Effect of climate change in electricity distribution systems in Nordic conditions

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Abstract

This study investigates the impact of climate change on electricity distribution systems in Nordic conditions, focusing on the effects of soil frost and crown-snow load on overhead distribution network power lines. Windstorms and snow and ice accumulation are the primary causes of faults in Nordic distribution networks. With climate change, soil frost days are decreasing, reducing the anchoring effect on trees, while crown-snow loads are increasing in certain regions, potentially leading to increased outage risks. The study uses high-resolution climate change scenarios and geospatial analysis to identify network sections with a high risk from these phenomena. The results indicate significant and varying changes with northern areas experiencing an average of 35% growth in crown-snow loads and 20 % decreases in soil frost days while south-western areas have a decrease in soil frost duration by an average of 30% and 15% decrease in snow loads. Furthermore, the variation in changes between DSO's even in the same area was found to be high. The findings underscore the need for distribution system operators to incorporate higher resolution climate scenarios into their long-term planning to mitigate future outage risks in a changing climate.

1 Introduction

In Finland 35% of faults are caused by windstorms and 38% of snow and ice. From previous studies it is known that in Nordic conditions soil frost has an anchoring effect on trees which reduces the risk of windfalls significantly, while the accumulation of crown-snow load is a significant factor in wintertime faults. The Finnish Meteorological Institute's studies show that soil frost days are significantly decreasing while crown-snow load amounts increase in some parts of Finland. Therefore, it is expected that wind and snow faults can increase dramatically in the areas where soil frost decreases, or crown-snow loads increase.

The accumulation of crown-snow load on trees is highly dependent on environmental factors such as the height above sea level, surrounding topography and temperature. This is evident in terrain with hills where the amount of snow on trees can have high variance even with small horizontal distances. Similarly, the soil frost depth can vary depending on the soil type and location in forest or open areas. Therefore, spatially accurate data is needed to estimate the effects correctly on overhead line network routes.

In this study the risk due to changes in crown-snow load and ground frost in different climate scenarios are identified for distribution system operators' (DSOs') networks in the whole of Finland. While the effect of soil frost and crown snow load on trees has been studied previously, the studies have been from a forestry perspective. This paper extends previous research by focusing on assessing the effect of climate change in soil frost and crown snow load in the distribution network environment which has not been covered in detail in previous studies.

The study uses openly available forestry and network data to identify network sections with potential tree risk. This is combined with high resolution climate change scenarios which allows for estimating the future weather-related outage risks in an individual line section level.

2 Distribution network environment

Reliable electricity distribution and cost-effective network business are based on high-quality network asset management. This applies to the long-term planning of the network as well as the day-to-day operation of the network. As society's demands have tightened in the construction of electricity networks, there has been an increasingly strong shift to weather-proof solutions. This has been able to have a positive effect on the risk of major network disruptions and the number and duration of power outages experienced by electricity users [1]. Even though networks are increasingly being built underground, overhead power lines remain a cost-effective

solution in the important role in the distribution of electricity in sparsely populated areas. In Nordic conditions the largest causes of outages have been wind and snow, or ice related as seen in Figure 2.1. Monitoring the changes in weather phenomena and understanding their effects will continue to be important for the owners of electricity distribution networks.

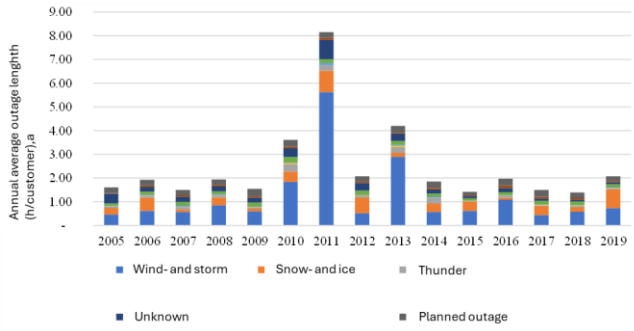

Figure 2.1. Outage events per type in Finland in the period 2005-2019 [1].

2.1. Finnish network environment

Even though underground cabling has been carried out extensively in the recent decade, Finland retains an extensive overhead line network with large sections of the network located in forested areas as shown in Figure 2.2.

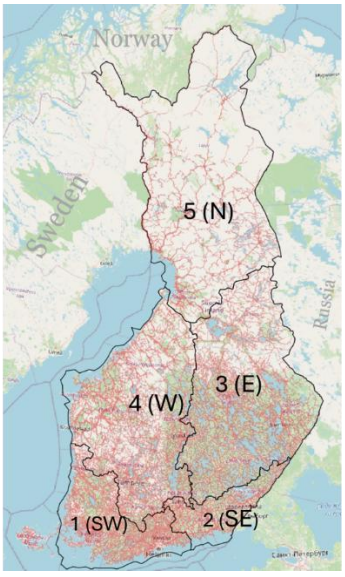

Figure 2.2. Medium voltage overhead line network in Finland and the five major regions.

