduced. This can be done by increasing the share of underground cabling or developing new materials which resist the short circuits and developing new techniques for construction and maintenance, like winter time cabling or vehicles capable in operating in changed environments. As a conclusion, climate change is a threat to the profitability of electricity network business, but the effects can be compensated by taking the scenario results into account in design phase.

1. Introduction

The issue of climate change and energy is usually considered from the viewpoint of limiting future changes in climate through mitigation. In other words: how the greenhouse gas emissions from the energy sector can be reduced to mitigate the climate change. However, climate change is already underway, so it is also relevant to find out how this situation will affect the energy sector and how the energy sector should adapt to the situation to minimise possible negative impacts. It is important to find out what kind of challenges climate change will present to the energy sector. Climate change affects not only energy resources and their availability but also the way of utilising energy sources and distributing energy to consumers.

The information on the impacts of climate change is uncertain. This is due to the long calculation chain, which includes uncertainty in many points. Firstly, greenhouse gas and aerosol particle emission scenarios for the future are uncertain. The processes controlling the atmospheric concentrations of greenhouse gases are also not exactly known. These include carbon cycling between atmosphere and oceans and between atmosphere and terrestrial ecosystems. The response of climate to the perturbation of the radiative balance is not known accurately. Also many impacts on the energy system depend on extreme weather conditions the occurrence of which is more difficult to assess than the changes in average conditions.Many extreme events occur at scales that are finer than grid box sizes of contemporary climate models. Processes and mechanisms occurring at subgrid scales, such as those related to clouds and convective precipitation, need to be parameterized, and the details of these procedures vary from model to model. The uncertainty can be assessed at least to some extent by using different scenarios for emissions and different global and regional models, giving a range of future impacts. Despite many uncertainties and difficulties, it is important to estimate the possible impacts to outline potential harmful or beneficial effects occurring due to changing climate.

A literature analysis has been conducted to investigate how the impacts of climate change on the energy sector have been studied in Finland and in some other countries: what kinds of assessments have been made and what issues have been considered. Based on the review, a preliminary set of critical questions regarding impacts, necessary adaptation measures and adaptation possibilities of the energy system and infrastructure in Finland can be identified.

The objective of this study is to survey and analyse studies of climate change impacts on the energy sector. As stated above, climate change is usually studied from the mitigation point of view. On the other hand, it is also desirable to investigate how energy sector could adapt to climate change. By studying adaptation, opportunities may be identified for minimising future disruptions to the distribution of electricity and heat caused by a changing climate.

Figure 1 shows schematically how climate change impacts grow over time. The extent of the impacts varies according to what actions have been made to mitigate the climate change. The world with no climate change policies has the largest impacts and the impacts of climate change are getting larger over time. This is presented with a red line. The green line presents the effects of climate change with mitigation policies, resulting in lower impacts than in the world without climate change policies. Impacts can also be reduced by adaptation. The world with mitigation and adaptation has the smallest impacts of climate change. This is presented with a blue line.

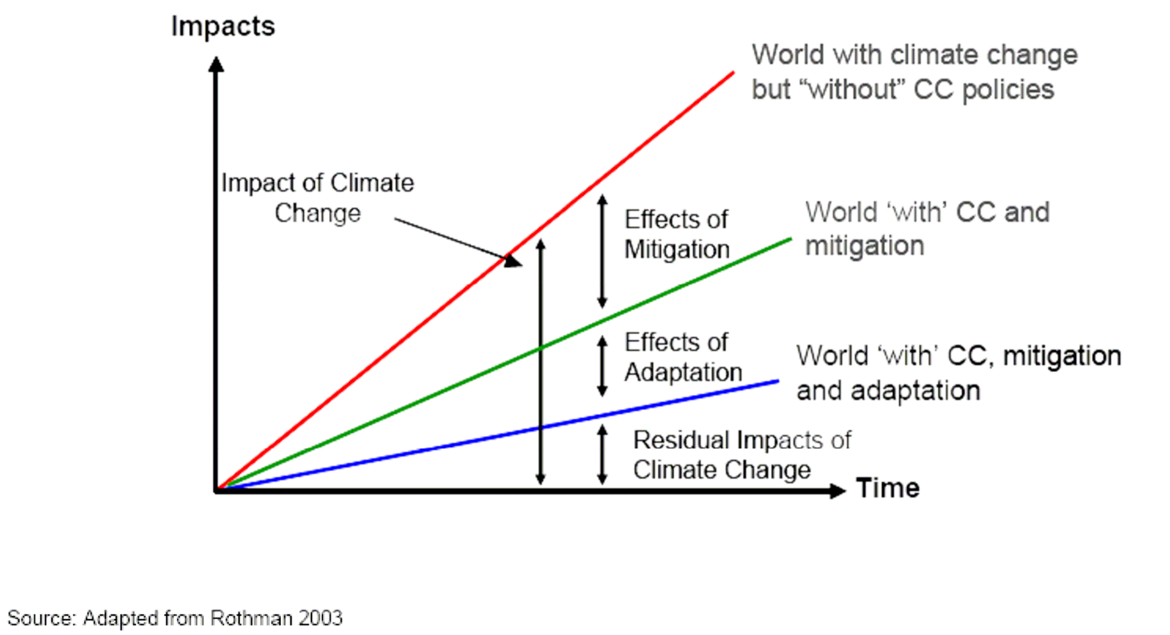

Figure 1. The impacts of climate change grow over time (Rothman et al. 2003). The impacts can be lowered with mitigation (reduction of greenhouse gas emissions and enhancement of emissions sinks) and with adaptation to the changing conditions. (Commission of the European Communities 2005)

Figure 1 shows why it is relevant to find out the effects that climate change has on the energy sector. If the effects are foreseen and there are possibilities to do adaptation measures, the effects can be reduced. In the energy sector investments are large and designed for several decades. Timely adaptation measures may thus help to avoid costly later adjustment and repair operations.

This work focuses mainly on studies not older than 10 years. Older studies than this have been analysed only if the studies have been significant and there are no recent studies about the subject. Information about climate and its changes has undoubtedly been changing during the last years, which should be taken into consideration when analysing studies. Only limited number of studies concerned Finland. Therefore the analysis was extended also to other regions.

The electricity network business has been adapted and designed for the present climate. As a consequence of climate change the climate variables are changing and this may have a great impact on the network business. The increase in the number of network faults will probably be the most significant disadvantage caused by climate change. Especially activities in network planning, construction and maintenance must be developed so that a network system will be as reliable in the future as today.

2. Literature review

This section presents a literature review of the sources of information available in this study. The chapter is divided into subsections by the sources from different country or region. Sources of information are also summarised in Table 1 at the end of this section.

2.1. Finland

The literature work was started by collecting Finnish studies. In the ILMAVA study the effect of climate change in Finland from 1961–1990 to 2021–2050 upon heating demand of buildings, hydropower production, climatological potential of peat production, bioenergy and wind energy was examined. Changes in montly mean air temperature, precipitation and wind speed over the periods 2021–2050 (predicted by climate models) were used as input for hydrological models and for heating demand, wind power and peat harvesting computation. The climate projections used in ILMAVA were primarily taken from Hadley Centre's global climate model, HadCM3, simulations assuming emission scenarios A2 and B2 of the IPCC Special Report on Emission Scenarios (SRES – Nakicenovic et al., 2000). The estimates of biomass changes were based on earlier studies (mainly SILMU, more information in next chapter and IPCC 2000). The ILMAVA project was a part of a broader programme on Technology and climate change (CLIMTECH) conducted in 1999–2003 and financed by the Finnish National Technology Agency (Tekes) (Savolainen et al. 2003, Lehtilä & Syri 2003).

On-going project on Natural hazards to infrastructure in a changing climate is managed by VTT (Makkonen 2004). The aim of the study is to define the occurrence of extreme circumstances in a changing climate - since storms, floods and other natural phenomena have a much bigger influence on a safe and eco-efficient dimensioning of the built environment than the average climate change. The occurrence of unusual natural phenomena is determined by assessment tools created in the study and are then used in interpreting the results from a climate change simulation model. This subject is very important in energy sector, because energy supply and facilities are vulnerable to extreme weather conditions.

Martikainen (2005) studied the impacts of climate change on electricity network business in Finland. In this study the changes in meteorological parameters were taken from the Rossby Centre regional climate model RCAO2 run with global models HadAM3-H and ECHAM4-OPYC3. The emission scenarios utilized were A2 and B2 from the IPCC. The climate parameters under examination were temperature, precipitation, hoarfrost, thunder, ground frost and wind. Also floods, soil moisture and sea level rise were taken account. This study is presented in more detail in the end of chapter 3.4 “The reliability of energy supply”.

VTT has made a study called Impacts of climate change on the built environment (Ala-Outinen et al. 2004). This study investigates how climate change affects the existing infrastructure and how climate change should be taken into consideration in future constructing. From the energy sector point of view this subject needs to be considered, when new facilities or electricity network are constructed. Global climate models (IPCC 2001) were used in assessments as well as scenarios and assumptions used in SILMU (Roos et al. 1996).

Venäläinen et al. (2004) examined the influence of climate change on energy production & heating demand in Finland. The future climate conditions were primarily taken from simulations by the Hadley Centre's global climate model, HadCM3.

Finland’s national strategy for adaptation to climate change was recently compiled by the Ministry of Agriculture and Forestry (Marttila et al. 2005). This work was based mainly on other studies such as Tammelin et al. (2003). It includes a rough assessment on how climate change affects the different parts of the society in Finland including the energy sector. The study covers narrowly same areas from energy sector as ILMAVA e.i. wind power, hydropower, peat production, bioenergy and heating demand. Also some other preliminary examinations have been made concerning the research needs on the impacts and adaptation (Carter & Kankaanpää 2003, Carter & Kankaanpää 2004).

Ruosteenoja et al. (2005) have studied climate scenarios for FINADAPT studies of climate change adaptation. Ruosteenoja et al. have constructed climate change scenarios for Finland for three tridecadal periods, 1991–2020, 2021–2050 and 2070–2099, with respect to the baseline period 1971-2000. Scenarios for the mean temperature and precipitation are based on output from six global climate models; minimum and maximum temperature, solar radiation, snow amount, soil moisture and wind velocity projections on 3-4 models. Projections are composed separately for the SRES A2 and B1 forcing scenarios.

The Finnish Governmental Institute for Economic Research has made a report concerning background economic scenarios in Finland (Honkatukia et al. 2005). This report considers the ability of adaptation to climate change of the Finnish economy. The assessment of direct impacts is based on SILMU study and the effects on the world economy are taken from the IPCC scenarios.

There exist also some other Finnish studies, including those conducted for the Finnish Research Programme on Climate Change (SILMU) during the early 1990s. The research provided a knowledge base on climate change and its potential impacts (Kuusisto et al. 1996, Roos et al. 1996, Kanninen 1992). The goals of SILMU were to increase knowledge on climate change, its causes, mechanisms and consequences, to strengthen the research on climate change in Finland, to increase the participation of Finnish researchers in international research programmes and to prepare and disseminate information for policy makers on adaptation and mitigation. It comprised results from individual research groups.

Also a master's thesis has been made about how climate change affects extreme floods and what kind of evaluation methods there exist (Veijalainen 2004). In this study two different statistical methods for estimating extreme floods were evaluated.

