Nordic and Baltic Grid Disturbance Statistics 2019

Regional Group Nordic

European Network of
Transmission System Operators
for Electricity
entsoe

Nordic and Baltic Grid Disturbance Statistics 2019

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Executive Summary

The Nordic and Baltic Grid Disturbance Statistics 2019 gives both an overview of the disturbances, faults, and energy not supplied (ENS) in the Nordic and Baltic transmission systems, as well as a deeper dive into the statistics of individual HVAC components used in the power system. To interpret the results of the statistics correctly, one must understand the definition of a disturbance and the scope of a fault within it.

A *fault* is defined as the inability of a component to perform its required function, with the addition that faults only are reported when they result in a trip of one or several breakers. A *disturbance* is an event including one or more faults. In short, a disturbance is a combination of one or several faults as long as they occur in the same area and time. Disturbances always focus on the fault initiating the disturbance.

Summary of 2019

The year 2019 continued to be unusually warm during the summer, which we see as a concentration of disturbances during the summer period. Lightning and other environmental causes caused approximately 44 % of the disturbances during 2019. The total number of disturbances during 2019 was 1601, which is about 500 disturbances more than in 2018, but still lower than the 10-year average of 1801.4 disturbances per year. Of all disturbances during 2019, only 333 (nearly 21 %) caused ENS.

Energy not supplied (ENS) in the Nordic and Baltic countries is continuing its decreasing trend in 2019 and was nearly 5.0 GWh in 2019 (10-year average 6.9 GWh). However, it was approximately 2.3 GWh higher in 2019 than in 2018. On the other hand, 2018 was a remarkably good year regarding ENS. When ENS is normalised by the consumption, the 5-year moving average is still showing a decreasing trend for the Nordic and Baltic countries combined, as seen in Figure E.1. Increasing trends are seen in Iceland and Estonia while the other countries have steady trends.

Contrary to the number of disturbances, ENS did not show correlation with warmer months in the way disturbances did in 2018. The high percentage could be explained with the transmission grid being most often constructed according to the N-1 principle and thus being well protected against occasional impairment of transmission network units. ENS was caused most by other environmental causes (36 % of the total ENS) and technical equipment (29 % of the total ENS).

Secondary faults, which are closely connected to disturbances with multiple faults, caused approximately 2 % of the total Nordic and Baltic ENS in 2019. In 2018, secondary faults caused approximately 9 % of the total ENS [1]. Over 70 % of the secondary faults were caused by technical equipment, operation and maintenance, and other causes in 2019. However, other causes were the reason for 71 % of all secondary faults ENS. Other causes were also the dominating cause of secondary faults ENS in 2018.

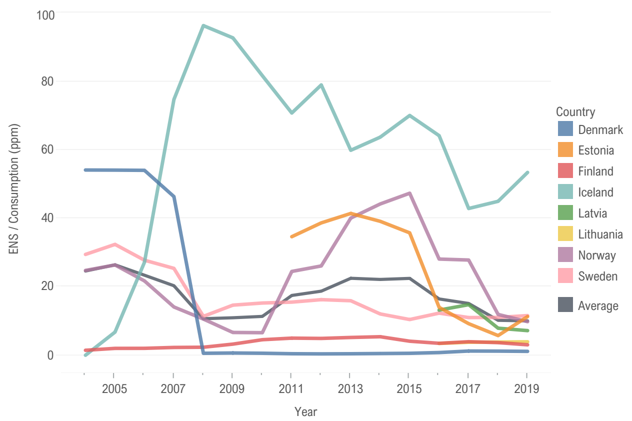

Figure E.1: 5-year moving average amount of ENS divided per consumption (ppm) since 2000. Iceland's high values are a result of power-intensive industries that cause substantial amounts of ENS even during short interruptions.

The most vulnerable HVAC component type in the Nordic and Baltic area, as seen from the statistics, is overhead line with 61 % of all faults (10-year average 64 %) and 26 % of all ENS (10-year average 53 %). The high percentage could be explained by overhead lines being the most used and exposed HVAC component used in the transmission grid. Still, the number of overhead line faults per 100 km of line trend is decreasing, as seen in Figure E.2. In 2019, most ENS was caused unusually by faults in power transformers. 27 % of all ENS was caused by power transformer faults, while only 3 % of the faults occurred in them. On average, power transformer faults cause approximately 6 % of the annual ENS, while control equipment faults cause about 9 % of the ENS per year. Increasing fault trends can be seen in 220–330 kV control equipment and circuit breakers and 380–420 kV cables and power transformers.

Baltic summary

The number of grid disturbances in 2019 in the Baltic area increased slightly compared to 2018 (416 vs 344) but was still lower than the 10-year average of approximately 500 disturbances per year. The amount of energy not supplied (ENS) in 2019 is, however, nearly triple the amount of ENS in 2018 due to incidents in Estonia causing above-average ENS. ENS is showing an increasing trend in Estonia and a decreasing trend in Latvia and Lithuania, as demonstrated in Figure E.1.

Secondary faults, which are closely connected to disturbances with multiple faults, caused only about 1 % of the total ENS in 2019 in the Baltic area while still standing for about 10 % of the number of faults. The change is significant compared to 2018 [1], when 47 % of the total ENS in the Baltic area was due to secondary faults, and is an excellent example of how secondary faults may sometimes have a significant impact on the grid. Over 70 % of the secondary faults were due to technical equipment and operation and maintenance in 2019, and they caused nearly approximately 81 % of the Baltic ENS due to secondary faults.

The power system components that were most prone to faults in 2018 in the Baltic area were overhead lines and control equipment, causing 59 % and 14 % of the faults respectively. On average, overhead lines tend to account for 65 % of all faults per year and control equipment 9 %. 11 % of all faults originated from outside the Baltic statistical area.

Faults in other high voltage appliances caused most of the ENS, approximately 32 % of the total ENS, in the Baltic area during 2019. Second and third most of the ENS was caused by faults in control equipment (29 % of the total Baltic ENS) and faults originating from the adjoining grid (15 % of the total Baltic ENS). The ENS in 2019 deviates considerably from the average values, which are similar to the perceived percentage distribution of faults per power system components. On average, overhead line faults cause 54 % of the ENS, faults from outside the statistical area produces 15 % of the ENS, and control equipment faults cause 12 %. The deviation from the average is due to the incidents in Estonia in 2019. Decreasing fault trends are seen in overhead lines for each Baltic country, as shown in Figure E.2. Furthermore, most other components also show decreasing fault trends. Increasing fault trends can only be seen in 110–150 kV and 220–330 kV control equipment for each Baltic country, 100–150 kV circuit breakers for Latvia, and Lithuania and 100–150 kV instrumental transformers for Latvia.

Nordic summary

The number of grid disturbances in 2019 in the Nordic area increased slightly compared to 2018 (1185 vs 1033) but was still lower than the 10-year average of 1306.2 disturbances per year. Only 24 % of the disturbances caused ENS in the Nordic region. External influences, operation and maintenance, and technical equipment were the cause of 73 % of those disturbances.

Energy not supplied (ENS) in 2019 amounted to 4.6 GWh and is approximately 30 % less than the 10-year average of about 6.9 GWh of ENS per year. Iceland and Denmark are showing an increasing trend in ENS per consumption. Norway shows a decreasing trend, and Finland and Sweden show steady values, as seen in Figure E.1.

Secondary faults, which are closely connected to disturbances with multiple faults, caused approximately 6 % of the total ENS in 2019 in the Nordic area. The change is minimal when compared to the year 2018, when around 7 % of all faults were secondary faults. Approximately 31 % of the secondary faults were due to other causes in 2019. However, other causes accounted for nearly three-quarters of the Nordic ENS due to secondary faults.

The power system components that were most prone to faults in 2019 in the Nordic area were overhead lines and control equipment, causing 61 % and 15 % of the faults respectively. Compared to the 10-year average, neither they nor the other power system components deviated exceptionally from the norm. The percentage distribution of faults per power system component has usually been similar to the ENS distribution per power system component. However, 28 % of all ENS in the Nordic region was caused by a power transformer fault in Iceland, which also made 2019 an exceptional year regarding the ENS distribution per power system component.

Fault trends of overhead lines are decreasing for all Nordic countries and with all voltage levels combined, as shown in Figure E.2. However, increasing trends can be found for 220–330 kV overhead lines in Denmark, Iceland and Sweden. When assessing control equipment faults, Denmark and Finland are showing decreasing trends, and Iceland, Norway and Sweden are showing increasing fault trends. Lastly, power transformer faults are also showing an increasing trend in Denmark, Iceland and Finland.

Conclusion

In 2019, 74 % of the disturbances in the Nordic and Baltic area occurred in the Nordic region, which includes the Danish, Finnish, Icelandic, Norwegian and Swedish transmission grids. Furthermore, 93 % of the energy not supplied (ENS) in the Nordic and Baltic area was caused in the Nordic transmission network. However, this is understandable because the Nordic network is significantly larger than the Baltic network. The Nordic and Baltic transmission grids are very comparable when the energy not supplied is scaled according to, for example, each country's consumption. For every terawatt-hour of consumption, there are approximately 11.3 MWh of ENS in the Nordic and Baltic area. The values for the Nordic and Baltic regions are 11.2 and 12.1, respectively. These values are significantly lower than the 10-year average of 15.9 MWh of ENS per 1 TWh of consumption, and the trend is showing a slightly decreasing trend.

The year 2019 continued to be warm, and 54 % of all disturbances occurred between May and August. Nevertheless, the total number of disturbances, as well as the amount of energy not supplied (ENS) caused by them, is significantly lower than the corresponding 10-year average values. The monthly percentage distribution of ENS did not follow the disturbance distribution but was at its highest points in January, July–August and December.

Secondary faults, which are closely connected to disturbances with multiple faults, have not shown to cause a significant portion of energy not supplied (ENS) in the Nordic and Baltic area. The change compared to 2018 is remarkable, when secondary faults caused nearly half of all the Baltic ENS, and is an excellent example of how secondary faults may sometimes have a significant impact on the grid.

The most vulnerable HVAC component type in the Nordic and Baltic transmission grid is overhead line, which has the most number of faults of all HVAC components during 2019 and on average during 2010–2019. However, the average trend of overhead line faults per 100 km of line is decreasing, as seen in Figure E.2. Surprisingly in 2019, substation faults accounted for approximately 59 % of the total ENS in the Nordic and Baltic area. On average, overhead line faults have caused 53 % of the total ENS. However, this is partly due to an exceptional storm in Iceland in December. A single power transformer fault caused over a fifth of the entire Nordic and Baltic ENS, and the December storm accounted for around 95 % of all ENS in Iceland.

Fault trends of other power system components are showing similar, decreasing values as overhead lines. However, increasing fault trends can be seen in 220–330 kV control equipment and circuit breakers and 380–420 kV cables.