Finland has currently more than 70 distribution system operators with large variations in area size and network environment. As seen from the figure 2.2. the overhead line network is considerably less dense in Northern Finland where there are large uninhabited areas.

2.2. Effect of soil frost in distribution networks

In Nordic countries the majority of power outages in distribution networks are caused by wind uprooting or breaking trees, which fall into overhead lines [1]. Seasonal freezing of the soil occurs in regions with extended periods of sub-zero temperatures. Key factors influencing the extent and duration of soil frost include air temperature, soil composition, vegetation, precipitation, and snow cover. During the cold season, soil frost typically helps to stabilize trees, making them more resistant to strong winds. Previous research by Haakana et al. [2] indicates that soil frost can reduce fault interruptions by 66% to 86%, with the strongest correlation observed when soil temperatures are below −0.5 °C in a depth of 7–28 cm.

2.3. Effect of crown snow loads in distribution networks

Snow accumulation on tree crowns is most common while heavy snow fall is combined with temperatures hovering around 0°C for extended periods. Excess snow loads result in the mechanical overload and tree breakage or bending because of the progressive accumulation of snow mass. Empirical studies show that the snow is not displaced by wind or short temperature change. Damaging snow loads usually ranges between 10-40 kg/m² depending on the tree characteristics. In terms of species-specific snow tolerance variation, Norway spruces withstand snow load of 20 kg/m² before incipient damage occurs whereas Scots pines show structural failure under 10 kg/m². These biomechanical responses are characterised by crown architecture, wood density and specially tree morphology. [3].

3 Climate change in Finland

It has been estimated that, because of the climate warming, winters in the Nordics will be milder than before, in which case considerable changes may occur in regional weather conditions. This means changes especially in soil frost and snow accumulation on trees. In Nordic conditions, the impact of climate change on other factors, such as storm winds and the occurrence of thunderstorms, is estimated to be minor or unclear. [4] The increase in temperatures in Finland for different climate change scenarios is shown in Figure 3.1.

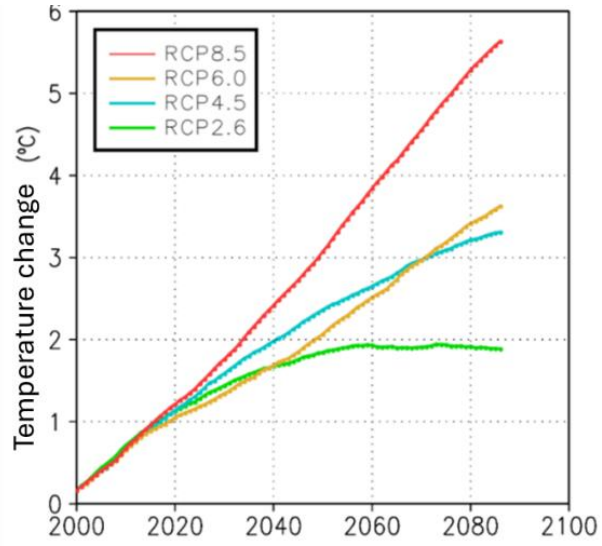

Figure 3.1. Estimated temperature increase caused by climate change in Finland with different scenarios [4].

Due to increasingly mild winters, the amount of snow cover is estimated to decrease in the Nordics. The impact of climate change is estimated to be strong in many areas regarding snow accumulating on trees, and partly on wires. Crown snow load is further increased by the presence of favourable conditions for the accumulation of frost and the increase of wet snow precipitation in higher climates. Snow accumulation is estimated to increase in the central part of Northern and Eastern Finland. In the rest of the country, accumulations of snow are estimated to decrease, and especially in the RCP 8.5 scenario of strong warming, heavy snow loads would become rarer in the southern and southwestern parts of Finland. Changes in crown snow load in Finnish DSO's network areas are shown in Figure 3.2.

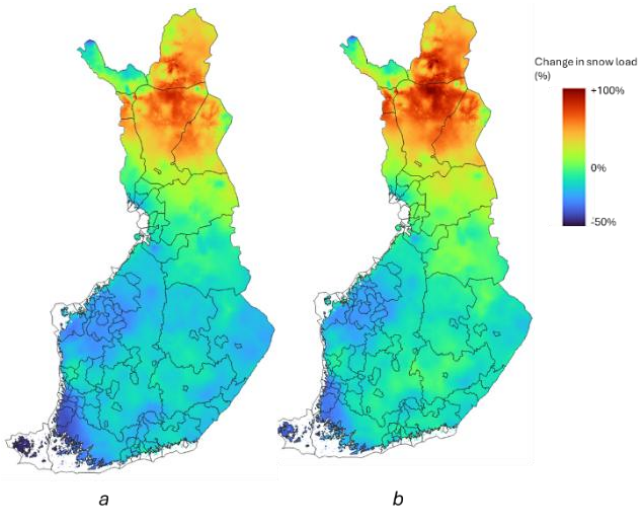

Figure 3.2. Average changes in crown snow load in reference period 1981-2010 compared to 2021-2050 period in RCP4.5 scenario a) and RCP 8.5 scenario b) in Finnish DSO network areas.