2.2. Nordic countries

Studies of climate change impacts on the energy sector have also been made in the Nordic Countries. An ongoing Climate and Energy (CE) project 2003–2006 is financed by The Nordic Council. This study investigates impacts of climate change on renewable energy sources and their role in the Nordic energy system (CE 2005). 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 pattern and variability.

Pryor and Barthelmie (2004) have studied winds in the CE project. In this report, the impacts of climate change on wind energy have been assessed by using different models and scenarios e.g.: using the Rossby Centre coupled Regional Climate Model (RCM) RCAO during the control period (1961–1990) and two Global Climate Models (GCM): HadAM3H and ECHAM4/OPYC3 and emissions scenarios (SRES A2 and B2). Clausen et al. (2005) describe the initial achievements in the wind energy work package of CE project, especially extreme winds and icing conditions in the Baltic Region caused by climate change.

The Nordic Council has also another study about climate change impacts on hydropower (Bergström et al. 2003), which describes briefly the present knowledge of methods for hydrological interpretation of climate change, present existing results from Nordic studies on climate change and hydropower production, and compares different strategies for conducting hydrological impacts assessment simulations.

Sælthun et al. (1998) have studied climate change impacts on runoff and hydropower in the Nordic Countries in the Nordic research program "Climate and energy production". The main objective of this research program was to analyse the effects of a future global climate change on the Nordic system for hydroelectric power production due to increased anthropogenic emissions of greenhouse gases in the atmosphere. The scenario formulated in this study demonstrated a realistic Nordic climate, which was mainly based on state of art information from IPCC.

In Sweden, some work is underway about the subject, e.g., Swedish Meteorological and Hydrological Institute (SMHI) is working on studies about adaptation to climate change (Räisänen et al. 2004, Rummukainen et al. 2005). Räisänen et al. (2004) have a study about climate simulations. Rummukainen et al. (2005) have studied the need for adaptation to climate change in different areas, energy sector is included with a general overview. Lundahl (1995) has made an assessment about impacts of climatic change on renewable energy in Sweden. Hydropower, wind power, bioenergy and solar energy are covered in this scientific article. Bergström (2002), Bergström et al. (2000) and Gardelin et al. (2002) have made short studies about climate change and how it affects the energy sector in Sweden. The studies have mainly concerned hydropower.

In Norway, the Center for International Climate and Environmental Researches (CICERO) is studying climate change and its impacts and adaptation from economic and social point of view (Sygna et al. 2004). In this report the impacts and adaptation have been assessed by developing different vulnerability analysis and methodological framework and that way identifying and analysing the situation in different sectors in Norway.

2.3. Europe

In Europe, there are recent studies about climate and adaptation. The Europe ACACIA Project has made a study about Assessment of potential effects and adaptations for climate change in Europe (Parry 2000). In ACACIA project the potential effects and adaptations are based upon an expert review of current knowledge. The ACACIA project covers all sectors, and the energy sector is mentioned only shortly. In energy sector extreme weather conditions and changing heating and cooling demands have especially been pointed out.

The recent PRUDENCE (Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects) project has investigated the future climate in Europe (Christensen 2005). The aim of PRUDENCE was to quantify our confidence and the uncertainties in predictions of future climate and its impacts, using an array of climate models and impact models and expert judgement on their performance, and to interpret these results in relation to European policies for adapting to or mitigating climate change. PRUDENCE provided a series of high-resolution climate change scenarios for 2071-2100 for Europe, characterising the variability and level of confidence in these scenarios as a function of uncertainties in model formulation, natural/internal climate variability, and alternative scenarios of future atmospheric composition. The project provided a quantitative assessment of the risks arising from changes in regional weather and climate in different parts of Europe, by estimating future changes in extreme events such as flooding and windstorms and by providing a robust estimation of the likelihood and magnitude of such changes. The project also examined the uncertainties in potential impacts induced by the range of climate scenarios developed from the climate modelling results.

As a part of PRUDENCE, Fronzek and Carter (2005) have assessed the uncertainties in climate change impacts on resource potential for Europe based on projections from RCMs and GCMs. This analysis presents the estimated impacts of climate change on resource potential in Europe under a wide range of model-based climate scenarios. The energy sector was considered e.g. by assessing impacts on the growing season, potential biomass and potential energy demand for indoor cooling. Impacts were estimated for climate during the 1961–1990 baseline period and projected during 2071–2100 based on outputs from a range of regional climate models (RCMs) driven by general circulation models (GCMs) assuming forcing by SRES emission scenarios A2 and B2, and from six atmosphere-ocean GCMs forced by a wider range of emissions scenarios. All analyses were conducted on a regular 0.5 x 0.5° grid across Europe.

Jylhä et al. (2005) have studied the changes in frost and snow in Europe and Baltic sea ice by the end of the 21st century. This study was also a part of the PRUDENCE project. Changes were analysed based on experiments performed with seven regional climate models (RCMs). The RCMs regionalized information from two general circulation models (GCMs), applying either the SRES A2 or B2 forcing scenario. Ice cover over the Baltic Sea was examined by using a statistical model that explained the annual maximum extent of ice by wintertime coastal temperatures. The projected changes would have implications across a diverse range of activities, including e.g. heating from the energy sector.

A scientific article by Lehner et al. (2005) investigated the impact of global change on the hydropower potential of Europe by a model-based analysis. The model used both climate and socioeconomic changes. Parkboom et al. 2004 have studied climate change impacts on electricity demand especially in Thailand according to information from existing studies. Harrison & Wallace (2005a) have contributed a short note about the current level of understanding on climate change and the potential implications for a range of renewable energy sources including hydropower, wind and wave energy. Harrison & Whittington (2002) have an article about renewable energy and climate change, where especially hydropower has been considered. Another on-going project is about vulnerability and adaptation to climate change impacts in Europe by the European Environment Agency (EEA).

2.4. Global

Many international studies about climate change and adaptation exist. They include studies about how climate change affects, e.g., agriculture, human health, forestry, hydrology and tourism. However, analysis of the impacts on the energy sector and especially adaptation of the energy sector to climate change are lacking from many studies. The most important international assessments are those of the Intergovernmental Panel on Climate Change (IPCC 1996, IPCC 1998, IPCC 2001). These studies cover energy sector quite briefly by concluding the most important results. Also International Institute for Applied Systems Analysis (IIASA) has made studies concerning the subject. The institute has made an inventory about the research on the impacts of climate change, where it aims to identify the current and proposed research and assessments being undertaken by international organisations as well as the major national research groups regarding climate change and its effects on different sectors. The report also identifies possible gaps in this research (Cesar 2004).

Organisation for Economic Co-operation and Development (OECD) has performed studies about estimating the global impacts of climate change (Smith & Hitz 2003). This work surveyed the literature on global impacts of climate change up to 2100 and to a limited extent delineated some regional impacts as well. Different categories were examined including energy. The results were mainly based on Tol's (2002b) study (listed later on). International Institute for Sustainable Development (IISD) has a study focusing on adapting to climate change in developing countries. In this investigation Venema & Cisse (2004) study how well-designed decentralized renewable energy projects are in fact a mitigative and an adaptive response to climate change. Decentralized renewable energy projects (DREs) address core sustainable development priorities and build adaptive capacity to climate change, without increasing greenhouse gas emissions.

The Arctic Climate Impact Assessment (ACIA) investigated the impacts of climate change on the Arctic (ACIA 2004). Energy sector is reviewed by energy resources (e.g. oil, gas and biomass and their utilisation), transportation of resources (by sea and land) and facilities. ATEAM's (Advanced Terrestial Ecosystem Analysis and Modelling) objective was to assess the vulnerability of human sectors relying on ecosystem services with respect to global change (Schröter et al. 2004). Energy sector was covered narrowly, only bioenergy was examined.

In the United States, there are many organisations investigating climate change and adaptation. Unfortunately energy sector is usually considered quite generally or not at all. Often studies contain information that only slightly relates to the impacts of climate change on energy sector. A study about climate change and its impacts was made by the Pew Center on Global Climate Change. This study is called Community adjustment to climate change policy (Greenwald et al. 2001) and it covered energy sector narrowly. The scientific article by Breslow and Sailor (2001) investigates the vulnerability of wind power resources to climate change in the continental United States. In Canada a study about climate change and the Canadian energy sector exists. The report concerns the vulnerability of the Canadian energy sector and possible adaptation (Mirza 2004). In this report the future climate due to climate change has been prognosticated and its impacts on energy sector (energy production, energy transmission and sectoral energy demand in a warmer climate) have been studied. Amato et al. (2005) have investigated regional energy demand responses to climate change and especially methodology and application to the commonwealth of Massachusetts.

Some individual studies have been made about climate change and its impacts (Hardy 2003). This study investigates different sectors also including energy. The demand of energy, biomass and hydropower resources are studied, but at a very general level. The impacts are mainly considered from an economic point of view. An annotated summary of climate change related resources (U.S. Environmental Protection Agency 2000) helps to identify the range of available resources pertaining to climate change including the energy sector. Obasi (2000) has investigated some impacts of climate change on the energy sector. Phinney and McCann (2005) and Trask (2005) have studied the impacts of global climate change on hydropower in California.

Table 1 Sources of information

Regions and Sources	Energy resources and exploitation of the resources							Energy conversion		The demand of electricity and heat	The reliability of energy supply	Economic point of view	Information about scenarios
	Hydro-power	Wind power	Bioenergy	Peat	Solar power	Fossil fuels	Nuclear power	Condensing power	Combined heat and power				
Finland													
Ala-Outinen et al. 2004											x		
Carter et al. 2005													x
Carter & Kankaanpää 2003													x
Carter & Kankaanpää 2004													x
Honkatukia et al. 2005												x	
Kanninen 1992	x	x	x	x				x	x	x			
Kuusisto et al. 1996	x	x	x	x				x	x	x			
Lehtilä & Syri 2003												x	x
Makkonen 2004											x		
Makkonen et al. 2001		x											
Martikainen et al. 2005										x			
Marttila et al. 2005	x	x	x	x				x	x	x			
Roos et al. 1996	x	x	x	x				x	x	x			
Ruosteenoja et al. 2005													
Savolainen et al. 2003												x	x
Tammelin et al. 2001	x	x	x	x				x	x	x			
Veijalainen 2004	x												
Venäläinen et al. 2004										x			
Nordic Countries													
Bergström 2002	x		x										
Bergström et al. 2000	x												
Bergström et al. 2001	x												
Bergström et al. 2003	x												
CE 2005	x	x	x	x	x								
Clausen et al. 2005		x											
Gardelin et al. 2002	x												
Lundahl 1995	x	x	x		x								
Parkboom et al. 2004										x			
Pryor & Barthelmie 2004		x											
Rummukainen et al. 2005													
Räisänen et al. 2003													x
Saelthun et al. 1998	x												
Sygna et al. 2004												x	
Other Europe													
Christensen et al. 2005												x	
Fronzek and Carter 2005										x			x
Harrison and Wallace 2005a		x											
Harrison and Whittington 2002	x												
Jylhä et al. 2005													x
Lehner et al. 2005	x												
Parry 2000										x			
USA and Canada													
Amato et al. 2005										x			
Breslow and Sailor 2001		x											
Monirul Qader Mirza 2004		x	x		x	x				x	x		
Phinney & McCann 2005	x											x	
Global													
ACIA 2004			x			x				x	x		
Cesar et al. 2004													
Dlugolecki and Lafeld 2005												x	
IPCC 1996	x	x	x	x	x	x	x	x	x	x	x	x	x
IPCC 1998	x	x	x	x	x	x	x	x	x	x	x	x	x
IPCC 2001	x	x	x	x	x	x	x	x	x	x	x	x	x
Obasi 2000										x	x		
Schröter et al. 2004													x
Smith & Hitz 2003												x	
Trask 2005	x												
Tol 2002a												x	
Tol 2002b												x	
Venema & Cisse 2004													

Some studies concerned mainly the economical impacts of climate change on e.g. the energy sector such as Tol (2002a and 2002b) and Dlugolecki and Lafeld's (2005) study. Also many of the earlier mentioned studies (e.g. Fronzek and Carter 2005) cover the economic impacts of climate change. Table 1 summarises the sources of information available on the impacts of climate change on the energy sector.