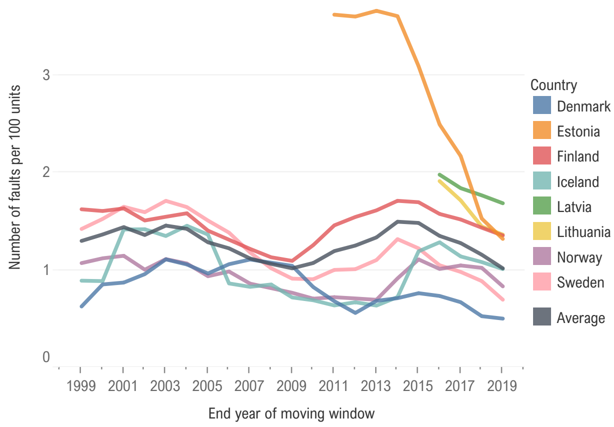

Figure E.2: 5-year moving average of overhead line faults per 100 km in each Nordic and Baltic country. All voltage levels have been included.

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1 Introduction

This report is an overview of the Nordic and Baltic HVAC transmission grid disturbance statistics for the year 2019. Transmission System Operators providing the statistical data are *Energinet* in Denmark, *Elering* in Estonia, *Fingrid Oyj* in Finland, *Landsnet* in Iceland, *Augstsprieguma tīkls* in Latvia, *Litgrid* in Lithuania, *Statnett SF* in Norway and *Svenska kraftnät* in Sweden. The statistics are published on ENTSO-E's website, www.entsoe.eu. Figure 1.1 presents the grids of the statistics.

The report includes faults causing disturbances in the 100–420 kV grids, and it is made according to the *Guidelines for Classification of Grid Disturbances above 100 kV* [2].

The report is organised as follows:

- Chapter 2 summarises the statistics, covering the consequences of disturbances in the form of energy not supplied (ENS) and covering the total number of disturbances in the Nordic and Baltic power system. Besides, each Transmission System Operator has presented the key events of the year 2019.
- Chapter 3 presents the disturbances and focuses on the analysis and allocation of the causes of disturbances.
- Chapter 4 presents the tables and figures of energy not supplied (ENS) for each country.
- Chapter 5 presents secondary faults and their impact on the Nordic and Baltic power systems.
- Chapter 6 presents an overview of all faults in the Nordic and Baltic power grids and a detailed view of faults for each type of power system component. An in-depth look is given for the following power system components: cables, overhead lines, circuit breakers, control equipment, instrumental transformers, power transformers, and compensation devices.

The disturbance, energy not supplied (ENS), secondary fault and fault sections should be considered on a general level. The section with faults in the power system components contains detailed information and is aimed for experts working with primary equipment.

The whole of Denmark is included in this report, although only the grid of eastern Denmark belongs to the Nordic synchronous network.

1.1 History

The Nordic and Baltic Grid Disturbance Statistics has a long history with mutual rules made already in 1964. In the beginning, the statistics covered Denmark, Finland, Norway and Sweden and was published by Nordel[1] in Swedish "Driftstörningsstatistik" (Eng. Fault statistics) along with a summary in English. Iceland joined in 1994.

In 2007, the statistics were translated to English, and the name became *Nordic Grid Disturbance Statistics*. In 2014, the Baltic countries joined the report, and the report changed its name to *Nordic and Baltic Grid Disturbance Statistics*, which is also the name of the report today.

[1] Nordel was the co-operation organization of the Nordic Transmission System Operators until 2009.

Figure 1.1: The Nordic and Baltic main grids [3]. All of Denmark is included in the disturbance data of this report, although only the grid of eastern Denmark belongs to the Nordic synchronous grid.

1.2 The Scope and limitations of the statistics

The scope of the statistics, per the guidelines [2], is the following:

> "The statistics comprise:
>
> - Grid disturbances
> - Faults causing or aggravating a grid disturbance
> - Disconnection of end-users in connection with grid disturbances
> - Outage in parts of the electricity system in conjunction with grid disturbance
>
> The statistics do not comprise:
>
> - Faults in production units
> - Faults detected during maintenance
> - Planned operational interruptions in parts of the electricity system
> - The behaviour of circuit breakers and relay protection if they do not result in or extend a grid disturbance."

Furthermore, HVDC units are not included in this report. However, DISTAC produces a separate report with HVDC statistics called *Nordic and Baltic HVDC Utilisation and Unavailability Statistics* [4].

The statistics cover the central systems and associated network devices with a voltage level of more than 100 kV. Control equipment and installations for reactive compensation are also included in the statistics. A graphical interpretation of the components included in the statistics is presented in Figure 1.2.

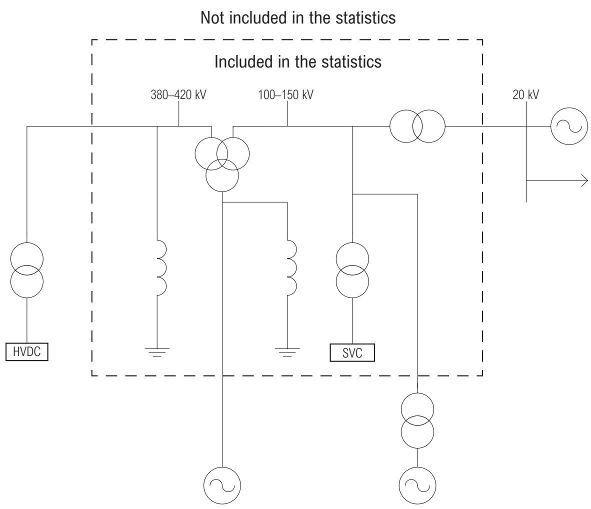

Figure 1.2: A graphical representation of the included power system components in the statistics.

Although the statistics are built upon mutual guidelines [2], there are slight differences in the interpretations between different countries and companies. However, these differences are considered to have a minor impact on the statistical material. Nevertheless, readers should – partly because of these differences, but also because of the different maintenance and general policies in each company – use the appropriate published average values. Values concerning control equipment and unspecified faults or causes should be used with looser margins than other values.

1.3 Available data in the report

Most charts and tables include data for the period 2010–2019. In some cases, where older data has been available, even lengthier periods have been used. For example, trend data for cables, overhead lines, circuit breakers, control equipment and instrumental and power transformers is available since 1995.

However, not all of the participating TSO's have data for the whole period 2010–2019. In these cases, the tables and figures show all the available data. In this report, Latvia and Lithuania have reported for the period 2012–2019.

1.4 Definitions

This chapter defines terms and main concepts that are essential when examining this report. Each concept has a separate section.

1.4.1 Fault categories

Each disturbance and fault must have a cause reported to it. For faults, the cause is the cause that has the most significant impact on the fault, while for disturbances, the reported cause is the same as the cause of its primary fault. The used causes are lightning, other environmental causes, external influences, operation and maintenance, technical equipment, other and unknown, as presented and detailed in Table 1.1. The exact definitions are listed in Section 4.2.9 in the HVAC Guidelines [2].

It should be noted that there are some minor differences in the definitions of fault causes and disturbances between countries. Some countries use up to 40 different options, and others differentiate between primary and underlying causes. The guidelines [2] describe the relations between the exact fault causes and the mutual cause allocation. Furthermore, each country in these statistics has its own detailed way of determining the cause of each fault. Appendix B describes how each TSO in the Nordic and Baltic power systems examines the cause of line faults.

Table 1.1: The fault cause categories used in the Nordic and Baltic Grid Disturbance Statistics as defined in the HVAC Guidelines for classification of disturbances above 100 kV [2].

Fault cause	Explanation
Lightning	The category Lightning is separated from the environmental causes because its impact is insignificant from a maintenance perspective, mainly because the Nordic grid is well protected against lightning.
Other environmental causes	Environmental causes except for lightning, such as moisture, ice, low temperatures, earthquakes, pollution, rain, salt, snow, vegetation, wind, heat and forest fires.
External influences	Fire due to a third party, animals and birds, aircraft, excavation, collision, explosion, tree felling, vandalism.
Operation and maintenance	Lack of monitoring, fault in settings, fault in connection plan, fault in relay plan, incorrect operation, errors in documentation, human fault.
Technical equipment	Dimensioning, error in technical documentation (e.g., guidelines, manuals), design, corrosion, materials, installation, production, vibration, ageing.
Other	Operating problems, faults at customers', faults in other networks, issues in conjunction with faults in other components, system causes, other
Unknown	Unknown causes

1.5 Voltage levels in the Nordic and Baltic networks

Table 1.2 presents the transmission system voltage levels of the networks in the Nordic and Baltic countries. In the statistics, voltage levels are grouped as statistical voltages per the table. Table 1.3 presents the coverage of the statistics in each country. The network statistics of each country cover data from several grid owners, and the representation of their statistics is not entirely consistent.

Table 1.2: Nominal voltage levels (U_N) in the respective statistical voltages and the percentage of the grid at the respective nominal voltage level (P).

		Statistical voltage range, kV		
Country		100–150 kV	220–330 kV	380–420 kV
Denmark	U_N / P %	150 kV / 62 % 132 kV / 38 %	220 kV / 100 %	400 kV / 100 %
Estonia	U_N / P %	110 kV / 100 %	330 kV / 92 % 220 kV / 8 %	–
Finland	U_N / P %	110 kV / 100 %	220 kV / 100 %	400 kV / 100 %
Iceland	U_N / P %	132 kV / 100 %	220 kV / 100 %	–
Latvia	U_N / P %	110 kV / 100 %	330 kV / 100 %	–
Lithuania	U_N / P %	110 kV / 100 %	330 kV / 100 %	400 kV / 100 %
Norway	U_N / P %	132 kV / 98 % 110 kV / 2 %	300 kV / 90 % 220 kV / 10 %	420 kV / 100 %
Sweden	U_N / P %	130 kV / 100 %	220 kV / 100 %	400 kV / 100 %

Table 1.3: Percentage of national networks included in the statistics. The percentage is calculated by counting the length of lines included in the statistical material divided by the actual length of lines in the grid. The network statistics of each country cover data from several grid owners, and the representation of their reports is not absolutely consistent.

	Voltage level		
Country	100–150 kV	220–330 kV	380–420 kV
Denmark	100 %	100 %	100 %
Estonia	100 %	100 %	–
Finland[1]	91 %	100 %	100 %
Iceland[2]	100 %	100 %	–
Latvia	100 %	100 %	–
Lithuania	100 %	100 %	100 %
Norway[3]	100 %	100 %	100 %
Sweden	96 %	100 %	100 %

[1] Finland's data from 2019 covers approximately 91 % of the Finnish 110 kV lines and about 82 % of the 110/20 kV transformers.
[2] Iceland's network statistics include the entire 220 kV and 132 kV voltage levels.
[3] A large part of Norway's 110 and 132 kV network is resonant-earthed. This category is combined with the 100–150 kV solid-earthed network in these statistics.

1.6 Contact persons

Each country is represented by at least one contact person, responsible for his/her country's statistical information. The contact person can provide additional information concerning the ENTSO-E Nordic and Baltic disturbance statistics. The relevant contact information is given in Appendix C.

There are currently no mutual Nordic and Baltic disturbance statistics for voltage levels lower than 100 kV. However, Appendix D presents the relevant contact persons for these statistics.

2 Summary

In 2019, there were 1601 grid disturbances in the Nordic and Baltic 100–420 kV grids, which is below the 10-year average of 1801.4 disturbances. The energy not supplied (ENS) due to faults in the Nordic transmission network reached 4.6 GWh and 340 MWh in the Baltic. There were approximately 5.0 GWh of ENS in the Nordic and Baltic transmission network, which is below the ten-year average 6.9 GWh. Out of these disturbances, 333 caused ENS, which is also below the 10-year average of 401.3 disturbances causing ENS.