Soil frost duration decreases in the whole of Finland as can be seen from Figure 3.3.

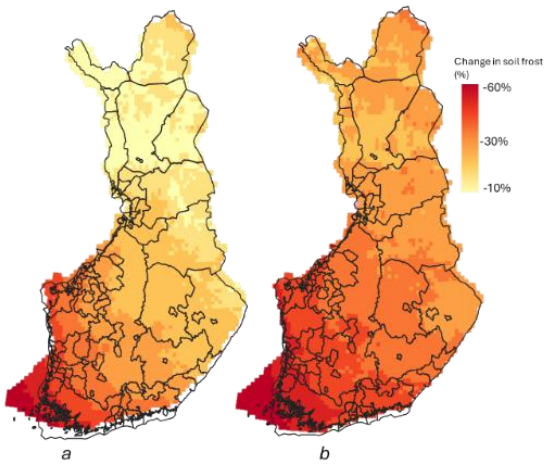

Figure 3.3. Average changes in soil frost days in silt and clay-based soils in reference period 1981-2010 compared to 2021-2050 period in RCP4.5 scenario a) and RCP 8.5 scenario b) in Finnish DSO network areas.

The largest relative changes are in the south-western areas, where the duration of soil frost decreases up to -60%, in Northern areas the changes are relatively smaller. This translates to changes of 25 days in a year on average.

4 Methodology

Geospatial analysis is used to identify overhead lines located near forests and to link soil frost and crown snow load scenario data to the overhead line sections. The changes in different climate scenarios are calculated for individual overhead line sections and aggregated to DSO network areas. The methodology and data used are described in Figure 4.1.

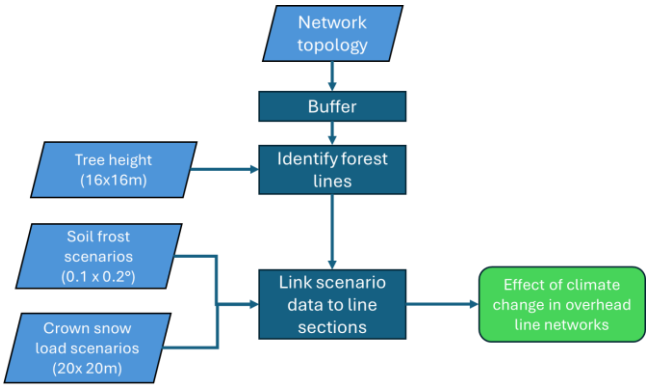

Figure 4.1. Methodology used in the paper.

Climate change scenario data for soil frost and crown snow load was obtained from Finnish meteorological institute (FMI). Both datasets are the average of six climate change models for RCP4.5 and RCP 8.5 scenarios.

The crown snow load data used in this analysis describes the modelled mean annual maximum snow loads for the period 1981-2010 based on historical data and for period 2021 – 2050 with RCP 4.5 and RCP 8.5 scenarios as an average of six climate models. In the data, the snow accumulation is modelled to a cone shaped object resembling a crown of a spruce tree. The model takes into account various climatological and environmental variables such as temperature, precipitation, and wind speed. More detailed description on the methodology is shown in [5]. The data is openly available from Finnish meteorological institute.

The soil frost data is modelled separately for peat based and silt/clay soils. For this study, the average number of soil frost days per year was calculated from the data with an assumption of 50/50 split between the soil types. A soil frost day was defined as day when soil frost is deeper than 20cm. The data was obtained from FMI and a more detailed explanation on the soil frost model is shown in [4]. This definition is in line with previous studies where correlation between distribution system faults and wind faults in frost days has been studied [2].

Identification of forest lines was based on 16 x 16m forest height data obtained from Natural Resources Institute Finland (Luke). A line section was identified as a forest line if maximum height of the tree stands in a 20m buffer area of the overhead line section exceeded 5 m.

5 Results

5.1. Changes in crown snow load

The change in crown-snow load in the overhead line sections located in forests for all Finnish DSOs is shown in Figure 5.1.