3. The impacts of climate change on the energy sector

The impacts on energy production and infrastructure are studied mainly in the following areas: energy resources and their exploitation, energy conversion in thermal power plants, demand of energy and reliability of energy supply.

3.1. Energy resources and their exploitation

The energy resources on which climate change may have impacts are hydropower, wind power, bioenergy, peat, solar energy, fossil fuels and nuclear power.

3.1.1. Hydro power

For hydropower production, the main issue is the resource and its variations: runoff and how it is distributed over the year. In Scandinavia the main inflow to the rivers and reservoirs is in late spring when the snow melts, and there is very low inflow during wintertime. This is why the reservoir management aims to save the water for high load situations in wintertime. Norway and Sweden have a much larger hydro power production than Finland, and the reservoirs have some capacity also for inter annual regulation. In Finland, the yearly hydro power production is 14 TWh/a in an average year, and this can be as low as 9 TWh/a during a dry year. The total reservoir content is 5.5 TWh. Much of the hydropower potential in Finland has already been harnessed excluding the rivers falling under environmental protection programmes. The potential to increase production is about 2 TWh/a (Finnish Energy Industries 2005). There is also potential to increase the production by decreasing the amount of bypassed water, which is today about 0.75 TWh/a. These losses due to diversion or bypassing the water come from the spring floods, when the inflow is stronger than the system can take, and also because there are rules of how the rivers can be regulated.

Generally, climate change is expected to strengthen the hydrological cycle (IPCC 2001) which may lead to increased precipitation and an increased average hydropower potential. Increased precipitation increases the inflow to hydropower plants and the amount of produced energy increases. When estimating the impacts to production, it has to be taken into account that climate change increases temperature and evaporation. Evaporation may decrease the amount of water the hydro power plants have in their use especially in catchment with abundant of lakes, and as a result, the amount of produced energy decreases (Tammelin et al. 2002). The impact depends on local and regional changes and conditions.

According to climate models, there will be a change in the seasonal distribution of annual cycle of precipitation, snowmelt and inflow to hydro reservoirs. Climate change shortens winter, which leads to a thinner snow cover and decreased amount of melting snow in spring. This affects the amount of spring floods and reduces the reservoir spillage due to diversion of flood water. This may result in increased energy production in hydro power plants. On the other hand, when precipitation increases, it may affect autumn floods when the need for diversion increases and it may reduce the amount of produced energy. Dam safety is crucial if the seasonal distribution of inflow to the reservoirs changes. It is important to be prepared for potential heavy rains in late summer autumn or even winter instead of keeping the reservoirs filled for wintertime after spring floods.

Climate change will probably affect the long-term planning of hydro power. On average, the ability to predict the production of hydropower decreases, which makes hydro power more difficult to utilize (Marttila et al. 2005).

In ILMAVA project, climate change approximations were made based on two different simulations. The information about temperature, precipitation and wind predictions used on power production were from HadCM3 global climate model of the UK Hadley Centre, using the SRES emission scenarios A2 and B2. ECHAM4-GSD and HadCM3-AA simulations were used to study the changes in the degree-day statistics. These two simulations propose that climate change will increase the amount of produced hydropower by 7 or 11% (Tammelin et al. 2002) from the period 1961–1990 to 2021–2050. The annual runoff will increase 0–8% depending on the location of the watershed and on the climate scenario used. It has been estimated that the increase in annual runoff and changes in annual distribution might cause even greater increase in hydropower production than earlier assessment have suggested. In a SILMU study, the production of hydropower was estimated to be 2% greater in 2025 and 2100 than in 1961–1990 (Roos et al. 1996).

The first results from Nordic Climate and Energy project suggest that the yearly variations in inflow to hydro power plants will become greater especially in Southern Finland where snow cover will diminish or even vanish. The time of maximum runoff will change from spring to autumn in some rivers. For dam safety, the design precipitation will increase and the time of design floods will change and the magnitude of design floods will increase on most dams. Spring floods will decrease and summer floods increase and become the design floods in southern and central Finland.

In Sweden, the increased runoff according to different scenarios will give potentially up to 40% higher hydropower production. How much of this will really exist is unclear, as the production systems probably will change during the time horizon of the used scenarios (Bergström et al. 2003). In an older study by Lundahl (1995), the estimations based on a scenario of doubled atmospheric CO_2–concentration suggest an increase of an annual hydropower production of 15% in Sweden. In Norwegian hydropower studies from 1990, it has been estimated that hydropower production will increase by 2–3% due to increased inflow and reduction of reservoir spill for 30 years ahead. A more recent study from 1998 suggests that hydropower production will increase by about 2.5% over 30 years (Saelthun et al. 1998). These results from Sweden and Norway are very different. Previous studies in Nordic countries cannot be directly compared, as they used different projects on regional climate modeling (RegClim Norway and SweClim Sweden). The preliminary results from Nordic Climate and Energy project suggest that the runoff will increase in Northern Sweden (where most of the hydro power production is) and stay close to the same in Southern Sweden. Also the evapotranspiration will increase in Northern Sweden. The study on streamflow time series from 1920 up to year 2003 confirm that there is an increasing trend of autumn and winter streamflows, also in annual streamflows if the exceptionally wet 1920's is excluded. There is also a trend for earlier timing of spring floods.

A study investigating the change in Europe's hydropower potential up until the 2070s, according to different climate scenario projections and future water use assumptions, suggests an increase of 15–30% and above in Scandinavia and northern Russia. The regions most prone to a decrease in developed hydropower potential are Portugal and Spain in Southern Europe, as well as Ukraine, Bulgaria and Turkey in the southwest, with decreases of 20–50% and more. In Western and Central Europe, the United Kingdom and Germany maintain a rather stable developed hydropower potential compared to other European countries. For the whole Europe, the gross hydropower potential is estimated to decline by about 6% by the

2070s, while the developed hydropower potential (i.e. mean supplied electricity) plants show a decrease of 7–12%. For Finland and other Nordic countries this study shows the increasing trend of hydropower potential (Lehner et al. 2005).

Adaptation to climate change in hydropower sector means utilizing a greater possibility for increasing the production of hydropower, and on the other hand making sure that dam safety is maintained in changing seasonal inflow patterns. It needs to be considered whether the dams are designed to endure possible extreme floods or inflow occurring in different times of the year than previously planned for. Flood mapping and optimizing the operational strategies will be important in the future. Increased winter runoff might create possibilities to increase the turbine capacity and water storage, if possible for environmental reasons. It is also notable that the climate sensitivity of energy production is related to the available storage. Greater storage tends to lower the sensitivity (Harrison & Whittington 2002).

3.1.2. Wind power

The production of wind power is very dependent on the wind resource of the site of the wind farm. The turbines start producing at 3…5 m/s (cut-in wind speed), reach their nominal power at 12…16 m/s and are shut down during storms to protect the turbine components (cut-out wind speed usually 25 m/s). An increase of mean wind speed at turbine rotor height of 1 m/s will increase the yearly power production by roughly 20 %. Wind speeds increase with increasing height from ground level. As the towers of the modern 1–3 MW turbines are 60…100 m high, their performance is better than the performance of smaller turbines. The aerodynamics of turbine blades is sensitive to increasing roughness of the blade surface. Potential causes for increased surface roughness are erosion of blade surface, icing of the blades, rain or impurities of the air (e.g. insects). The variability of wind and turbulent gusts, affect both power production and blade loads. In Finland, the most potential areas to produce wind power are on the coast and archipelago, on off-shore sites and in the Lapland fjell areas. In Finland the average wind speed is greater in the winter than in the summer.

In ILMAVA report (Tammelin et al. 2002) the climate change impacts on wind power production in Finland have been studied with the help of scenario results from climate models. The results from these climate models suggest that wind power production could increase in typical production areas approximately 7%, and off-shore wind potential would increase 10–15% annually from the period 1961–1990 to 2021–2050. These results are based on changes in mean wind speeds (Tammelin et al. 2002). Assessments made concerning wind power are uncertain firstly due to the uncertainty of the average values from climate change scenarios, and secondly due to the uncertainty of extreme cases, like storms and weak winds. The changes in distribution of wind speeds are also important for wind power production. If there is an increase in storm winds and weak winds outside the operating range of the turbines, the production of wind power may decrease (Marttila et al. 2005, IPCC 2001). However Ruosteenoja et al. (2005) have studied wind and did not found statistically significant changes in wind velocities in Finland.

The changes in wind variability may affect both the production and loads (life-time) of the turbines. The impact of rain may be important for wind power production, as wind turbine efficiency will be reduced, perhaps by as much as 20%, with only light rainfall (Lundahl 1995). The impact of icing is even more crucial, as the production losses may easily be 50% or more if no anti- or deicing technology is used (Laakso et al. 2005). Small amounts of ice on the blades cause imbalances in the rotor and increase the loads on wind turbine (Makkonen et al. 2001).

From the climate model runs in Rossby Centre made for Nordic Climate and Energy project in 2005, a small increase in annual wind energy resource between the control run (1961 –

1990) and climate change projection period (2071 –2100) has been found on the 10 m wind speeds. There is also increase in energy density during the winter season (December – February), but the uncertainty of these prognoses remains high (Pryor and Barthelmie, 2004). For northern sites the wind speed increase is more, so for Finland there is more probably an increase in the wind resource in the future. From the same data, an increase of in the 50-year extreme wind speed in the Baltic sea of up to 15% has been found. This is likely to affect the design criteria of some turbine parts. The impact of climate change on icing is to reduce the icing time at least on lower levels (up to 60 m.a.g.l) (Clausen et al. 2005).

Climate change has been estimated to reduce wind power potential in the United States. Two different models of Hadley Center's HADCM II and the Canadian Climate Center's CGCM I were used to present possible scenarios of the atmospheric response to global warming induced by increased CO_2 concentrations. The results from the Canadian model gave stronger reductions in wind resource than the Hadley Centre's model. The estimations are very uncertain, but give some kind of base estimate how climate change may affect the wind resource in the United States (Breslow & Sailor 2001).

Climate change will probably increase wind resources in Finland. There is a need for more information on the change in distribution of wind speeds, variability in annual, seasonal and hourly basis and extreme events, like storms and gusts. Adapting to climate change in wind power sector means minimising production losses from storms, variable winds and icing. This may require stronger design for power plants.