The following sections present the summaries for each Nordic and Baltic country. The summaries include an overview of the number and causes of disturbances and the resulting energy not supplied. Furthermore, secondary faults, which are tightly related to disturbances with multiple faults, are shortly included. Lastly, the summaries present the most significant issues in 2019, referred by the country's Transmission System Operator.

2.1 Summary of Denmark

In Denmark, the energy not supplied (ENS) caused by disturbances was 13.8 MWh in 2019 (10-year average 27.0 MWh). There were 54 grid disturbances (10-year average 55.9) and 4 of them caused ENS. On average, 7.0 disturbances per year caused ENS in 2010–2019.

In 2019, 100.0 % of the total ENS was caused by substation faults. The most significant reasons for ENS caused by disturbances were other environmental causes (32.1 %) and technical equipment (30.7 %). Disturbances were caused most by external influences (31.5 %) and technical equipment (22.2 %).

Secondary faults in Denmark accounted for 10 % of all faults in 2019 and caused approximately 34 % of the total ENS. They were mostly caused by operation and maintenance (67 %) and other causes (33 %), and the ENS was primarily due to operation and maintenance (55 %) and other causes (45 %).

The three most influential disturbances in 2019 were the following:

- A substation in North-Jutland got disconnected due to a flashover on a 150 kV transformer on 5 January. Salt had established on the insulation due to a combination of high winds and short proximity to the North Sea and resulted finally in the flashover. The outage lasted 19 minutes and caused 4.4 MWh of ENS.
- A faulty transformer component caused an outage of a 150/60 kV transformer in South-Jutland 5 April. The outage lasted 46 minutes and caused 4.2 MWh of ENS.
- During work on a 400 kV station in central Zealand 8 October, a faulty breaker caused a short-circuit and consequently disconnected the connected 400 kV busbar and HVDC link. The HVDC link happened to be importing power at 600 MW at the time. Furthermore, two power generating units got disconnected and caused a total of approximately 1100 MW to be disconnected. No ENS occurred; however, every power reserve in DK2 was activated due to the incident. The disturbance resulted in a large unbalance towards Sweden and N-1 violations between SE3 and SE4.

2.2 Summary of Estonia

In Estonia, the energy not supplied (ENS) caused by disturbances was 266.2 MWh in 2019 (10-year average 192.8 MWh). There were 138 grid disturbances (10-year average 199.4) and 18 of them caused ENS. On average, 30.5 disturbances per year caused ENS in 2010–2019.

In 2019, 78.4 % of the total ENS was caused by substation faults, and 2.6 % by overhead line faults. The most significant reasons for ENS caused by disturbances were technical equipment (77.1 %) and other causes (18.9 %). Disturbances were caused most by technical equipment (24.6 %) and external influences (18.8 %).

Secondary faults in Estonia accounted for 5 % of all faults in 2019 and caused approximately 0 % of the total ENS. They were mostly caused by technical equipment (43 %) and other environmental causes (29 %), and the ENS was primarily due to technical equipment (100 %).

The three most influential disturbances in 2019 were the following:

- The overhead line L300 Baltic-Tartu and the 110 kV busbars of two autotransformers were switched off due to a fire on 18 May 2019 18:58. The fire was caused by the wrong settings on a current transformer resulted in interruptions for multiple consumers. The fire was put off at 20:28, and the overhead line was back in operation at 20:33.
- The overhead line L8060 Kunda-Estonian Cell dead-end line was switched off from Kunda substation by application of overcurrent protection on 21 September 2019 at 06:42. The overhead line circuit breaker could not be switched on via telematics. The line was energised at 09:04, and consumer interruption totalled 2 hours and 22 minutes.
- Võru substation was switched off 27 October 2019 at

16:32. The failure was caused by pieces of roof of the substation building that flew into the 110 kV busbars due to strong winds and caused severe damage to the equipment. The incident caused interruptions for multiple consumers.

2.3 Summary of Finland

In Finland, the energy not supplied (ENS) caused by disturbances was 351.7 MWh in 2019 (10-year average 341.5 MWh). There were 395 grid disturbances (10-year average 440.1) and 37 of them caused ENS. On average, 74.0 disturbances per year caused ENS in 2010–2019.

In 2019, 92.2 % of the total ENS was caused by overhead line faults, and 6.6 % by substation faults. The most significant reasons for ENS caused by disturbances were technical equipment (82.2 %) and unknown causes (11.9 %). Disturbances were caused most by other environmental causes (43.5 %) and lightning (25.3 %).

Secondary faults in Finland accounted for 1 % of all faults in 2019 and caused approximately 4 % of the total ENS. They were mostly caused by operation and maintenance (33 %), and the ENS was primarily due to technical equipment (54 %) and other environmental causes (44 %).

The three most influential disturbances in the 110–400 kV grid in 2019 were:

- Carrier wave coil of 110 kV line fault. ENS 273 MWh.
- Earth fault on 110 kV line. Unknown reason. ENS 11 MWh
- Bushing fault on 110 kV / 20 kV main transformer. ENS 8 MWh.

Finland's data from 2019 covers approximately 91 % of the Finnish 110 kV lines and about 82 % of the 110/20 kV transformers.

2.4 Summary of Iceland

Iceland had a very unusual year in 2019. Majority of the ENS and disturbances were due to a phenomenal storm 10–12 December with extreme winds, salt and ice. The ENS in December caused approximately 95 % of the ENS in 2019.

The total energy not supplied (ENS) caused by disturbances was 1749.4 MWh in 2019 (10-year average 995.9 MWh). There were 51 grid disturbances (10-year average 37.1), and 18 of them caused ENS. On average, 18.3 disturbances per year caused ENS in 2010–2019.

In 2019, 80.1 % of the total ENS was caused by substation faults, and 17.1 % by overhead line faults. The most significant reasons for ENS caused by disturbances were other environmental causes (94.7 %) and unknown causes (2.7 %). Disturbances were caused most by other causes (43.1 %) and other environmental causes (35.3 %).

Secondary faults in Iceland accounted for 34 % of all faults in 2019 while still causing no ENS. They were mostly caused by other causes (69 %) and other environmental causes (31 %), and the ENS was due to other causes (100 %).

The worst disturbance in Iceland during 2019 happened on the 66 kV voltage level, where long-lasting disturbances caused high ENS.

The three most influential disturbances during 2019 in the 132 and 220 kV network happened to occur during the same day on 10 December. They were the following:

- A 132 kV power transformer at substation HNJ tripped due to enormous icing and resulted in 1116 MWh of ENS.
- The 220 kV transmission line TR1 tripped due to icing and resulted in 194 MWh of ENS.
- A 132 kV substation tripped due to salt and icing and resulted in widespread transmission line trips and 268 MWh of ENS.

2.5 Summary of Latvia

In Latvia, the energy not supplied (ENS) caused by disturbances was 21.0 MWh in 2019 (8-year average 78.7 MWh). There were 131 grid disturbances (8-year average 138.9) and 10 of them caused ENS. On average, 16.6 disturbances per year caused ENS in 2012–2019.

In 2019, 76.7 % of the total ENS was caused by overhead line faults, and 22.7 % by substation faults. The most significant reasons for ENS caused by disturbances were other environmental causes (74.0 %) and operation and maintenance (12.4 %). Disturbances were caused most by other environmental causes (23.7 %) and unknown causes (22.9 %).

Secondary faults in Latvia accounted for 15 % of all faults in 2019 and caused approximately 10 % of the total ENS. They were mostly caused by technical equipment (74 %) and operation and maintenance (26 %). The ENS was primarily due to operation and maintenance (75 %).

The most influential disturbances in 2019 were the following:

- Fallen trees on overhead lines due to strong wind gusts outed four regional substations and caused 13.5 MWh of ENS.
- Manual operational error on a busbar caused an outage of both substation busbars. The disturbance caused a blackout of 3 substations for 5 minutes and 2.6 MWh of ENS.

2.6 Summary of Lithuania

In Lithuania, the energy not supplied (ENS) caused by disturbances was 52.4 MWh in 2019 (8-year average 41.5 MWh). There were 147 grid disturbances (8-year average 156.9) and 19 of them caused ENS. On average, 19.1 disturbances per year caused ENS in 2012–2019.

In 2019, 64.3 % of the total ENS was caused by substation faults, and 33.9 % by overhead line faults. The most significant reasons for ENS caused by disturbances were operation and maintenance (50.7 %) and external influences (33.9 %). Disturbances were caused most by external influences (35.4 %) and unknown causes (19.0 %).

Secondary faults in Lithuania accounted for 11 % of all faults in 2018 and caused approximately 1 % of the total ENS. They were mostly caused by operation and maintenance (39 %) and unknown causes (28 %), and the ENS was primarily due to other causes (100 %).

The most influential disturbances in 2019 were the following:

- A contractor employee damaged a disconnector in an operational circuit during reconstruction works. The disturbance outed the 110 kV substation, lasted for more than two hours and caused 23.8 MWh of ENS (45 % of total ENS).
- The feeding overhead line of a 110 kV substation tripped because a tree fell on it. The tree fell due to unsafe logger work close to the overhead line. The disturbance caused 18 % of total ENS during 2019.

2.7 Summary of Norway

Norway had a terrific year regarding ENS during 2019. The energy not supplied (ENS) caused by disturbances was 854.0 MWh in 2019 (10-year average 3463.4 MWh). There were 273 grid disturbances (10-year average 297.3) and 73 of them caused ENS. On average, 86.1 disturbances per year caused ENS in 2010–2019.

In 2019, 55.8 % of the total ENS was caused by substation faults, and 20.0 % by cable faults. The most significant reasons for ENS caused by disturbances were technical equipment (68.3 %) and other environmental causes (11.0 %). Disturbances were caused most by other environmental causes (23.8 %) and lightning (22.0 %).

Secondary faults in Norway accounted for 9 % of all faults in 2019 and caused approximately 8 % of the total ENS. They were mostly caused by technical equipment (42 %) and operation and maintenance (23 %), and the ENS was primarily due to other causes (96 %).

There was only one significant disturbance in Norway during 2019. The disturbance was caused by unintentional manual tripping of a 300 kV line from Fana to Lillesotra. It created a load drop of approximately 400 MW at Kollsnes natural gas processing plant.

2.8 Summary of Sweden

In Sweden, the energy not supplied (ENS) caused by disturbances was 1649.5 MWh in 2019 (10-year average 1656.6 MWh). There were 412 grid disturbances (10-year average 475.8) and 154 of them caused ENS. On average, 149.7 disturbances per year caused ENS in 2010–2019.

In 2019, 46.1 % of the total ENS was caused by substation faults, and 29.3 % by overhead line faults. The most significant reasons for ENS caused by disturbances were lightning (41.7 %) and unknown causes (26.2 %). Disturbances were caused most by lightning (44.9 %) and unknown causes (26.5 %). The reason of Sweden having more disturbances and ENS due to unknown causes is that if the cause of a disturbance is not 100 % certain, which might be the case with lightning, it is assigned as an unknown cause as explained in Appendix B.