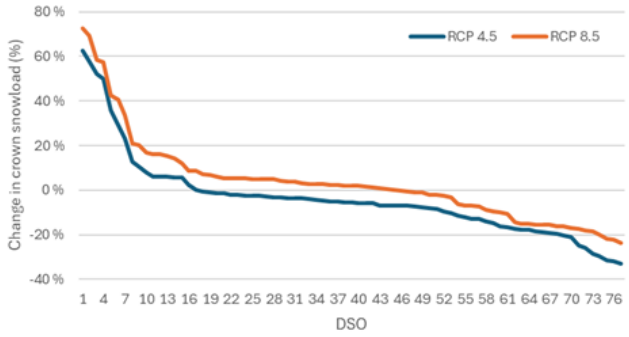

Figure 5.1. Change in crown snow load in DSO network areas.

The results show that the effect of crown-snow load varies highly depending on the location from a decrease of -35% for southern DSOs to an increase of 70% in northern DSOs. Table 1 depicts the changes in crown-snow load aggerated to the five major regions shown in Figure 5.1.

Table 1 The historical and projected crown snow loads for RCP 4.5 and 8.5 in five major regions of Finland.

Area	Medium voltage line length in forests (km)	1981-2010 kg/m³	2021-2050 RCP 4.5 kg/m³	2021-2050 RCP 8.5 kg/m³	Change RCP 4.5 (%)	Change RCP 8.5 (%)
1 (SW)	7 289	11.0	9.5	10.4	-14 %	-5 %
2 (SE)	5 757	18.9	17.8	19.2	-6 %	2 %
3 (E)	28 028	22.3	21.7	23.9	-3 %	7 %
4 (W)	18 285	18.4	17.1	18.2	-7 %	-1 %
5 (N)	13 210	19.9	26.9	28.6	35 %	44 %
All DSOs	72 570	19.3	19.8	21.5	2 %	11 %

Changes in snow load can also vary drastically in the DSOs network area. For the example for the DSO Rovakaira Oy the changes in snow load are up to +100% for the feeders located in the northern part of the network while in the southern areas, changes are approximately +30%.

5.2. Changes in soil frost

Changes in soil frost are approximately between -15% and -50% with the largest changes in DSOs located in the Southern part of Finland.

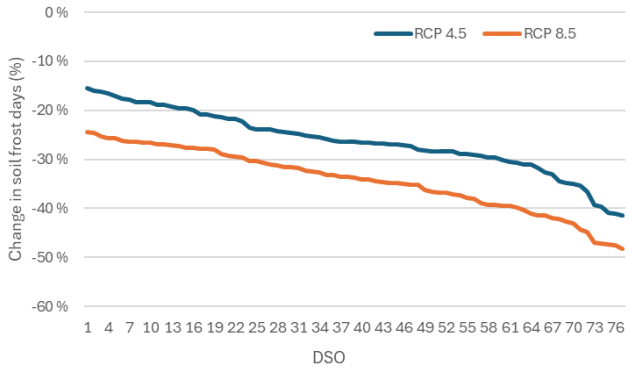

Figure 5.2. Change in soil frost in DSO network areas.

The soil frost changes in the RCP4.5 and RCP 8.5 scenarios aggregated into the five major regions are shown in Table 2.

Table 2 The historical and projected soil frost days for RCP 4.5 and 8.5 scenarios in five major regions of Finland.

Area	Medium voltage line length in forests (km)	1981-2010 Days/year	2021-2050 RCP4.5 Days/year	2021-2050 RCP8.5 Days/year	Change RCP4.5 (%)	Change RCP8.5 (%)
1 (SW)	7 300	75	51	44	-33 %	-43 %
2 (SE)	5 700	93	71	62	-23 %	-33 %
3 (E)	28 000	112	87	80	-23 %	-29 %
4 (W)	18 000	104	76	69	-27 %	-34 %
5 (N)	13 000	139	114	103	-19 %	-27 %
All DSOs	72 500	87	64	58	-24 %	-31 %

From figure 5.2 and table 2 it can be seen that soil frost is decreasing in the whole of Finland, however the relative change varies between regions. Largest decreases are seen in the southwestern Finland where soil frost days decrease by 30 days (31 %).

5 Conclusion

In this paper a methodology to assess effects of climate change in distribution networks in high resolution was presented. The results show that in Nordic areas, climate change has a large effect especially on soil frost and crown snow conditions. The amount and direction of the changes was found to have large variance in different geographical areas. Largest changes in crown snow loads were found in northern DSO's ´with average yearly increase of up to 100 %. while soil frost decreases up to 20%, can result in increases of both wind and snow caused outages. In south-western DSO areas the soil frost was found to be decreasing up to 50%, while crown snow load is estimated to decrease in these areas up to -14%.

The effects identified in this study have the potential of leading to increased outages in Finland. This study did not take into account other effects of climate change such as changes in soil moisture and the effects of average tree height growth in the arctic, which may further increase the risk of outages in the future. The relation of increased snow loads on the outage risk should be studied in further detail

6 Acknowledgments

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