3.1.3. Bio energy

Impacts of climate change on bio energy have been studied relatively little in the world. However, the impacts on agricultural and forestry productivity have been studied widely (IPCC 2001). At a general level, it can be assumed that if the agricultural and forestry productivity increases locally or regionally, also the conditions to produce bioenergy improve, and same proportional relationship holds for the decreasing productivity.

The growth of forest biomass in Finland is likely to be faster in the future due to increased temperature and precipitation under a changing climate. Climate change will increase forest growth especially in the northern part of the country (Marttila et al. 2005). The rise of the CO_2 concentration and the anthropogenic nitrogen deposition due to NO_x emissions from combustion and transportation as well as ammonia deposition from animal husbandry emissions contribute to the forest growth. The main user of the forest biomass is the mechanical and chemical wood processing industry. The wood wastes from the industries (e.g. sawmill residues, bark and black liquor) are used as fuels to generate electricity and heat. Also residues from cuttings are used as fuel. To a large extent the wood based waste fuels are used as fuel in cogeneration of heat and power (CHP). Climate change will probably also improve the conditions of agricultural production in Finland, thus the potential to produce biomass based fuel in agriculture increases also.

Tammelin et al. (2002) suggest that the annual growth of forests would increase by 20% and the amount of logging would increase approximately 15%. These studies are based on a climate scenario from SILMU study (Kanninen 1992, Kuusisto et al. 1996). The anticipated increase of biomass caused by climate change is considered to add the potential of bioenergy in the same relation with increase of logging potential, approximately 15% (Tammelin et al. 2002). n Sweden, the estimated annual increase of forests is about 50% in Northern and 25% in Southern Sweden (Lundahl 1995). In the Arctic, climate change impacts are becoming apparent in the boreal forests. In some species and some sites, reduced rates of tree growth due to pest outbreaks (especially in Russia) have been noticed when some other species and sites show growth (ACIA 2004).

The collection of biomass from forests and fields can become more difficult because of impaired road conditions (Marttila et al. 2005). ACIA has investigated the situation of the Arctic. Higher temperatures mean a longer time when the ground is thawed. This leads to a situation where the period during which timber can be moved from forests to mills becomes shorter (ACIA 2004). One aspect is that increasing frequency of extreme events may damage biomass crops (Parry 2000). A warmer and more humid climate will probably favor pathogens and pest insects. One reason is that the frost free time shortens, when forests are more vulnerable to damages. Ecosystems weakened by climate stress could also suffer more from windthrow. The frequency and intensity of forest fires may increase as a result of drought, wind and accumulation of fire fuel in connection with forest dieback. This could cut down on the stock of timber in boreal regions, available to forest industry (Kuusisto et al. 1996, Lundahl 1995).

Rising temperature and increase in CO_2-concentration will both increase the growth of biomass and the potential of biomass production in Finland. However, mild winters will be beneficial for insects and fungi. Harmful development could be avoided with right wood species and with the timing of harvesting (Kuusisto et al. 1996). Adaptation of bioenergy production to climate change will need surveys on how to maintain the conditions of roads. That is the requirement for increasing the use of bioenergy. Also a need to improve the production and harvesting technology emerges (Marttila et al. 2005).

3.1.4. Peat

Peat is used as fuel only in some countries, namely in Finland, Sweden, Estonia, Russia and Ireland. Very few studies on the impacts of climate change on the peat fuel production exist. Climate change has impacts on the harvesting of peat, especially on milled peat production where the peat is collected from the surface of a peat field. After milling a layer of peat, peat is left to dry on the peat production field. In good climate conditions the drying of milled peat takes 2–3 days. The production of peat is very climate-sensitive. Climate change affects peat production by the change of temperature and precipitation in climate. Increasing precipitation decreases the amount of annual harvesting cycles and decreases the peat production. Dependence between temperature and harvesting cycles is opposite: when temperature rises, drying of milled peat is faster and the amount of harvesting cycles increases. If the precipitation in important peat production areas increased by 11–20 mm and simultaneously the temperature rose by 1.6–1.7 °C, it would mean a 17–24% increase in the potential of peat production (Tammelin et al. 2002).

ILMAVA project concentrated on examining the impacts of climate change to peat harvesting. The formation of new peat or decay of existing peat land and impact of climate change on production sites (size and volume) were not studied.

Although peat production may increase, the problem may lie in the conditions of roads used when peat is transported from production areas to power plants. If the conditions of roads weaken, it may affect peat collection from field negatively and decrease the amount of peat available (Marttila et al. 2005).

For the adaptation of the peat production to climate change, there is potential for increasing production, but the variability of peat production may be greater in the future. Preparedness for the variability of peat production is crucial. The conditions of roads and how well the peat can be collected and transported from fields to power plants may be questions of peat production in the future (Marttila et al. 2005). One potential adaptation method could be new peat production method called biomass dryer. In this new method, the emissions from production phase reduce greatly and also production time shortens. In new production method only small area of peat production field is under harvesting, so this new technique is less weather-sensitive than old harvesting methods, which enables production even if precipitation or cloudiness increase due to climate change.

3.1.5. Solar energy

Very few studies consider the impacts of climate change on solar energy. Ruosteenoja et al. (2005) have studied solar radiation in Finland. In southern Finland during summer, solar radiation is projected to increase by 10%, whereas in Northern Finland solar radiation seems to remain almost unchanged around the year.

According to Lundahl (1995), current climate models provide little detail on future changes in solar insolation. The reason is the complexity of the atmosphere and the knowledge of the factors affecting the intensity and wavelength of solar radiation. These are e.g. cloudiness and atmospheric aerosol composition. Also the latitude and the time of the year and day affect solar insolation. Greenhouse-induced changes in cloud cover are uncertain. The picture is even more complicated because atmospheric aerosols affect cloud reflectivity and lifetimes. Aerosols also change the solar radiation balance through their direct backscattering effects. The change in cloudiness is the most important factor when changes in solar energy are concerned. Under cloud cover, solar-thermal and photovoltaic systems deliver only a fraction of their energy compared to that under clear sky conditions (Lundahl 1995). Diffuse versus direct radiation and the amount of reflection might increase and this would require changes in the tilting angle of the solar panels. The temperature of the cell will affect the efficiency (higher temperature gives less production). Increase in wind speeds would therefore influence beneficially the solar energy production.

According to Finland's national strategy for adaptation to climate change, the climate change would not have remarkable influences on solar energy (Marttila et al. 2005). Solar power will be reduced, if there are changes in annual solar radiation to the surface (Carter & Kankaanpää 2004, Kanninen 1992, IPCC 2001).

3.1.6. Fossil fuels and nuclear energy

Changing climate will probably have only minor direct impacts on the use of fossil and nuclear energy. Very few studies consider these impacts. In nuclear power plants and condensing power plants, climate change affects the temperature of cooling water, which may decrease the efficiency (Tammelin et al. 2002). Climate change may affect transportation of coal in central Europe, where transportation is made often along rivers. If climate change affects rivers by increasing extreme weather events, such as floods and droughts, it can make the transportation of coal to power plants more difficult. There are no studies made about this subject yet.

One problem related to nuclear power plants is that the storm events may raise the sea level remarkably. In Finland, nuclear power plants are situated at coastal sites. The storm in January 2005 raised the sea level of the Gulf of Finland approximately 2 m. Also flute heights were 7.2 m at their highest. The closure of Loviisa nuclear power plant was near during the storm in January 2005 due to the exceptionally high sea level (FIMR 2005).

In ACIA's report, it is studied how climate change affects Arctic areas, and how the changes may affect the use of oil and gas. The access to Arctic resources is estimated to change. The Arctic has significant oil and gas resources, most of them are located in Russia, some in Canada, Alaska, Greenland and Norway.

Marine access to oil and gas are likely to be enhanced in many places in a warmer Arctic, although the increased wave forces and ice movements may give rise to need of more stronger and adequate equipment. Also sea-level rise can affect off-shore gas and oil exploitation as well as oil imports and pipelines by destroying refineries and jeopardising safety and reliability of operations (Obasi 2000). Presumably this would only happen during extreme events such as storm surges, hurricanes or tsunamis.

In the Arctic, the access to resources by land is likely to be more difficult due to a shortened season, during which the ground is sufficiently frozen to travel. Climate change can damage infrastructure, too. The rising ground temperatures, inadequate design and construction practices for building on permafrost have resulted in major damages in infrastructure especially in Siberia. Damage to oil and gas transmission lines in permafrost zone presents serious situations (threats) caused by climate change (ACIA 2004).

Warming of the winter climate will decrease the sea ice extent and the duration of the ice covered period. This will be particularly significant in the Baltic Sea, as already predicted by Makkonen et al. (1984). The related easier winter navigation will reduce the transportation costs of fossil fuel to Finland. Also Jylhä et al. (2005) have investigated Baltic sea ice changes, where a drastic changes in annual maximum ice extent can be expected in the future. A large portion of years during 2071–2100 was estimated to have sea ice extents smaller than ever observed during three centuries of available observations.

3.2. Energy conversion in thermal power plants

3.2.1. Condensing power

The main impact on condensing power is due to the increase of cooling water temperature. Efficiency of a condensing power plant depends on the temperature of cooling water. According to Tammelin et al. (2002), the information from two scenarios in ILMAVA estimates that the temperature of sea water during ice coating during the years 2021–2050 would be approximately the same as has been during the years 1961–1990. The mean temperature of air between November and March would rise 2.6 °C in the coasts of the Gulf of Bothnia and the Gulf of Finland. These results suggest that the temperature of sea water would be one degree higher in spring and in the late autumn and two degree higher during summer and in the beginning of autumn. The impacts of warming climate to condensing power were simulated by modular calculation model, which noticed all part of power plant. The change of seawater temperature of surface layer is estimated to follow the change of air temperature. Thus the production of nuclear power lowers by 1%. In coal condensing power plants, the production decreases approximately by 0.2–0.3%. An increase of 1ºC in cold sea water (during winter) affects the efficiency by only about half of a similar rise in temperature in warm sea water (during summer) (Tammelin et al. 2002).

The factors affecting the temperature of sea water are many, such as air temperature, ice cover, currents, windiness etc. Ice cover decreases heat exchange between sea and air and also mixing of the water. Some of the factors affecting the temperature of water depend on local circumstances. Also some climate change effects may vary between sea gulfs and lakes.

3.2.2. Combined heat and power

Combined heat and power (CHP) has been studied in the ILMAVA study. In Finland, three quarters of the production of district heat is produced in combined heat and power plants. District heat produced electricity has a share of nearly 20% of the total electricity produced in

Finland. The amount of electricity is dependent on the amount of produced district heat, which depends on demand for heating.

Climate change increases temperature and reduces the need for district heating. Thus less electricity would need to be produced in combined heat and power plants. The electricity produced by CHP plants in Finland is estimated to decrease by 2.5 % by 2030 due to decreased amount of district heating. This estimation has been made assuming the share of district heating to remain the same. The gained saving in the need for electric heating would be one third of the decrease of combined heat and power electricity. Demographic changes were taken into account (Tammelin et al. 2002).