Secondary faults in Sweden accounted for 3 % of all faults in 2019 and caused approximately 1 % of the total ENS. They were mostly caused by technical equipment (29 %) and unknown causes (29 %), and the ENS was primarily due to unknown causes (98 %).

Sweden had one significant disturbance in 2019. A mechanical failure led to a dropper falling over a busbar in a transformer substation. The resulting outage caused 282.7 MWh ENS.

3 Disturbances

This chapter presents an overview of disturbances in the European countries included in this report. It also shows the connection between disturbances, their causes, energy not supplied, distribution during the year 2019, and the development during the last ten years.

Grid disturbances are defined as:

> "Outages, forced or unintended disconnection or failed reconnection as a result of faults in the power grid" [2].

It is essential to note the difference between a disturbance and a fault. A disturbance is initiated by a fault, called the primary fault, and may include zero or more faults that are related to the incident. Furthermore, a fault may have multiple primary faults. However, this report considers the primary fault with the most impact to be the primary fault of the disturbance. The voltage level of a disturbance is determined by the voltage level of its primary fault.

3.1 Annual number of disturbances during the period 2010–2019

Table 3.1 presents the sum of disturbances during the year 2019 and the annual average for the period 2010–2019. Figure 3.1 shows the annual number of disturbances during the period 2010–2019 in the Nordic and Baltic countries. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

The number of grid disturbances is not directly comparable between countries because of the vast differences between external conditions in the transmission networks of the European countries included in this report.

Table 3.1: The number of disturbances and disturbances causing ENS in 2019.

	Disturbances		Disturbances causing ENS	
Country	Number 2019	Average 2010–2019	Number 2019	Average 2010–2019
Estonia	138	199.4	18	30.5
Latvia[1]	131	138.9	10	16.6
Lithuania[1]	147	156.9	19	19.1
Baltic total	416	495.2	47	66.2
Denmark	54	55.9	4	7.0
Finland	395	440.1	37	74.0
Iceland	51	37.1	18	18.3
Norway	273	297.3	73	86.1
Sweden	412	475.8	154	149.7
Nordic total	1185	1306.2	286	335.1
Nordic & Baltic total	1601	1801.4	333	401.3

[1] The average values of Latvia and Lithuania use the period 2012–2019.

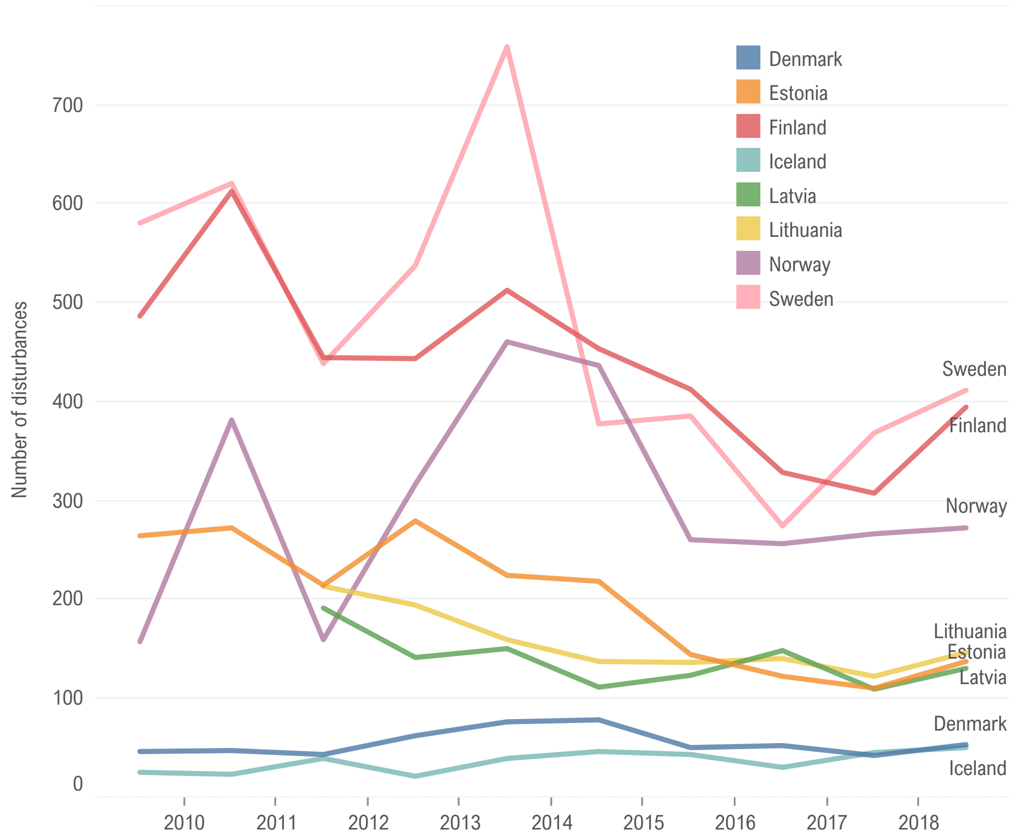

Figure 3.1: The annual number of grid disturbances in each Nordic country and Estonia during 2010–2019 and during 2012–2019 in Latvia and Lithuania.

3.2 Disturbances distributed per month

Table 3.2 presents the percentage distribution of grid disturbances per month for each Nordic country and Estonia during 2010–2019 and during 2012–2019 for Latvia and Lithuania. Table 3.3 presents the 10-year percentage distribution of grid disturbances per month for each Nordic country and Estonia during 2010–2019 and during 2012–2019 for Latvia and Lithuania. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

Table 3.2: Percentage distribution of grid disturbances per month in 2019 in each Nordic and Baltic country. The number of disturbances is usually largest during the summer period for all countries except Iceland. The number is high due to the high number of lightning strikes during summer.

Regions	Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Baltic	Estonia	1%	1%	7%	7%	13%	14%	18%	12%	7%	11%	2%	6%
	Latvia	3%	2%	5%	2%	8%	15%	9%	24%	10%	11%	2%	7%
	Lithuania	3%	2%	9%	7%	10%	12%	14%	28%	5%	4%	3%	2%
	Total	3%	1%	7%	6%	11%	14%	14%	21%	7%	9%	3%	5%
Nordic	Denmark	7%	7%	4%	15%	2%	13%	9%	15%	4%	9%	6%	9%
	Finland	13%	6%	2%	5%	10%	13%	13%	14%	7%	6%	2%	8%
	Iceland	6%	8%	10%	6%	2%	10%	6%	6%	0%	4%	4%	39%
	Norway	11%	10%	7%	5%	4%	16%	12%	7%	5%	6%	11%	7%
	Sweden	3%	5%	3%	5%	9%	18%	13%	22%	9%	4%	2%	5%
	Total	9%	7%	4%	6%	8%	15%	12%	15%	7%	5%	4%	8%
Grand Total		7%	5%	5%	6%	9%	15%	13%	17%	7%	6%	4%	7%

Table 3.3: Average 10-year percentage distribution of grid disturbances per month during 2010–2019 in each Nordic country and Estonia and during 2012–2019 in Latvia and Lithuania. The number of disturbances is usually largest during the summer period for all countries except Iceland. The number is high due to the high number of lightning strikes during summer.

Regions	Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Baltic	Estonia	3%	2%	4%	5%	9%	12%	22%	22%	6%	6%	3%	6%
	Latvia	4%	3%	5%	5%	10%	12%	14%	22%	7%	7%	5%	7%
	Lithuania	2%	2%	5%	6%	9%	10%	19%	29%	5%	6%	3%	3%
	Total	3%	2%	5%	5%	9%	11%	19%	24%	6%	6%	3%	5%
Nordic	Denmark	7%	6%	6%	6%	9%	10%	8%	9%	9%	9%	9%	11%
	Finland	7%	4%	3%	6%	10%	14%	23%	13%	7%	4%	4%	5%
	Iceland	10%	11%	13%	6%	5%	5%	6%	4%	5%	7%	9%	18%
	Norway	13%	8%	8%	4%	5%	8%	12%	9%	6%	6%	8%	14%
	Sweden	5%	4%	4%	5%	8%	13%	23%	17%	7%	5%	5%	6%
	Total	8%	5%	5%	5%	8%	12%	19%	13%	7%	5%	5%	8%
Grand Total		7%	4%	5%	5%	8%	12%	19%	16%	6%	5%	5%	7%

3.3 Disturbances distributed per cause

This chapter presents disturbances per cause, with the cause of a disturbance defined as the cause of the disturbance's primary cause. The used cause categories are lightning, other environmental causes, external influences, operation and maintenance, technical equipment, other and unknown. The fault categories used are explained in more detail in Section 1.4.1. Many disturbances caused by unknown reasons probably have their real cause in the categories other environmental cause and lightning.

Table 3.4 presents disturbances per cause in terms of the primary fault distributed for the year 2019 for each Nordic and Baltic country. Table 3.5 shows the respective average values for the period 2010–2019 in the Nordic countries and Estonia and during 2012–2019 in Latvia and Lithuania.

Table 3.6 presents disturbances that caused ENS distributed by its cause for the year 2019. Table 3.7 shows the respective average values during 2010–2019 in the Nordic countries and Estonia and during 2012–2019 in Latvia and Lithuania.

All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

Table 3.4: Percentage distribution of grid disturbances per cause in 2019 in each Nordic and Baltic country.

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	16%	1%	19%	12%	25%	16%	12%
	Latvia	11%	24%	22%	7%	2%	11%	23%
	Lithuania	13%	1%	35%	8%	8%	16%	19%
	Total	13%	8%	26%	9%	12%	14%	18%
Nordic	Denmark	13%	4%	31%	9%	22%	13%	7%
	Finland	25%	44%	1%	7%	3%	5%	15%
	Iceland	0%	35%	0%	12%	0%	43%	10%
	Norway	22%	24%	3%	15%	22%	7%	7%
	Sweden	45%	2%	2%	5%	14%	6%	26%
	Total	30%	22%	3%	9%	12%	8%	17%
Grand Total		25%	19%	9%	9%	12%	9%	17%

Table 3.5: Average distribution of grid disturbances per cause during 2010–2019 in each Nordic country and Estonia and during 2012–2019 in Latvia and Lithuania.

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	11%	22%	7%	15%	19%	10%	15%
	Latvia	10%	22%	24%	7%	9%	10%	19%
	Lithuania	9%	4%	24%	7%	7%	13%	35%
	Total	10%	17%	16%	11%	13%	11%	22%
Nordic	Denmark	10%	9%	21%	18%	18%	11%	13%
	Finland	23%	30%	1%	6%	4%	16%	20%
	Iceland	3%	38%	2%	12%	15%	27%	2%
	Norway	20%	33%	2%	13%	18%	10%	4%
	Sweden	36%	4%	2%	8%	14%	11%	25%
	Total	26%	21%	2%	9%	12%	13%	18%
Grand Total		22%	20%	6%	9%	12%	12%	19%

Table 3.6: Percentage distribution of grid disturbances causing ENS per cause in 2019 in each Nordic and Baltic country.