One way to adaptation to climate change could be district cooling systems, which may be reasonable at least in cities. One important adaptation measure for district electricity and heating companies would be the development of district cooling. District cooling is used for cooling the indoor air of office, industrial and residential buildings. District cooling means centralised production and distribution of cooling energy. Helsingin Energia Ltd. is already building a district cooling in the Helsinki inner city area. In the end of year 2005, the connection capacity of new customers will be 31 MW (Helsingin Energia 2005).

3.3. The demand for electricity and heat

As temperatures rise heating demand would be expected to decrease and cooling demand to increase (Fronzek and Carter 2005, IPCC 2001). Electricity demand is influenced not only by temperature but also by wind speed, humidity, precipitation, evaporation, evapo-transpiration and cloud cover. These influence air-conditioning, space heating, refrigeration and water pumping loads, which add electricity demand (Parkboom et al. 2004). There are many other things, which affect the need for heating, and which are not dependent on the predicted climate change. According to a population forecast, migration is directed to South Finland area, which is warmer and the need for heating is smaller. On the other hand, the growth of population, decreasing trend of household size and aging of population increase the need for heating (Carter et al. 2005). Also renewal of the building stock improves the energy economy of the buildings. This causes a decrease in the need for heating. The all-year use of summer cottages and the increased need for cooling of offices and service buildings can raise the consumption of energy.

In Finland, about 20% of all energy consumed goes to heating. As a consequence of climate change, the need for heating is estimated to decrease more than 10% by year 2030. The need for heating will decrease approximately 13% by the time period 2021–2050 when the effect of the migration is taken into account with the effects of climate change (Tammelin et al. 2002). According to Venäläinen et al. (2004) the demand for heating for the period 2021–2050 will decrease on average by some 10% from the period 1961–1990. The need of air conditioning would increase over 100% and the demand for heating energy would decrease 20–30% by the year 2080 (Carter & Kankaanpää 2003). Total energy consumption would decrease about 2% due to decreasing heating demand by 2030 (Tammelin et al. 2002). According to an earlier SILMU project, the decrease of total energy consumption would be 3 %. This is a result of an increase of temperature of 2–2.5 degrees, when the demand for heat decreases approximately by 10% and the demand for electricity approximately by 3% (Kuusisto et al. 1996).

According to Smith & Hitz (2003), the global energy use will eventually rise as global temperature rises. Demand for heating decreases and demand for cooling increases. The impacts of climate change on energy demand vary greatly by region. For example, in the United Kingdom and Russia a 2.0–2.2°C warming by 2050 will decrease space heating needs in the winter, thus decreasing fossil fuel demand by 5–10% and electricity demand by 1–3%.

Vadja et al. (2004) found that wintertime heating demand in Hungary and Romania will decrease by 6-8% by the period 2021-2050.

An important question is also how electricity production can meet peak demands in addition to average demands (Hardy 2003). On occasions of extreme temperatures this can stress electricity systems in meeting demand (Parkboom et al. 2004). When mean temperature rises, it means there will probably be less heating demand peaks. However, in areas with district CHP (combined heat and power) heating systems, the highest electricity demands may be encountered in summer time due to cooling needs. In Finland, the peak demands are caused by extreme cold periods so that climate change will in general not make this a serious concern.

3.4. The reliability of energy supply

Failure to keep the electricity distribution system running has serious and costly consequences. Thus, the reliability of the electricity system has to be kept at a very high level. Finnish society is very dependent on the functioning of transmission and distribution of electricity. This is something that will not change in the future. If there are problems in the distribution of electricity, it affects all technical systems, such as industrial processes, heat and water distribution, telecommunications and even sewage disposal. Availability of reliable supply of energy at moderate price is crucial for the whole economy.

The reliability of energy supply can be divided into two different parts: reliability of power plants and reliability of transmission and distribution.

The whole energy infrastructure may be threatened by quicker erosion or weakening because of variable temperature, wind and precipitation. Stronger winds result in larger wind loads and there is a need to pay more attention on design of structures, like power lines, and their construction (Ala-Outinen 2004). Climate change may increase combined ice and wind loads that power lines face at certain areas in Scandinavia. Increased precipitation is likely to have some effect on power lines as well. Climate change is estimated to increase a so called “wet time”, when relative humidity is over 80% and temperature is over 0°C. This makes all steel constructions, such as components of the electricity distribution network, more vulnerable to corrosion.

The rise of sea level or high water level in rivers may affect the power plants in coastal locations negatively e.g. by erosion (Kanninen 1992, ACIA 2004). However, this not the case in Finland. This subject has been studied in Finland by Johansson et al. (2004), and in most cases the rise in water level is expected to balance the land uplift in the Gulf of Finland, and the past declining trend of the relative sea level is not expected to continue. In the Gulf of Bothnia, the stronger uplift rate still results in a fall of a relative mean sea level in the future. However, reduction in the sea ice can allow higher waves and storm surges to reach the shore. This causes coastal erosion. Many power plants or storage areas of energy resources, like oil and coal, are often located close to the sea. These facilities are in danger when it comes to storms and erosion (ACIA 2004).

Thawing permafrost in the arctic causes destabilisation to facilities and reduced sea ice may also cause problems affecting the use of Arctic oil and gas resources (ACIA 2004).

Climate change and the increased extreme phenomena caused by climate change threaten the transmission and distribution of electricity. For example storms and heavy snow could uproot trees onto electricity distribution lines. In Norway, electricity distribution is highly prone to climate-related risks, such as snow avalanches, storms and heavy snowfall (Sygna et al. 2004). In the most recent study, Martikainen (2005) presents the effects of climate change on electricity network business in Finland. The increase of the number of network faults will be the most important and demanding disadvantage caused by climate change. Especially thunder, heavy snow and wind will cause more damages to overhead distribution lines in medium voltage network, unless the networks are developed more resistant for faults. Nowadays, the trend is to change especially overhead distribution lines to underground cables at least in suburbs (Marttila et al. 2005). Energy transmission is also affected by temperature increase, which means, e.g., lower capacity in power lines (Parry 2000). In Finland, this will not have a significant impact, but in Southern Europe the temperature rise due the climate change may affect the sag of wire and wires need to be re-designed.

From the adaptation point of view, ensuring the energy conversion and transmission in extreme conditions is very important. A more erratic climate will be a greater problem for energy systems than changes in the mean values (Lundahl 1995). Storms and floods may interrupt distribution, transmission and production of energy. It is important to keep the reliability of energy supply as a main requirement especially when the consumption of energy is increasing. The functionality of the remaining overhead distribution network and preparedness of the maintenance in the energy infrastructure are subjects for attention (Marttila et al. 2005). There have to be enough production capacity and the capacity needs to be available during demand peaks. The demand of heating decreases and the demand of cooling energy increases due increasing temperature, which is significant for the electricity consumption and the peak load of temperature-dependent electricity users (Martikainen 2005). In Finland, the energy supply is based on many different energy resources, which gives a good basis to face the challenges of adaptation. Nordic electricity markets give certain flexibility as well.

Box 1. Effects of climate change on the electricity network business

Extended summary of Martikainen (2005)

The results presented here are based on scenarios of changes in certain climate variables. The regional climate model, RCAO, and two global climate models ECHAM4-OPYC3 and HadAM3-H were used to calculate the scenarios (Räisänen *et al*., 2004). RCAO was the main component and the global climate models were used to deliver boundary conditions for the RCAO model. A2 and B2 emissions scenarios were used in the calculations.

Results from six 30-year regional climate model (RCM) runs have been adopted in the study. Two of these were control runs for the period 1961-1990 and four were scenario runs for the period 2071-2100. In this research the target period is 2016-2045, so for the purposes of the study, changes in climate between the control period 1961-1990 and 2016-2045 are assumed to be half of changes in climate between the control period and 2071-2100.

The aim was to focus on those climate variables that affect the electricity network business. Scenarios were constructed for temperature, precipitation, hoarfrost, thunder, ground frost and wind. Estimated are also made of how floods, ground moisture and sea level could affect the electricity network business in the future.

Four climate change scenarios were calculated for each climate variable. An example is given in Figure B1, which depicts low and high estimates of changes by 2016-2045 relative to the control period for ground frost. Labels above the figures describe the driving global climate model and emissions scenario used in the RCM-based scenarios. The determination of ground frost is based on frost sum, which is the accumulation of daily mean temperatures below -0°C calculated from the beginning of the frost period. Ground frost begins to form when the frost sum exceeds 25 °Ch.

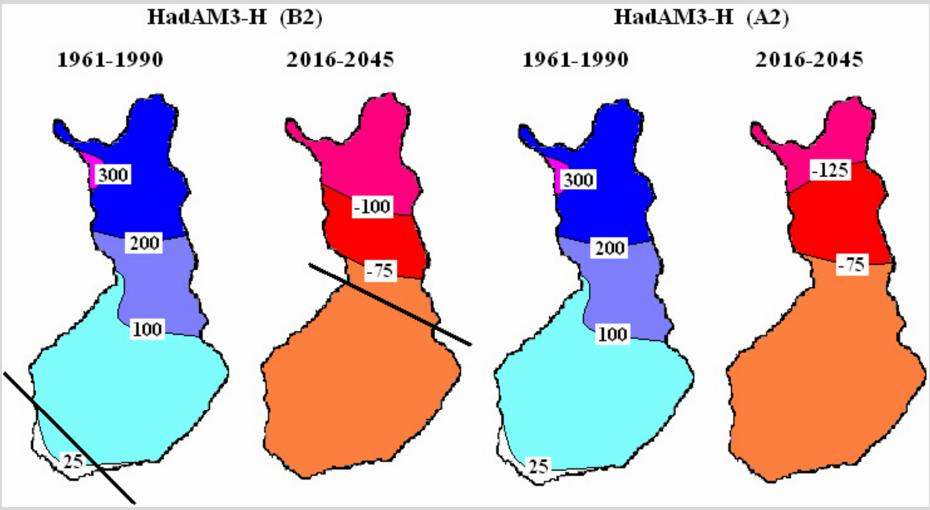

Figure B1 Changes in frost sum (°Ch) in November between the control period and 2016-2045. Two scenarios are presented: low change (B2 –two left hand maps) and high change (A2 – two right hand maps). The black line shows the ground frost limit at the end of November. To the south of this line the ground is unfrozen.

According to the climate model results, frost sum will decrease in autumn and spring, meaning that the ground frost period shortens. In the central and southern Finland the ground is unfrozen in November and often also in December. In northern Finland the ground is normally already frozen in December.

The effects of these projected changes in temperature, precipitation, hoarfrost, thunder, ground frost and wind on the electricity network business are considered in the following sections.

Effects of changing temperature

Both mean and extreme temperatures are projected to increase, with increases in winter greater than in summer. Higher temperatures have significant indirect effects on other variables, for example, days of thunder, ground frost and floods. The direct effects of changing temperature are presented below.

Higher temperatures increase electrical resistance, leading to greater losses in conductors and transformers (steel 0,16 %, aluminum 0,86 % and copper 1,36 %). The demand of heating energy decreases and the demand of cooling energy increases. This is significant for electricity consumption and peak load of temperature-dependent electricity users. The decreasing need for heating energy means that the incomes of electricity network companies can be expected to decrease. It has been estimated that a 2ºC increase in temperature could reduce total consumption in Finland by about 1 %. On the other hand, it is predicted that electricity consumption will increases by about 1,7 % per annum until 2015 and 1 % thereafter, hence negating the effect of warming.

An increasing need for cooling energy means that the peak loads are likely to increase in the summer. A high peak load in hot weather decreases the lifetime of transformers.

Increasing temperatures will also increase the growing season for plants. The growing season starts when the daily air temperature exceeds 5 ºC and ends when the temperatures remain below 5 ºC for 5-10 days. The longer growing season is estimated to increase the year growth of trees (Kellomäki 2005), which will raise the demand for right of way clearing and increase costs by approximately 10 %.

There are also benefits to be gained from increasing temperature. The RCM projections indicate that minimum temperature will increase in concert with mean temperature, so that problems of heavy frost will decline. These include problems in switchgears, conductors and vehicles.

Effects of changing precipitation

Under these scenarios, precipitation is projected to increase both in winter and in summer. This is likely to weaken the strength of soil, thus posing difficulties for the maintenance of the electrical network because wet ground can not carry heavy vehicles. Wet soils also provide weakened support for trees, which may fall more readily on overhead lines during strong winds, especially on slopes. The foundations of electricity poles may also be weakened by wetter soils, and when trees fall over a conductor this can result in damage occuring over a greater distance of the line that at present.

Precipitation can also change the consistency of soil such that mud avalanches occur. These can damage underground cables, especially in low and medium voltage networks (Heiskanen 2005, Metla 2004, VTT 2005).

Rising ground water should also be monitored as part of network maintenance. This threatens underground cables because they cannot withstand water on a continuous basis. Rising ground water and increasing precipitation also accelerate corrosion and decay. Corrosion weakens metal structures like stay wire and decay damages wood poles (VTT 2005).

Increasing precipitation increases corona losses in new transmission lines. Corona is a partial discharge that takes energy from an electrode and can cause significant losses in transmission lines (Fingrid 2005).

The increasing temperature and increasing mean and maximum precipitation in winter are favorable for heavy snow and freezing rain. The weight of snow accumulating on trees can cause them to fall on power lines, and freezing rain and sleet threaten switchgears. Deciduous trees are especially sensitive to heavy snow. If water and sleet freeze and cover switchgears, the operations of those devices are not reliable (VTT 2005, Fortum 2005).

Effects of changes in hoarfrost

The scenarios indicate that hoarfrost will decrease in all regions except the hills of Vaara-Suomi (Kainuu, North Karelia and northeast Finland). There, the amount of hoarfrost is projected to increase. Hoarfrost causes corona discharges and losses in energy, the magnitude of which are very sensitive to the thickness of the hoar frost. Even the thinnest hoar frost layer causes losses, which increase with thickness. Hoarfrost is a particular problem for transmission lines (Lahti 1996), where it can accumulate and, in the worst cases, break the lines through excessive loading. A more common effect of hoarfrost is where it accumulates on trees that bend onto the lines. This is a problem in distribution lines. Transmission lines have been constructed tree safe.

Accumulating hoarfrost and snow can also cause problems for transmission lines. At worst, over 10 centimeters of hoarfrost and snow cover have been observed accumulated around a conductor. This has to be removed because it can damage lines. More common is for hoarfrost and snow to accumulate around the shielding wire.

This can sag down to the same level as the conductors. Wind action can cause the shielding wire to sway into the conductor, causing an earth fault. In the worst case, the shielding wire can get broken because of heavy loading. Again, a broken shielding wire can drop over the conductor and cause a permanent earth fault.

Effects of changing thunder occurrence

It is not possible to predict the occurrence of thunder using climate models because their resolution is too coarse. However, it is expected that suitable conditions for thunder will increase as a result of climate change.

Thunder causes interruptions to electricity transmission through the effects of lightning and heavy squalls. We deal with the former here. The latter are introduced, with the effects of wind, in the following section.

Lightning strikes cause transient overvoltages on the conductors. These can cause earth faults and short circuits, resulting in voltage sags which cause problems especially for the process industries. Overvoltages can damage devices like transformers and are the most common reason for transformer damage, which is the source of long interruptions. Lightning can also damage underground cable networks. Then the interruptions are longer than in transformer damages.

Direct strikes can cause serious damage to transmission lines (the magnitude of the overvoltage can be several millions of volts). Lightning can cause severe interruptions if overvoltages damage devices of substations or transmission lines.

Effects of changes in ground frost

For the Fingrid Oyj, changes in ground frost are potentially one of the most damaging effects changes in climate. Maintenance work is usualy carried out when the ground is frozen. A shorter ground frost period or, in the worst case, a lack of ground frost, means considerable extra costs. There will be extra costs because vehicles or new maintenance technology must be developed (Fingrid 2005).

For distribution lines, changes in ground frost have both benefits and disadvantages. A decreasing amount of ground frost would make it possible to plough cable trenches in the winter time if the thickness of the ground frost is less than 20 cm and the depth of the cables can be lower (Fortum 2005).

Ground frost also provides better support for trees compared to unfrozen soil.

Effects of the change of occurrence of high wind speed

Winds are the most severe climatic threat for distribution lines. For example, the so-called "Rafael-storm", on 22-23 December 2004, caused damages that cost about 5 M€ for Fortum Distribution. The amount of standard compensation was about 1,5 M€.

Strong winds usually occur in autumn and winter in Finland. These include powerful squalls which can fell trees and throw boughs onto overhead lines causing outages. Heavy squalls can also appear in thunderstorms. Weak trees are subject to windthrow when wind speed is about 17 m/s, and major damage occurs above speeds of about 20-23 m/s (Metla 2004). Disruptions to ditribution lines are usually caused by single trees. When many trees fall onto lines, damage can be so severe that the lines have to be rebuilt. Since about half of the distribution lines are in forests, windthrow is a serious problem. However, while the transmission line network is built "tree safe", this option is too costly in the case of the overhead line distribution network.

Forestry has a significant effect on damages to distribution lines. Storms usually fell trees at the boundaries of harvesting areas. Therefore, the location of forest lanes or tree nurseries in the vicinity of distribution lines can pose a clear risk to the distribution networks (Metla 2004).

Conifers are more susceptible to windthrow than deciduous trees, with the latter more susceptible in summer (in full leaf) than in winter. Spruce is the most sensitive conifer species to windthrow (Metsätuhotyöryhmä 2003).
Heavy squalls also pose a risk to transmission networks. Squalls would not normally topple transmission towers, but heavy squalls can swing the phase conductors together, causing short circuiting (Fingrid 2005).

Winds also move ice floes, and may create pack ice that can cause damage to submarine cables. By advecting heat, winds can have a great cooling effect. This results in higher demand for heating energy. A change to windier conditions in the future would therefore imply higher income from heating energy.

Effects of changes in flooding and sea level

Sea level is projected to rise in the Baltic Sea in common with worldwide sea-level rise, but is not expected to cause problems along much of the Finnish coastline because post-glacial rebound is still operating to raise land surfaces. However, the trend in relative sea level fall seems likely to reverse during this century along coasts of the Gulf of Finland, where the rate of land uplift is already slowing.

According to climate model projections, more frequent heavy rains are expected to cause urban flooding. This could be hazardous for underground cables, link boxes and basement transformers.

The risk of large-scale flooding is real in Lapland, because the amount of precipitation is expected to increase. When rivers are in flood, water and ice floes can damage electricity poles and transformers.

Implications of climate change for the electricity network business

As a consequence of climate change, the activities of network planning, construction and maintenance in particular will need to be developed, so that the network system is as reliable in the future as nowadays.

A likely increase in the number of network faults is the most significant disadvantage for electricity network planning. It is possible to decrease the number of faults by developing the network. Underground cables offer the best reliability for electricity distribution, but it is not cost efficient to cable all medium voltage networks. The cost of underground cables is about twice that of overhead lines. It is also very difficult to construct underground cable networks into bedrock. Thus, it does not seem feasible to design an electricity network system that can gaurantee uninterrupted distribution.

A decreased lifetime of network components under changing climate is also of significance. For example, damage can be increased by decay due to higher precipitation or by hot weather stress on transformers due to increasing temperature. The decreasing lifetime increases costs in the long run.

As a consequence of increasing temperature, electricity consumption and peak loads are changing. Changes in peak loads affect the design of electricity networks.

The climate in southern Finland is projected to approach the present climate of southern Sweden and northern Germany during the second half of this century. However, it is not possible to incorporate experience from other countries directly into Finnish network design because our network differs in many respects (e.g. in its structure, age and dimensions).

The prospective need for increased maintenance of the electricity networks is a clear result of this study. The frequency of faults, the need for right of way clearance of trees, and stress on devices will all increase. Climate change would have much less impact on underground cable networks.

Construction work is expected to be more difficult with the present vehicles because of weakened soil strength due to increasing precipitation and decreasing ground frost. Investments in new vehicles or development of the present vehicles will be required, hence increasing utility costs.

It is expected that climate change will cause more damages than benefits to the electricity network business. Changes in climate variables will have a negative effect on the costs of operation, interruption and maintenance and incomes of network activity. The increasing costs and the decreasing incomes mean that the profitability of the electricity network business will decrease.

Martikainen, A. 2005. Ilmastonmuutoksen vaikutus sähköverkkoliiketoimintaan (Effect of climate change on the electricity network business). Master's thesis. Energy and Environmental Technology, Lappeenranta University of Technology (in Finnish). 100 pp. + app. 2 pp.

4. Discussion

There are many studies made about the impacts of climate change. However, most of these concern e.g. agriculture, human health, forestry, hydrology and tourism. There have been only a few studies concerning the impacts of climate change on energy. The studies approached in this study usually considered only narrow areas and were on a general level without details. Most of the studies concerned the impacts of climate change to hydropower, bio energy and peat. Bio energy studies were mostly on forests.

In the near future, there will be more completed studies concerning climate change and its impacts. On-going studies are, e.g., a study called Natural hazards to infrastructure in a changing climate project by the Technical Research Centre of Finland (Makkonen 2004). This study will be completed in the beginning of 2006. Nordic Council has a Nordic project on climate and energy. This study focuses on the impacts of climate change on renewable energy sources and their role in the Nordic energy system (CE 2005). The project will be completed during 2006. European Environment Agency is finishing their technical report about Vulnerability and Adaptation to Climate Change Impacts in Europe.

Adaptation was mentioned in only few studies reviewed in this work. When adaptation was mentioned, the consideration was usually very general and shallow. Although climate change is undoubtedly occurring, there is very little information about how the situation in the energy sector could be improved in the future. There are clear needs for additional studies. In the future, more work should be done on how climate change affects the energy sector, especially other parts than hydro power. More information is also needed regarding the impacts of extreme weather conditions on the energy sector.

The estimation of the future impacts of climate change on the energy sector is difficult. The climate models and scenarios vary a lot. Comparison of the results from different sources shows many discrepancies. However, the impacts of climate change are important because many functions of the society depend strongly on the availability of energy. In addition, the energy sector is very capital intensive and changes only slowly. The investments are significant and the repayment period of the investments is long. This is the reason why climate change impact on energy sector should be thoroughly examined, so that the right decisions and investments could be done.