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	0%	0%	0%	17%	44%	17%	22%
	Latvia	0%	30%	50%	10%	0%	10%	0%
	Lithuania	0%	0%	47%	21%	21%	5%	5%
	Total	0%	6%	30%	17%	26%	11%	11%
Nordic	Denmark	0%	25%	0%	50%	25%	0%	0%
	Finland	3%	5%	3%	5%	8%	5%	70%
	Iceland	0%	61%	0%	6%	0%	28%	6%
	Norway	27%	11%	1%	21%	29%	7%	4%
	Sweden	49%	1%	3%	8%	14%	5%	21%
	Total	34%	8%	2%	11%	16%	7%	22%
Grand Total		29%	8%	6%	12%	17%	7%	20%

Table 3.7: Average distribution of grid disturbances causing ENS per cause during 2010–2019 in each Nordic country and Estonia and during 2012–2019 in Latvia and Lithuania.

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	4%	8%	11%	26%	21%	20%	9%
	Latvia	1%	30%	27%	19%	15%	5%	3%
	Lithuania	5%	9%	37%	22%	14%	4%	9%
	Total	3%	13%	21%	23%	18%	13%	8%
Nordic	Denmark	4%	7%	1%	43%	24%	13%	7%
	Finland	17%	17%	3%	9%	8%	13%	34%
	Iceland	3%	45%	2%	13%	15%	20%	1%
	Norway	23%	28%	2%	17%	15%	12%	3%
	Sweden	39%	2%	2%	10%	12%	7%	27%
	Total	28%	15%	2%	12%	12%	10%	21%
Grand Total		24%	14%	5%	14%	13%	11%	19%

4 Energy not supplied (ENS)

This chapter presents energy not supplied (ENS) caused by faults and disturbances in the Nordic and Baltic power systems. The presentation includes the amount of ENS in 2019 and the average during 2010–2019. Furthermore, ENS has been compared with consumption and line length in Section 4.2, distributed per month in Section 4.3, distributed per cause in Section 4.4, divided according to voltage level in Section 4.5 and finally examined at component level in Section 4.6.

Energy not supplied is defined as:

> "The estimated energy, which would have been supplied to end-users if no interruption and no transmission restrictions had occurred" [2].

One should remember that the amount of ENS is always an estimation and its accuracy, as well as calculation method, varies between companies, as described in Appendix A.

4.1 Overview of energy not supplied (ENS)

Table 4.1 shows the amount of energy not supplied in 2019 and the annual average for the period 2010–2019. It should be noted that this table includes ENS caused by faults outside the statistical area of each country. Therefore, the amount of ENS in Table 4.1 may be higher than elsewhere in this report.

Table 4.1: Energy not supplied (ENS) due to faults in each Nordic and Baltic country in 2019 and the annual average for the period 2010–2019. The ENS also includes ENS caused by faults outside the TSO's statistical area.

	ENS (MWh)	
Country	2019	2010–2019
Estonia	266.2	192.8
Latvia[2]	21.0	78.7
Lithuania[2]	52.4	41.5
Baltic total	339.6	313.0
Denmark	13.8	27.1
Finland	351.7	358.3
Iceland	1749.4	1044.1
Norway	854.0	3463.4
Sweden[1]	1649.5	1649.7
Nordic total	4618.4	6542.5
Nordic & Baltic total	4958.0	6855.6

[1] One Swedish regional grid delivered incomplete data in 2012. The details of the origin of the fault were not reported, thus leaving 750 MWh of ENS missing from that year.
[2] The average values of Latvia and Lithuania use the period 2012–2019.

4.2 Energy not supplied and total consumption

Table 4.2 shows the energy not supplied normalised by the electricity consumption in each Nordic and Baltic country. Ppm (parts per million) represents ENS as a proportional value of the consumed energy, which is calculated as ENS/consumption × 10^6. The value of ENS is the total amount of ENS caused by all faults, that is, faults inside the statistical area and faults from outside the own grid that affect the own network.

Figure 4.1 presents the 5-year moving average of ENS scaled by consumption since 1995 in the Nordic countries, since 2007 in Estonia and since 2012 in Latvia and Lithuania. The total line length is the sum of the lengths of overhead lines and cables. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

One should note that there is a considerable annual variance due to occasional events, such as storms. These events have a significant effect on each country's yearly statistics.

Table 4.2: Consumption and energy not supplied (ENS) due to faults in each Nordic and Baltic country in 2019 and the average for the period 2010–2019. The ENS value is the total amount of ENS caused by all faults, that is, faults inside the statistical area and faults from outside the own grid that impact the other statistical area.

Country	Consumption (TWh) 2019	ENS (MWh) 2019	ENS / consumption (ppm) 2019	ENS / consumption (ppm) 2010–2019
Estonia	8.6	266.2	30.8	24.3
Latvia[1]	7.3	21.0	2.9	11.1
Lithuania[1]	12.2	52.4	4.3	3.9
Baltic total	28.1	339.6	12.1	12.2
Denmark	34.3	13.8	0.4	0.8
Finland	86.2	351.7	4.1	4.2
Iceland	18.4	1749.4	95.3	58.4
Norway	133.5	854.0	6.4	26.7
Sweden	138.3	1649.5	11.9	11.8
Nordic total	410.6	4618.4	11.2	16.1
Nordic & Baltic total	438.7	4958.0	11.3	15.9

[1] The average values of Latvia and Lithuania use the period 2012–2019.

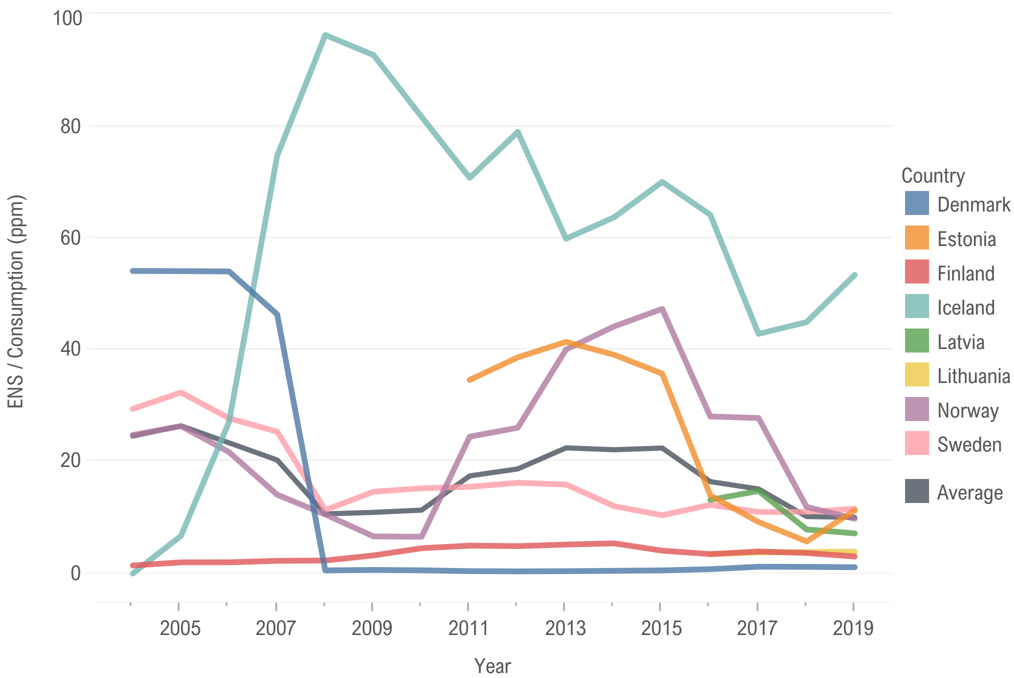

Figure 4.1: 5-year moving average amount of ENS divided per consumption (ppm) since 2000 in the Nordic countries, since 2007 in Estonia and since 2012 in Latvia and Lithuania. Denmark's low values are a result of various elements such as having a meshed grid and compared to the other Nordic countries, a mild climate. Iceland's high values are a result of power intensive industries that cause substantial amounts of ENS even during short interruptions. The unusually high ENS divided by consumption during 2011–2015 in Norway was caused by extreme weather conditions in December 2011 (aka the storm named Dagmar).

4.3 Energy not supplied distributed per month

This section presents energy not supplied (ENS) distributed per month. Table 4.3 shows the distribution of energy not supplied per month for the year 2019 in each Nordic and Baltic country. Table 4.4 presents the respective average values during 2010–2019 in the Nordic countries and Estonia during 2012–2019 in Latvia and Lithuania. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

Table 4.3: Percentage distribution of ENS per month in 2019 in each Nordic and Baltic country.

Regions	Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Baltic	Estonia	18%	0%	0%	1%	13%	1%	0%	0%	22%	44%	1%	0%
	Latvia	2%	0%	3%	0%	3%	0%	1%	12%	9%	65%	0%	5%
	Lithuania	0%	2%	29%	12%	2%	2%	47%	0%	0%	0%	3%	2%
	Total	14%	0%	5%	3%	11%	1%	7%	1%	18%	38%	1%	1%
Nordic	Denmark	32%	0%	3%	31%	0%	19%	15%	0%	0%	0%	0%	0%
	Finland	5%	4%	0%	2%	2%	0%	0%	78%	1%	0%	0%	7%
	Iceland	1%	0%	3%	1%	0%	1%	0%	0%	0%	0%	0%	95%
	Norway	30%	5%	1%	3%	1%	12%	32%	1%	3%	4%	3%	4%
	Sweden	14%	14%	6%	1%	1%	4%	17%	26%	7%	6%	2%	2%
	Total	11%	6%	4%	2%	1%	4%	12%	15%	3%	3%	1%	38%
Grand Total		11%	6%	4%	2%	1%	4%	12%	14%	4%	5%	1%	35%

Table 4.4: Average percentage distribution of ENS per month during 2010–2019 in each Nordic country and Estonia and during 2012–2019 in Latvia and Lithuania.

Regions	Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Baltic	Estonia	4%	3%	2%	2%	5%	3%	6%	6%	5%	14%	11%	38%
	Latvia	2%	0%	2%	0%	4%	5%	10%	11%	9%	45%	5%	6%
	Lithuania	3%	8%	6%	6%	6%	26%	20%	7%	2%	11%	1%	3%
	Total	4%	3%	3%	2%	5%	6%	9%	7%	5%	21%	9%	27%
Nordic	Denmark	8%	16%	7%	2%	9%	5%	1%	4%	0%	34%	4%	10%
	Finland	7%	5%	9%	4%	2%	6%	13%	14%	15%	3%	8%	14%
	Iceland	37%	9%	5%	2%	3%	5%	3%	0%	4%	4%	4%	23%
	Norway	8%	8%	30%	3%	1%	5%	2%	2%	1%	1%	4%	35%
	Sweden	5%	6%	3%	5%	5%	12%	25%	13%	5%	10%	5%	7%
	Total	12%	7%	18%	3%	2%	7%	9%	5%	3%	4%	4%	25%
Grand Total		11%	7%	17%	3%	3%	7%	9%	5%	3%	5%	5%	25%

4.4 Energy not supplied distributed per cause

This section presents energy not supplied (ENS) due to faults, distributed per cause. The cause of a fault is determined as the cause with the most significant impact. The used cause categories are lightning, other environmental causes, external influences, operation and maintenance, technical equipment, other and unknown. The fault categories used are explained in more detail in Section 1.4.1.

Table 4.5 presents the distribution of energy not supplied per cause in 2019 in each Nordic and Baltic country. Table 4.6 shows the respective average values during 2010–2019 in the Nordic countries and Estonia and during 2012–2019 in Latvia and Lithuania. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

Table 4.5: Percentage distribution of ENS per cause in 2019 in each Nordic and Baltic country.

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	0%	0%	0%	3%	77%	19%	1%
	Latvia	0%	74%	3%	20%	3%	0%	0%
	Lithuania	0%	0%	34%	50%	13%	3%	1%
	Total	0%	5%	5%	11%	63%	15%	1%
Nordic	Denmark	0%	32%	0%	22%	31%	15%	0%
	Finland	0%	3%	0%	0%	84%	1%	12%
	Iceland	0%	95%	0%	1%	0%	5%	0%
	Norway	2%	11%	0%	5%	68%	10%	3%
	Sweden	30%	0%	0%	4%	22%	22%	21%
	Total	11%	38%	0%	3%	27%	12%	9%
Grand Total		10%	36%	1%	3%	29%	12%	9%

Table 4.6: Average percentage distribution of ENS per cause during 2010–2019 in each Nordic country and Estonia and during 2012–2019 in Latvia and Lithuania. The reason of Sweden having more disturbances and ENS due to unknown causes is that if the cause of a disturbance is not 100 % certain, which might be the case with lightning, it is reported as an unknown cause as explained in Appendix B.

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	3%	4%	23%	8%	36%	24%	2%
	Latvia	0%	51%	15%	23%	10%	0%	1%
	Lithuania	1%	14%	34%	14%	31%	4%	2%
	Total	2%	15%	23%	12%	30%	17%	2%
Nordic	Denmark	1%	9%	0%	49%	31%	7%	4%
	Finland	8%	26%	4%	9%	26%	19%	8%
	Iceland	2%	52%	1%	14%	13%	18%	0%
	Norway	3%	65%	0%	5%	13%	12%	2%
	Sweden	29%	1%	7%	9%	27%	8%	19%
	Total	10%	44%	2%	8%	17%	12%	6%
Grand Total		10%	43%	3%	8%	18%	12%	6%

4.5 Energy not supplied per voltage level

This section presents energy not supplied (ENS) per voltage level, that is, 100–150 kV, 220–330 kV and 380–420 kV. Table 4.7 shows the amount of energy not supplied and its distribution per voltage level. The voltage level of a disturbance is determined by the voltage level of its primary fault.

Table 4.8 presents the energy not supplied per the different voltage levels in 2019, and Table 4.9 summarises the energy not supplied per the different voltage levels during 2010–2019. The values only account for faults and the caused ENS inside each country's statistical area. Therefore, the presented values may differ to the values in Table 4.7.

Table 4.7: Energy not supplied (ENS) in each Nordic and Baltic country in 2019 and the average during 2010–2019. Furthermore, the percentage distribution of ENS per voltage level for 2010–2019 is shown. The voltage level is determined by the voltage level of each individual fault. It should be noted, that the ENS in this table includes ENS caused by faults outside the TSO's statistical area. This table is therefore not directly comparable to Table 4.9. The percentages may slightly deviate from 100 % due to rounding.

	ENS (MWh)		ENS per voltage level for 2010–2019			
Country	2019	2010–2019	100–150 kV	220–330 kV	380–420 kV	Other[1]
Estonia	266.2	192.8	76 %	2 %	0 %	21 %
Latvia[2]	21.0	78.7	97 %	3 %	0 %	0 %
Lithuania[2]	52.4	41.5	96 %	3 %	0 %	2 %
Baltic total	339.6	313.0	84 %	3 %	0 %	14 %
Denmark	13.8	27.1	94 %	0 %	0 %	6 %
Finland	351.7	358.3	86 %	1 %	3 %	10 %
Iceland	1749.4	1044.1	33 %	50 %	0 %	16 %
Norway	854.0	3463.4	33 %	8 %	59 %	0 %
Sweden	1649.5	1649.7	81 %	9 %	3 %	7 %
Nordic total	4618.4	6542.5	48 %	15 %	32 %	5 %
Nordic & Baltic total	4958.0	6855.6	50 %	14 %	30 %	6 %

[1] The category *Other* contains energy not supplied from, for example, system faults, auxiliary equipment, lower voltage level networks and connections to foreign countries. Additionally, it is not included in the total ENS. Instead, it shows the degree of effect from the outside grid to the 100–420 kV grid. This category is described further in the guidelines [2].
[2] The average values of Latvia and Lithuania use the period 2012–2019.

Table 4.8: Percentage distribution of energy not supplied (ENS) per voltage level in 2019 in each Nordic and Baltic country. It should be noted, that the ENS in this figure only includes ENS caused by faults inside the TSO's statistical area.

		100–150 kV	220–330 kV	380–420 kV
Baltic	Estonia	83%	17%	0%
	Latvia	100%	0%	0%
	Lithuania	100%	0%	0%
	Total	88%	12%	0%
Nordic	Denmark	100%	0%	0%
	Finland	100%	0%	0%
	Iceland	88%	12%	0%
	Norway	60%	38%	1%
	Sweden	99%	1%	0%
	Total	87%	12%	0%
Grand Total		87%	12%	0%

Table 4.9: Average percentage distribution of Energy not supplied per voltage level during 2010–2019 in the Nordic countries and Estonia and during 2012–2019 in Latvia and Lithuania. It should be noted, that the ENS in this figure only includes ENS caused by faults inside the TSO's statistical area.

		100–150 kV	220–330 kV	380–420 kV
Baltic	Estonia	97%	3%	0%
	Latvia	97%	3%	0%
	Lithuania	98%	2%	0%
	Total	97%	3%	0%
Nordic	Denmark	100%	0%	0%
	Finland	95%	1%	3%
	Iceland	40%	60%	0%
	Norway	33%	8%	59%
	Sweden	87%	10%	3%
	Total	51%	16%	33%
Grand Total		53%	15%	32%

4.6 Energy not supplied distributed per component

Table 4.10 presents the distribution of energy not supplied per installation. The sum of the ENS divided per installation may not be exactly 100 % because all the ENS is not always connected with a cause. Table 4.11 shows the distribution of energy not supplied per component in each Nordic and Baltic country in 2019, and Table 4.12 shows the respective average values for the period 2010–2019 for the Nordic countries and Estonia and the period 2012–2019 for Latvia and Lithuania.

Table 4.10: Energy not supplied (ENS) due to faults in each Nordic and Baltic country in 2019 and the 10-year average for 2010–2019 in the Nordic countries and Estonia and for 2012–2019 in Latvia and Lithuania. Additionally, ENS divided by installation type is presented for the Nordic countries and Estonia for the period 2010–2019 and for the period 2012–2019 for Latvia and Lithuania. It should be noted, that the sum of the ENS divided per installation may not be exactly 100 % because all the ENS is not always connected with a cause. Furthermore, some countries register the total amount of energy not supplied in a disturbance in terms of the primary fault. Therefore, the data is not necessarily comparable. The ENS in this table includes ENS caused by faults outside the TSOs statistical area.

	ENS (MWh)		ENS per installation for 2010–2019			
Country	2019	2010–2019	Lines	Substation components	Compensation devices	Other
Estonia	266.2	192.8	52 %	24 %	2 %	22 %
Latvia[1]	21.0	78.7	65 %	35 %	0 %	0 %
Lithuania[1]	52.4	41.5	49 %	50 %	0 %	2 %
Baltic total	339.6	313.0	55 %	30 %	1 %	14 %
Denmark	13.8	27.1	3 %	91 %	1 %	6 %
Finland	351.7	358.3	63 %	26 %	1 %	10 %
Iceland	1749.4	1044.1	16 %	66 %	0 %	18 %
Norway	854.0	3463.4	71 %	29 %	0 %	0 %
Sweden	1649.5	1649.7	47 %	45 %	1 %	7 %
Nordic total	4618.4	6542.5	55 %	39 %	0 %	5 %
Nordic & Baltic total	4958.0	6855.6	55 %	39 %	0 %	6 %

[1] The average values of Latvia and Lithuania use the period 2012–2019.

Table 4.11: Percentage distribution of energy not supplied per HVAC component in 2019 each Nordic and Baltic country. It should be noted that some countries register the total amount of energy not supplied in a disturbance in terms of the primary fault. Therefore, the data is not necessarily comparable.

		Baltic				Nordic						
		Estonia	Latvia	Lithuania	Region total	Denmark	Finland	Iceland	Norway	Sweden	Region total	Nordic & Baltic
Lines	Cables	0%	0%	0%	0%	0%	0%	0%	20%	0%	4%	3%
	Overhead lines	3%	77%	34%	12%	0%	92%	17%	16%	29%	27%	26%
	Total	3%	77%	34%	12%	0%	92%	17%	36%	29%	31%	29%
Substation components	Busbars	0%	12%	4%	1%	0%	0%	0%	0%	0%	0%	0%
	Circuit breakers	0%	2%	6%	1%	0%	0%	0%	2%	4%	2%	2%
	Common ancillary equipment	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Control equipment	36%	8%	2%	29%	68%	0%	2%	37%	12%	12%	13%
	Disconnectors and earth connectors	0%	0%	50%	8%	0%	0%	0%	1%	4%	2%	2%
	Instrumental transformers	0%	0%	2%	0%	0%	2%	0%	3%	4%	2%	2%
	Other high voltage appliances	40%	0%	0%	32%	0%	0%	15%	1%	0%	6%	8%
	Power transformers	2%	0%	0%	1%	32%	4%	64%	0%	11%	28%	27%
	Surge arresters and spark gaps	0%	0%	0%	0%	0%	0%	0%	11%	11%	6%	6%
	Total	78%	23%	64%	73%	100%	7%	80%	56%	46%	58%	59%
Compensation devices	Reactors	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Series capacitors	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Shunt capacitors	0%	0%	0%	0%	0%	0%	0%	0%	5%	2%	2%
	SVC and statcom	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Synchronous compensators	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Total	0%	1%	0%	0%	0%	0%	0%	0%	5%	2%	2%
Other	Adjoining grid	19%	0%	2%	15%	0%	1%	3%	0%	20%	8%	9%
	System faults	0%	0%	0%	0%	0%	0%	0%	8%	0%	1%	1%
	Total	19%	0%	2%	15%	0%	1%	3%	8%	20%	10%	10%

Table 4.12: Average percentage distribution of energy not supplied per HVAC component in during 2010–2019 in the Nordic countries and Estonia and during 2012–2019 in Latvia and Lithuania. It should be noted that some countries register the total amount of energy not supplied in a disturbance in terms of the primary fault. Therefore, the data is not necessarily comparable.