Figure 2 summarises model projections of changes in precipitation and temperature in winter and summer in Finland by the 2080s. The wide distribution of results gives a picture on difficulties in prediction and on possible reliability of results.

Wave and tidal energy was investigated in few sources. Marine energy is so far utilised mainly in the United Kingdom. In Finland, tidal energy exploitation is not feasible due to the nonexistent tide. The wave power resources are also limited compared to the countries by the Atlantic Ocean. Climate change has impacts on the sea level rise, which may affect marine energy by changing the design of tidal control and wave energy systems. The assumed increased windiness increases wave potential, which increases the potential of marine energy (Parry 2000). Wave energy converters are designed to capture energy from specific wave height, period and direction ranges, just like with wind turbines. If these circumstances change, it will affect energy capture (Harrison & Wallace 2005).

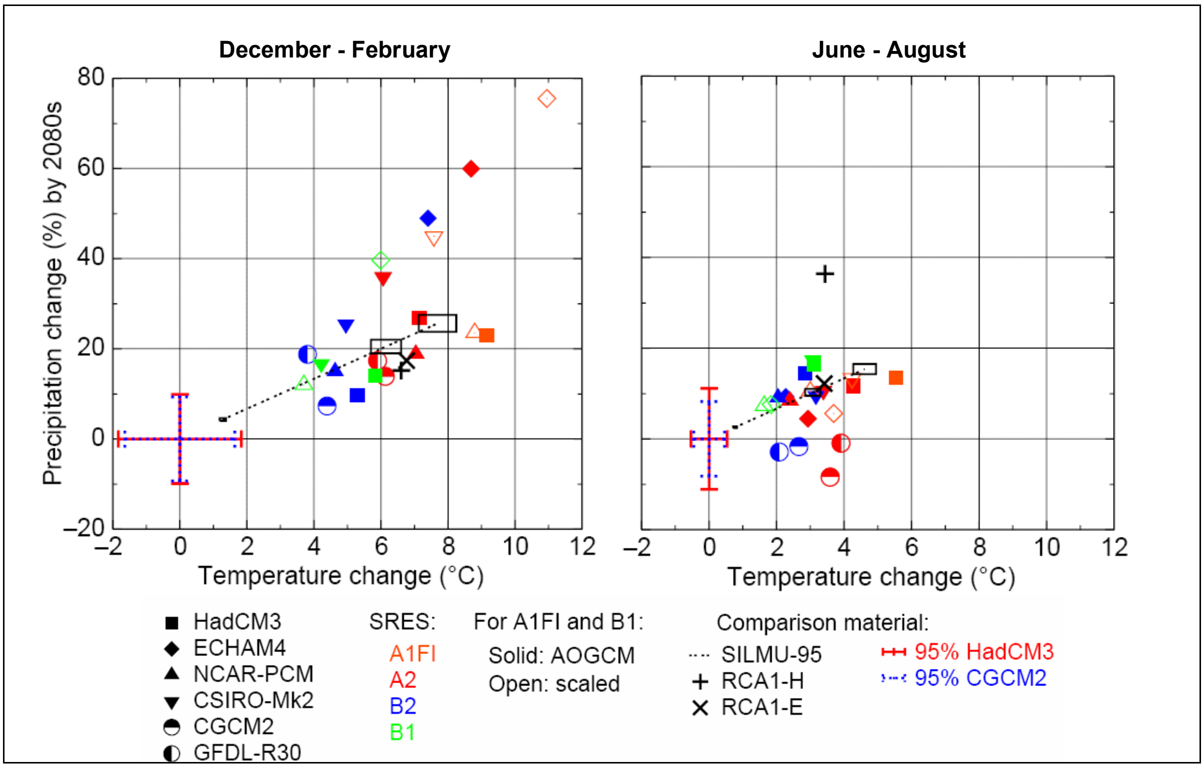

Figure 2 Average changes of precipitation and temperature by the 2080s in Finland relative to 1961-1990 in December–February and June–August according to different climate model runs (Jylhä et al. 2004).

Figure 3 and Figure 4 show the impacts of climate change on different parts of the energy sector according to the changes in temperature and precipitation. It can be seen that the direction and magnitude of different impacts vary. Also different scenarios and time period used in these assessments cause varying results (see e.g. hydropower). The results in figures concern mainly Finland. The impact of climate change on hydropower 3) concerns Nordic countries for a 30 years period. The impacts of hydropower 1), peat 5), fossil fuels 6), nuclear energy 7), the share of electricity in combined heat and power 8) and the demand for heating 9) were by period 2021–2050. Information about hydropower 2), bioenergy 4) and the demand for heating 10) were given by the year 2050. The demand for electricity 11) concerns situation in Finland.

Figure 3 and Figure 4 show only a small sample of impacts, but give some kind of direction how different they can be. However, it is important to remember, that temperature and precipitation are not the only parameters which determine the impacts on the energy sector. Also many other parameters are important, for example windiness affects wind power etc.

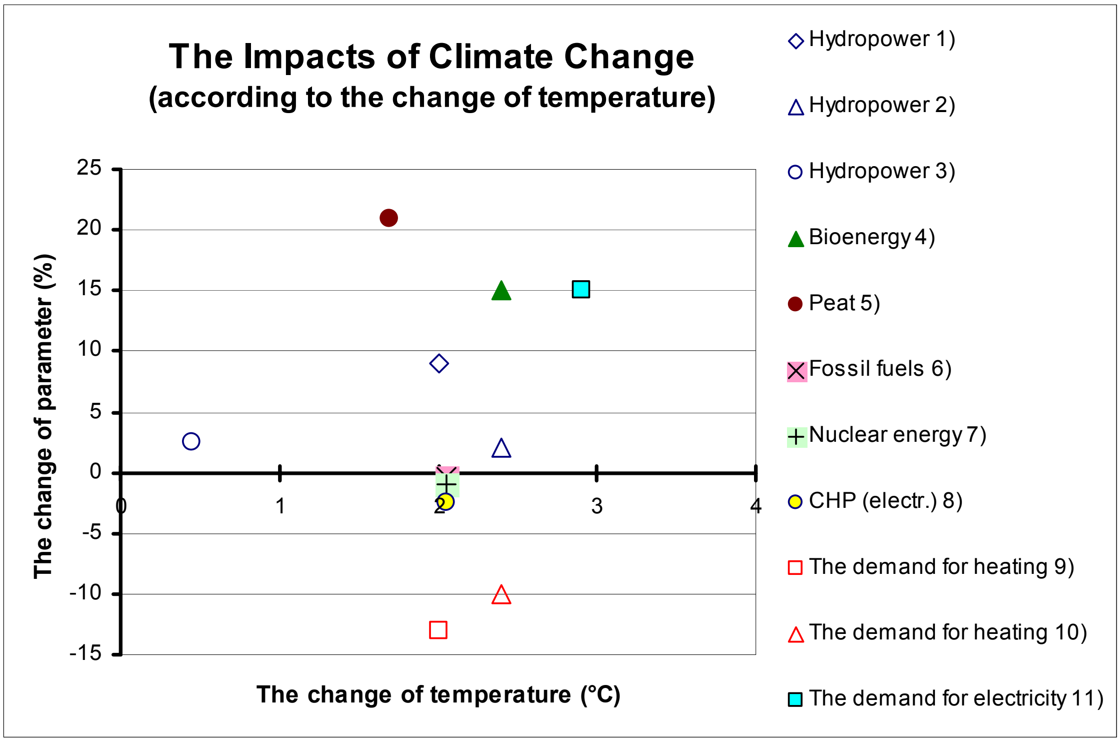

Figure 3 **Summary of the impacts of changes in mean annual temperature on different parts of the energy sector. Numbered sources: 1) Tammelin et al. 2002, 2) Kuusisto et al. 1996, 3) Saelthun et al. 1998, 4) Kuusisto et al. 1996, 5) Tammelin et al. 2002, 6) Tammelin et al. 2002, 7) Tammelin et al. 2002, 8) Tammelin et al. 2002, 9) Tammelin et al. 2002, 10) Kuusisto et al. 1996 and 11) IPCC 1998**

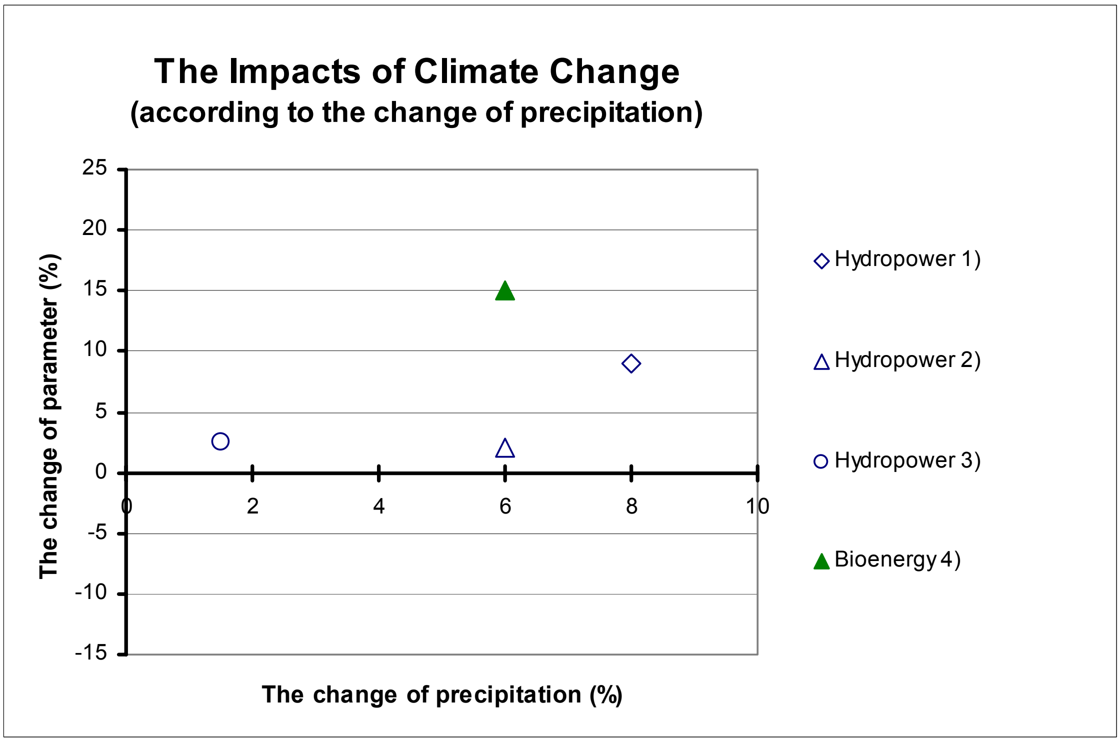

Figure 4 **Summary of the impacts of changes in mean annual precipitation on different parts of energy sector. Numbered sources as in Figure 4.**

5. Recommendations for future research

The adaptation of the energy sector to climate change needs additional investigations. Finland's national strategy for adaptation to climate change made by the Ministry of Agriculture and Forestry has been the main source of information about adaptation (Marttila et al. 2005). Nevertheless, the results presented are mainly quite general and are based on Tammelin et al. (2003) study. More detailed information concerning the energy sector is clearly needed.