		Baltic				Nordic						
		Estonia	Latvia	Lithuania	Region total	Denmark	Finland	Iceland	Norway	Sweden	Region total	Nordic & Baltic
Lines	Cables	1%	0%	1%	1%	0%	0%	0%	3%	5%	3%	3%
	Overhead lines	52%	65%	48%	54%	2%	62%	16%	68%	42%	53%	53%
	Total	52%	65%	49%	55%	3%	63%	16%	71%	47%	55%	55%
Substation components	Busbars	0%	3%	1%	1%	50%	1%	0%	3%	3%	3%	3%
	Circuit breakers	1%	0%	8%	2%	6%	3%	29%	1%	4%	7%	6%
	Common ancillary equipment	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%
	Control equipment	6%	22%	27%	12%	10%	9%	16%	8%	6%	9%	9%
	Disconnectors and earth connectors	0%	4%	9%	2%	8%	1%	0%	3%	2%	2%	2%
	Instrumental transformers	1%	0%	1%	1%	7%	4%	0%	2%	7%	3%	3%
	Other high voltage appliances	11%	0%	0%	7%	0%	2%	7%	6%	13%	8%	8%
	Power transformers	4%	4%	1%	4%	11%	4%	14%	3%	8%	6%	6%
	Surge arresters and spark gaps	0%	0%	2%	0%	0%	2%	0%	3%	2%	2%	2%
	Total	24%	35%	50%	29%	91%	26%	66%	29%	45%	39%	39%
Compensation devices	Reactors	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%
	Series capacitors	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%
	Shunt capacitors	2%	0%	0%	1%	0%	0%	0%	0%	1%	0%	0%
	SVC and statcom	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Synchronous compensators	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Total	2%	0%	0%	1%	1%	1%	0%	0%	1%	0%	0%
Other	Adjoining grid	22%	0%	2%	15%	6%	10%	9%	0%	7%	4%	4%
	System faults	0%	0%	0%	0%	0%	0%	9%	0%	0%	2%	2%
	Total	22%	0%	2%	15%	6%	10%	18%	0%	7%	5%	6%

5 Secondary faults and disturbances with multiple faults

This chapter presents statistics about secondary faults, that is, faults that originate from primary faults. A term that closely relates to secondary faults is *disturbances with multiple faults*. A disturbance with multiple faults occurs when a disturbance has one or more secondary faults. The probability of a disturbance having more than one fault is significantly smaller than a disturbance having only one fault. However, these disturbances have a chance to cause more ENS partly because the main grids are designed to withstand a single fault without degrading the performance. It may, therefore, be valuable to register and analyse secondary faults separately.

Section 5.1 gives an overview of secondary faults, and Section 5.2 presents secondary faults and their produced ENS distributed per cause.

It should be noted that this chapter is still new to this report and therefore, under development. Thus, only data for 2019 is presented as there is not enough historical data available. Average values and trend curves are shown when a sufficient amount of data about secondary faults has been collected.

5.1 Overview of secondary faults

Table 5.1 presents the number of faults, faults causing energy not supplied (ENS), total ENS (MWh) and the number of secondary faults and amount of ENS (MWh) caused by them in 2019 in each Nordic and Baltic country.

As can be seen, the number of secondary faults and faults with ENS is significantly smaller than the total number of faults. Slightly more than 7 % of all faults were secondary faults, and they caused approximately 2 % of the entire Nordic and Baltic ENS in 2019.

Table 5.1: The number of faults, faults causing ENS, total ENS (MWh) and the number of secondary faults and amount of ENS (MWh) caused by them in 2019 in each Nordic and Baltic country.

	Faults in 2019			Secondary faults in 2019	
Country	Number	causing ENS	ENS (MWh)	Number	ENS (MWh)
Estonia	148	17	266.2	7	0.1
Latvia	154	11	21.0	23	2.2
Lithuania	165	19	52.4	18	0.5
Baltic total	467	47	339.6	48	2.8
Denmark	60	6	13.8	6	4.7
Finland	401	37	351.7	6	12.6
Iceland	77	18	1749.4	26	0.2
Norway	299	74	854.0	26	71.3
Sweden	426	154	1649.5	14	8.4
Nordic total	1263	289	4618.4	78	97.3
Nordic & Baltic total	1730	336	4958.0	126	100.0

5.2 Secondary faults and their ENS distributed per cause

Table 5.2 presents the percentage distribution of secondary faults per cause in 2019. Table 5.3 shows the percentage distribution of energy not supplied (ENS), caused by secondary faults, per cause in 2019.

As can be seen, the dominating causes of secondary faults were other causes and technical equipment in the Nordic countries. In contrast, technical equipment and operation and maintenance were the dominating causes in the Baltic countries. The dominating cause of ENS due to secondary faults were other causes in the Nordic countries and operation and maintenance in the Baltic countries. However, ENS due to secondary faults was minimal compared to the total amount of ENS in the Nordic and Baltic countries, as mentioned in Section 5.1.

Table 5.2: Percentage distribution of secondary faults per cause in the Nordic and Baltic countries in 2019.

		Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	0%	29%	0%	0%	43%	29%	0%
	Latvia	0%	0%	0%	26%	74%	0%	0%
	Lithuania	6%	0%	0%	39%	11%	17%	28%
	Total	2%	4%	0%	27%	46%	10%	10%
Nordic	Denmark	0%	0%	0%	67%	0%	33%	0%
	Finland	0%	17%	17%	33%	17%	17%	0%
	Iceland	0%	31%	0%	0%	0%	69%	0%
	Norway	19%	4%	0%	23%	42%	4%	8%
	Sweden	14%	0%	0%	14%	29%	14%	29%
	Total	9%	13%	1%	18%	21%	31%	8%
Grand Total		6%	10%	1%	21%	30%	23%	9%

Table 5.3: Percentage distribution of ENS caused by secondary faults per cause in the Nordic and Baltic countries in 2019.

		Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	0%	0%	0%	0%	100%	0%	0%
	Latvia	0%	0%	0%	75%	25%	0%	0%
	Lithuania	0%	0%	0%	0%	0%	100%	0%
	Total	0%	0%	0%	58%	23%	19%	0%
Nordic	Denmark	0%	0%	0%	55%	0%	45%	0%
	Finland	0%	44%	0%	0%	54%	2%	0%
	Iceland	0%	0%	0%	0%	0%	100%	0%
	Norway	0%	0%	0%	4%	0%	96%	0%
	Sweden	0%	0%	0%	0%	2%	0%	98%
	Total	0%	6%	0%	6%	7%	73%	8%
Grand Total		0%	5%	0%	7%	8%	71%	8%

6 Faults in power system components

This chapter presents an overview of all faults in the Nordic and Baltic transmission network. Furthermore, faults for each type of power system component are shown. It should be noted that the grid in each country contains a different set of elements. Values have been normalised by the length of overhead line or cable, or the number of installed components in each country to allow comparable results. Readers who need more detailed data should use public statistics published by the national regulators.

A component fault is defined as:

> "The inability of a component to perform its required function" [2].

A fault in a component implies that the component is not able to perform its function correctly. The erroneous function may be caused by several reasons, for example, by manufacturing defects or insufficient maintenance. In this report, the fault cause is defined as the cause that has the most significant impact on the fault. The cause categories used in these statistics are presented in Section 1.4.1. Furthermore, only faults resulting in a trip are reported.

Section 6.1 gives an overview of all faults, and Section 6.2 shows faults per cause category. Section 6.3 to Section 6.8 present a detailed view, along with fault trends, of cables, overhead lines, circuit breakers, control equipment, and instrumental and power transformers. Lastly, short statistics of compensation devices are shown in Section 6.9.

It should be noted that all countries do not own every single kind of power system component. Therefore, some figures may be missing values. If this is the case, it is informed about in the caption of the respective figure.

6.1 Overview of faults

This chapter presents an overview of faults in the Nordic and Baltic countries. The summary compares faults separately with ENS and disturbances. Finally, the percentage distribution of faults per component type is shown.

One should take note of both the causes and consequences of the fault when analysing the fault frequencies of different devices. Furthermore, it should be noted that all countries do not have every type of equipment in their network. For example, static VAR compensators (SVCs) or STATCOM installations do not exist in every country. The distribution of the number of components can also vary from country to country, so one should be careful when comparing countries. Note that statistics also include faults that begin outside the voltage range of the statistics (typically from networks with voltages lower than 100 kV) but still influence the statistical area.

Table 6.1 presents the number of faults and the amount of ENS caused by them in 2019 and the average during 2010–2019 for each Nordic and Baltic country. Table 6.2 shows the number of faults and disturbances and the 10-year average faults to disturbance ratio.

Table 6.3 shows the distribution of faults per component in each Nordic and Baltic country in 2019, and Table 6.4 shows the respective average values for the period 2010–2019 for the Nordic countries and Estonia and the period 2012–2019 for Latvia and Lithuania. The component groups used in these statistics are further described in the guidelines [2].

Table 6.1: Number of faults and amount of energy not supplied (ENS) in 2019 and their averages during 2010–2019.

	Number of faults		ENS (MWh)	
Country	2019	2010–2019	2019	2010–2019
Estonia	148	204.5	266.2	192.8
Latvia[1]	154	153.0	21.0	78.7
Lithuania[1]	165	169.2	52.4	41.5
Baltic total	467	526.8	339.6	313.0
Denmark	60	63.2	13.8	27.1
Finland	401	460.3	351.7	358.3
Iceland	77	53.5	1749.4	1044.1
Norway	299	341.5	854.0	3463.4
Sweden	426	490.7	1649.5	1649.7
Nordic total	1263	1409.2	4618.4	6542.5
Nordic & Baltic total	1730	1936.0	4958.0	6855.6

[1] The average values of Latvia and Lithuania use the period 2012–2019.

Table 6.2: Number of faults and grid disturbances in 2019 and the average during 2010–2019. Additionally, the average ratio between faults and disturbances is shown.

	Number of faults		Disturbances		Ratio
Country	2019	2010–2019	2019	2010–2019	2010–2019
Estonia	148	204.5	138	199.4	1.0
Latvia[1]	154	153.0	131	138.9	1.1
Lithuania[1]	165	169.2	147	156.9	1.1
Baltic total	467	526.8	416	495.2	1.1
Denmark	60	63.2	54	55.9	1.1
Finland	401	460.3	395	440.1	1.0
Iceland	77	53.5	51	37.1	1.4
Norway	299	341.5	273	297.3	1.1
Sweden	426	490.7	412	475.8	1.0
Nordic total	1263	1409.2	1185	1306.2	1.1
Nordic & Baltic total	1730	1936.0	1601	1801.4	1.1

[1] The average values of Latvia and Lithuania use the period 2012–2019.

Table 6.3: Percentage distribution of faults per HVAC component in 2019 each Nordic and Baltic country.