This literature review has summarised the information available on adaptation in the energy sector. Based on this, the following gaps in knowledge or research needs can be identified:

- A comprehensive study is needed for the whole energy sector, where the impacts and adaptation are studied using the same meteorological models and emission scenarios, so that the results would be comparable. (This should also be reported in international scientific literature e.g. in the form of scientific articles.)
- Adaptation to extreme weather events: How energy infrastructure can adapt to climate change? Safety/robustness of structures, such as dam safety in increased hydro inflow, how wind turbines can handle the increased wind speed etc.
- As a consequence of climate change the number of network faults will increase. What are the technical solutions that give better reliability to the network system? For the improvement of the reliability of electricity distribution, could electricity transmission and distribution overhead lines be underground cabled at least close to the densely populated area? How to develop processes of planning and construction of electric networks, to meet challenges of climate change?
- Risk management of fossil fuel and nuclear power plants, including adaptation to storms. (e.g. during the storm of January 2005 the Loviisa nuclear power plant was almost closed in Finland due to rising water level)
- How electricity production could adapt to evening distribution of demand over the year - during hotter summer the need for cooling increases, during milder winter the need for heating decreases. Need for peak-load power plants might decrease or what is the consequence?
- Do new energy technologies (e.g. hydrogen, biofuels etc.) help to adapt to climate change?
- In Finland it should be studied how the increased hydropower potential can or can not be utilised. This subject is especially interesting, because this energy resource is CO_2-free and domestic energy resource.
- Also wind power potential should be investigated, because according to Ruosteenoja et al. (2005) there are no statistical changes in windiness while some other studies (e.g. Tammelin et al. 2001) suggest, that there are increase in windiness?
- How much of the increased potential of bioenergy and peat due climate change is possible to exploit? Bioenergy is especially interesting due being CO_2-free fuel, peat is interesting for Finland due being domestic fuel and creating employment to rural regions.
    - How new peat harvesting technology (biomass dryer, developed in Finland) helps to adapt to climate change? Does it bring opportunities to peat production by minimizing the greenhouse impact of peat utilisation?
- A study about impacts on solar power would be justified, especially for regions where there is considerable potential for additional solar energy exploitation, e.g. Southern Europe. (In Finland the potential of solar power exploitation is quite small, due to climate change smaller or bigger?)

- Some economical questions should be considered, e.g. How much the adaptation will cost and will the value of benefits be greater or not? (Cost-benefit analyses)

6. Summary

This work investigates the studies concerning the impacts of climate change on the energy sector. The main objective was to find studies concerning Finland, but because there were only few studies made, this review was extended to concern also other studies made internationally or nationally. The results concerning the impacts of climate change vary widely due to different climate change scenarios. The results should be used with caution, because the uncertainties of the scenarios are large. The main areas investigated were energy resources and exploitation of the resources, energy production, demand of energy and reliability of energy supply. Energy sources considered were hydropower, wind power, bioenergy, peat, solar power, fossil fuels and nuclear power. The most notable impacts of climate change are due to changes in precipitation, temperature, wind speed and unusual weather conditions, and rise of sea level. These were the factors affecting the energy sector most.

The most significant impacts of climate change are those on hydropower. The estimates about how much hydropower will change and where vary a lot. In Finland, the estimated increase in hydropower production from the period 1961–1990 to 2021–2050 is 7 or 11% depending on the scenarios assumed. According to some other studies, the estimates have been that the amount of produced energy by hydropower will increase by 2% in the year 2025 and 2100. According to some studies, the increase of hydropower production can be even 38%. Wind power potential in Finland has been estimated to increase by 7% in typical production areas on land and 10–15% off shore from the period 1961–1990 to 2021–2050. The potential of bioenergy has been estimated to increase due to an assumed increase in growth of forests, which increases logging potential. In Finland, the potential of biomass have been suggested to grow by 15%. The changed conditions of climate would cause a 17–24% increase in the potential of peat production.

There are only minor impacts on solar energy, fossil fuels and nuclear power. Solar energy will be affected, if there are changes in cloudiness. The efficiency of energy conversion in condensing power plants is likely to decrease due to higher temperature of the cooling waters in future. In Finland, a one-degree increase in temperature of sea water lowers the energy production potential of nuclear power by 1%. The production of combined heat and power will probably slightly decrease along the changing climate, as the increasing temperatures will decrease the need for district heating.

The demand of energy will probably decrease because of the increased temperature, which decreases the demand of heating. It has been estimated that the need for heating will decrease by 10% by the year 2030 and 20–30% by the year 2080 in Finland. On the other hand, the demand of energy can increase because of the increased need for cooling. There are other factors, which have strong impacts on energy demand in the long term, like changes in population structure, dwelling, consumption habits, technical energy efficiency etc.

For the reliability of energy supply, the increase in extreme weather conditions is the crucial issue. Storms or other extreme weather conditions cause damages to electricity distribution lines. A more erratic climate will cause more problems to energy systems than changes in the mean values.

It is expected that climate change will cause more damages than benefits on electricity network business. The increase of the number of network faults will be the most significant disadvantage caused by climate change. The most remarkable fault factors are thunder, heavy snow load and wind. The increasing number of faults and the need of maintenance will be great challenges to network business and, also need of invest to new vehicles or development of present vehicles increase costs. Decreasing need of heating energy will decrease incomes. As a result the profitability of network business will decrease if climate changes along the predictions.

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Documentation page

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Title of publication	Impacts on the energy sector and adaptation of the electricity network business under a changing climate in Finland	
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Abstract	Climate change is expected to have notable impacts on the energy sector. Several general-level studies exist on the plausible impacts on energy resources and exploitation of the resources, on energy production, on demand of energy and on the reliability of energy supply. This report presents a literature review on these impacts and discusses the possible adaptation measures. Energy sources considered were hydropower, wind power, bioenergy, peat, solar power, fossil fuels and nuclear power. The most notable impacts of climate change on energy sector are due to changes in precipitation, temperature, wind speed and unusual weather conditions. The main focus of the work was Finland, but due to the limited amount of available studies, the work was extended to cover also other world regions. The main impacts of climate change on energy sector in Finland are: - Moderate increase of renewable energy resources (hydro, wind, biomass). Changes in seasonal distribution of hydro inflow are likely to impact operational practice of hydropower production. The electricity system can be adapted by taking into account the changes in the availability of various resources and adding new capacity, if needed. - Possible increase in extreme weather conditions may increase faults in electricity distribution network. To minimize network faults, design requirements and management practices for electricity distribution networks should be adapted to the new conditions. - Temperature increase will lower the heating demand and increase the cooling demand. Seasonal differences in electricity demand will slightly decrease. The adaptation of the energy sector to climate change needs additional investigations. Especially renewable energy sources, the robustness of facilities, the demand of cooling energy and adaptation to extreme weather events are topics which need more studies.	
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Julkaisun nimi	Muuttuvan ilmaston vaikutukset energiasektoriin ja sähkön jakeluverkkoyritysten sopeutuminen Suomessa	
Julkaisun osat/ muut saman projektin tuottamat julkaisut		
Tiivistelmä	Ilmastonmuutoksen tiedetään vaikuttavan energiasektoriin. Tässä työssä tehtiin kirjallisuuskatsaus energiasektorille aiheutuvista muutoksista. Tutkitut aihealueet olivat energian lähteet ja niiden hyödyntäminen, energian tuotanto, energian tarve ja energian jakelun luotettavuus. Energianlähteistä käsiteltiin vesivoimaa, tuulivoimaa, bioenergiaa, turvetta, aurinkoenergiaa, fossiilisia polttoaineita ja ydinvoimaa. Merkittävimmät ilmastonmuutoksen aiheuttamat muutokset aiheutuvat muutoksista sadannassa, lämpötilassa, tuulen nopeudessa ja sään ääri-ilmiöissä. Työ kattoi sekä Suomea koskevat tutkimukset että ulkomaiset tutkimukset. Ilmastonmuutoksen aiheuttamat merkittävimmät vaikutukset energiasektoriin Suomessa ovat: - Uusiutuvien energian lähteiden lievä kasvu (vesi, tuuli, biomassa). Muutokset kausittaisissa veden virtaamissa vaikuttavat vesivoiman tuotannon ohjauskäytäntöihin. Energiajärjestelmä tulee sopeuttaa ilmastonmuutokseen huomioimalla muutokset energianlähteiden saatavuudessa ja mitoittamalla käytettävissä oleva kapasiteetti tämän mukaisesti. - Sään ääri-ilmiöiden mahdollinen lisääntyminen voi lisätä vikoja sähkön jakelujärjestelmään. Sähköverkkojen vikojen minimoinniksi tulisi sähkön jakeluverkon suunnitteluvaatimukset ja ohjauskäytännöt sopeuttaa muuttuneeseen tilanteeseen. - Lämpötilan nousu vähentää lämmityksen tarvetta ja lisää jäähdytyksen tarvetta. Kausittaiset muutokset sähkön tarpeessa vähentyvät hieman. Energiasektorin sopeutumisesta ilmastonmuutokseen tarvitaan lisätutkimuksia. Erityisesti uusiutuvat energianlähteet, laitoksien ja tuotantorakenteiden kestävyys, jäähdytysenergian tarve sekä säiden ääri-ilmiöt tarvitsevat lisäselvityksiä.	
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Climate change is expected to have notable impacts on the energy sector. This report presents a literature review on the plausible impacts on energy resources and exploitation of the resources, energy production, demand for energy and the reliability of energy supply, and discusses possible adaptation measures. The energy sources considered were hydropower, wind power, bioenergy, peat, solar power, fossil fuels and nuclear power. The most notable impacts of climate change on the energy sector are due to changes in precipitation, temperature, wind speed and anomalous weather conditions. The main focus of the work was Finland, but due to the limited amount of available studies, the work was extended to cover other world regions as well. It is concluded that the electricity system can be adapted to climate change by taking into account changes in the availability of various resources and adding new capacity, if needed. To minimize network faults, design requirements and management practices for electricity distribution networks should be adapted to the new conditions.

Tämä raportti esittelee kirjallisuuskatsauksen ilmastonmuutoksen energiasektorille aiheuttavista muutoksista ja käsittelee mahdollisia sopeutumistoimia. Tutkitut aihealueet olivat energian lähteet ja niiden hyödyntäminen, energian tuotanto, energian tarve ja energian jakelun luotettavuus. Energianlähteistä käsiteltiin vesivoimaa, tuulivoimaa, bioenergiaa, turvetta, aurinkoenergiaa, fossiilisia polttoaineita ja ydinvoimaa. Merkittävimmät ilmastonmuutoksen aiheuttamat muutokset aiheutuvat muutoksista sadannassa, lämpötilassa, tuulen nopeudessa ja sään ääri-ilmiöissä. Työ kattoi sekä Suomea koskevat tutkimukset että ulkomaiset tutkimukset. Energiajärjestelmä tulee sopeuttaa ilmastonmuutokseen huomioimalla muutokset energianlähteiden saatavuudessa ja mitoittamalla käytettävissä oleva kapasiteetti tämän mukaisesti. Sähköverkkojen vikojen minimoinniksi tulisi sähkön jakeluverkon suunnitteluvaatimukset ja ohjauskäytännöt sopeuttaa muuttuneeseen tilanteeseen.

This report is also available at the FINADAPT Web site:
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