		Baltic				Nordic						
		Estonia	Latvia	Lithuania	Region total	Denmark	Finland	Iceland	Norway	Sweden	Region total	Nordic & Baltic
Lines	Cables	0%	0%	0%	0%	7%	0%	0%	2%	0%	1%	1%
	Overhead lines	48%	66%	62%	59%	47%	83%	19%	49%	59%	61%	61%
	Total	48%	66%	62%	59%	53%	83%	19%	52%	59%	62%	61%
Substation components	Busbars	3%	1%	2%	2%	3%	0%	0%	1%	1%	1%	1%
	Circuit breakers	3%	3%	4%	3%	2%	0%	5%	3%	1%	2%	2%
	Common ancillary equipment	0%	0%	0%	0%	0%	0%	0%	3%	0%	1%	1%
	Control equipment	15%	16%	13%	14%	17%	8%	10%	21%	15%	14%	14%
	Disconnectors and earth connectors	6%	0%	1%	2%	0%	0%	0%	1%	1%	1%	1%
	Instrumental transformers	3%	2%	1%	2%	0%	1%	0%	2%	2%	1%	1%
	Other high voltage appliances	1%	0%	1%	1%	0%	0%	13%	1%	2%	2%	2%
	Power transformers	6%	1%	1%	2%	8%	3%	8%	1%	2%	3%	3%
	Surge arresters and spark gaps	0%	1%	2%	1%	0%	0%	0%	1%	0%	1%	1%
	Total	37%	23%	25%	28%	30%	13%	36%	34%	25%	24%	25%
Compensation devices	Reactors	3%	0%	0%	1%	2%	0%	0%	1%	2%	1%	1%
	Series capacitors	0%	0%	0%	0%	0%	1%	0%	0%	2%	1%	1%
	Shunt capacitors	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%
	SVC and statcom	0%	1%	1%	1%	2%	0%	0%	9%	0%	2%	2%
	Synchronous compensators	0%	0%	0%	0%	8%	0%	0%	1%	0%	1%	0%
	Total	3%	1%	1%	1%	12%	1%	0%	13%	5%	6%	5%
Other	Adjoining grid	12%	10%	12%	11%	5%	2%	30%	0%	11%	6%	8%
	System faults	0%	0%	0%	0%	0%	0%	14%	1%	0%	1%	1%
	Total	12%	10%	12%	11%	5%	2%	44%	1%	11%	8%	9%

Table 6.4: Average percentage distribution of faults per HVAC component in during 2010–2019 in the Nordic countries and Estonia and during 2012–2019 in Latvia and Lithuania.

		Baltic				Nordic						
		Estonia	Latvia	Lithuania	Region total	Denmark	Finland	Iceland	Norway	Sweden	Region total	Nordic & Baltic
Lines	Cables	0%	0%	0%	0%	5%	0%	0%	1%	1%	1%	1%
	Overhead lines	62%	66%	68%	65%	45%	81%	34%	49%	62%	63%	64%
	Total	63%	66%	68%	65%	50%	81%	34%	50%	63%	64%	64%
Substation components	Busbars	2%	1%	1%	1%	4%	0%	0%	1%	1%	1%	1%
	Circuit breakers	3%	2%	5%	3%	4%	1%	5%	5%	2%	2%	3%
	Common ancillary equipment	0%	0%	1%	0%	0%	0%	0%	1%	0%	1%	1%
	Control equipment	4%	14%	10%	9%	14%	7%	15%	18%	9%	11%	11%
	Disconnectors and earth connectors	3%	1%	1%	2%	2%	0%	0%	1%	1%	1%	1%
	Instrumental transformers	1%	1%	1%	1%	3%	1%	0%	2%	1%	1%	1%
	Other high voltage appliances	7%	0%	0%	3%	3%	1%	4%	10%	3%	4%	4%
	Power transformers	5%	4%	1%	4%	7%	2%	4%	2%	5%	4%	4%
	Surge arresters and spark gaps	0%	0%	1%	0%	0%	0%	0%	1%	0%	0%	0%
	Total	26%	24%	21%	24%	37%	13%	30%	42%	23%	25%	25%
Compensation devices	Reactors	1%	1%	0%	0%	2%	0%	0%	0%	2%	1%	1%
	Series capacitors	0%	0%	0%	0%	0%	1%	0%	0%	3%	2%	1%
	Shunt capacitors	0%	0%	0%	0%	0%	0%	1%	1%	0%	1%	0%
	SVC and statcom	0%	0%	0%	0%	1%	0%	0%	5%	2%	2%	1%
	Synchronous compensators	0%	0%	0%	0%	2%	0%	0%	1%	0%	0%	0%
	Total	1%	1%	0%	1%	4%	2%	2%	7%	7%	5%	4%
Other	Adjoining grid	10%	10%	11%	10%	8%	4%	16%	0%	6%	4%	6%
	System faults	0%	0%	0%	0%	0%	0%	18%	0%	0%	1%	1%
	Total	10%	10%	11%	10%	8%	4%	34%	0%	6%	5%	6%

6.2 Faults distributed per cause

This chapter presents faults according to cause, with the cause of a fault defined as the cause with the most impact. The used cause categories are lightning, other environmental causes, external influences, operation and maintenance, technical equipment, other and unknown. The fault categories are explained in more detail in Section 1.4.1.

Furthermore, each country in these statistics has its own detailed way of gathering data per fault cause, as explained in Appendix B. The guidelines [2] describe the relations between the exact fault causes and the mutual cause allocation.

Table 6.5 presents faults per cause the year 2019 for each Nordic and Baltic country. Table 6.6 shows the respective average values for the period 2010–2019 in the Nordic countries and Estonia and during 2012–2019 in Latvia and Lithuania. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

Many faults caused by unknown reasons probably have their real cause in the categories other environmental cause and lightning.

Table 6.5: Percentage distribution of faults per cause in 2019 in each Nordic and Baltic country.

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	16%	1%	18%	11%	28%	15%	11%
	Latvia	9%	20%	19%	10%	13%	10%	19%
	Lithuania	12%	1%	32%	12%	8%	16%	20%
	Total	12%	7%	23%	11%	16%	13%	17%
Nordic	Denmark	12%	3%	28%	15%	20%	15%	7%
	Finland	25%	43%	1%	8%	3%	5%	15%
	Iceland	0%	34%	0%	5%	0%	61%	0%
	Norway	22%	22%	3%	15%	24%	7%	7%
	Sweden	41%	2%	2%	5%	14%	14%	23%
	Total	27%	22%	3%	9%	12%	13%	15%
Grand Total		23%	18%	8%	9%	13%	13%	15%

Table 6.6: Average distribution of faults per cause during 2010–2019 in each Nordic country and Estonia and during 2012–2019 in Latvia and Lithuania.

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	11%	22%	6%	16%	20%	10%	15%
	Latvia	9%	20%	21%	10%	12%	10%	18%
	Lithuania	9%	3%	22%	9%	8%	13%	35%
	Total	10%	16%	15%	12%	14%	11%	22%
Nordic	Denmark	10%	9%	19%	20%	17%	12%	12%
	Finland	22%	29%	1%	7%	5%	16%	20%
	Iceland	2%	32%	1%	9%	16%	41%	0%
	Norway	19%	31%	2%	15%	19%	11%	4%
	Sweden	35%	4%	2%	8%	15%	13%	24%
	Total	24%	20%	2%	10%	13%	14%	17%
Grand Total		21%	19%	5%	10%	13%	13%	18%

Table 6.7 presents faults that caused ENS distributed by its cause for the year 2019. Table 6.8 shows the respective average values during 2010–2019 in the Nordic countries and Estonia and during 2012–2019 in Latvia and Lithuania. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

Table 6.7: Percentage distribution of faults causing ENS per cause in 2019 in each Nordic and Baltic country.

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	0%	0%	0%	18%	41%	18%	24%
	Latvia	0%	27%	18%	36%	18%	0%	0%
	Lithuania	0%	0%	47%	16%	21%	11%	5%
	Total	0%	6%	23%	21%	28%	11%	11%
Nordic	Denmark	0%	17%	0%	50%	17%	17%	0%
	Finland	0%	5%	0%	5%	11%	8%	70%
	Iceland	0%	61%	0%	6%	0%	33%	0%
	Norway	27%	11%	1%	20%	28%	8%	4%
	Sweden	44%	1%	3%	8%	12%	17%	17%
	Total	30%	8%	2%	11%	15%	15%	19%
Grand Total		26%	8%	5%	13%	17%	14%	18%

Table 6.8: Average distribution of faults causing ENS per cause during 2010–2019 in each Nordic country and Estonia and during 2012–2019 in Latvia and Lithuania.

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	4%	8%	11%	27%	21%	20%	9%
	Latvia	1%	23%	15%	30%	26%	2%	4%
	Lithuania	3%	9%	36%	23%	16%	6%	8%
	Total	3%	12%	18%	27%	21%	12%	8%
Nordic	Denmark	4%	6%	1%	41%	24%	17%	6%
	Finland	15%	15%	3%	12%	8%	14%	33%
	Iceland	3%	43%	1%	12%	16%	25%	0%
	Norway	22%	26%	2%	19%	15%	13%	3%
	Sweden	36%	2%	2%	10%	14%	10%	26%
	Total	25%	13%	2%	13%	13%	13%	20%
Grand Total		22%	13%	4%	15%	14%	12%	18%

6.3 Faults in cables

This section presents cable faults in 2019 and for 2010–2019 at the voltage levels 100–150 kV, 220–330 kV and 380–420 kV.

Table 6.9 presents the installed length of cables in kilometres, the number of faults, and the 10-year average number of faults in 2019. Table 6.10 presents additionally the number of faults per 100 km of cable in 2019 and the average for 2010–2019.

Table 6.11 shows the percentage distribution of faults per cause in 2019. Table 6.12 presents the respective average values for the period 2010–2019 in the Nordic countries and Estonia and for 2012–2019 in Latvia and Lithuania. The used causes are lightning, other environmental causes, external influences, operation and maintenance, technical equipment, other and unknown. The fault categories used are explained in more detail in Section 1.4.1. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

Figure 6.1, Figure 6.2 and Figure 6.3 present the 5-year moving average of 100–150 kV, 220–330 kV and 380–420 kV cable faults per 100 km in each Nordic and Baltic country. Trend curves are used to filter out the annual deviation and make it easier to follow on trends and decide on whether actions have to be taken in the future.

Table 6.9: Length of line and number of cable faults, separated by voltage level, in each Nordic and Baltic country in 2019. The average number of faults is presented for 2010–2019 for the Nordic countries and Estonia and for 2012–2019 for Latvia and Lithuania.

		100–150 kV			220–330 kV			380–420 kV		
Regions	Country	km	Number of faults	10-year average # faults	km	Number of faults	10-year average # faults	km	Number of faults	10-year average # faults
Baltic	Estonia	78	0	0.2	0	0	0.0	0	0	0.0
	Latvia	82	0	0.1	17	0	0.1	0	0	0.0
	Lithuania	93	0	0.1	0	0	0.0	0	0	0.0
	Total	254	0	0.4	18	0	0.1	0	0	0.0
Nordic	Denmark	1 663	3	1.5	331	1	0.3	204	0	0.1
	Finland	10	1	0.6	0	0	0.0	0	0	0.0
	Iceland	90	0	0.1	0	0	0.0	0	0	0.0
	Norway	422	3	1.8	98	0	0.0	25	4	0.7
	Sweden	481	0	1.1	139	0	1.4	14	0	0.4
	Total	2 666	7	5.1	568	1	1.7	243	4	1.2
Grand Total		2 920	7	5.4	585	1	1.8	243	4	1.2

Table 6.10: Number of cable faults, length of cable (in km) and the number of faults per 100 km cable in 2019, grouped by voltage level. Furthermore, the 10-year average number of faults per 100 km of cable is presented for 2010–2019 for the Nordic countries and Estonia and for 2012–2019 for Latvia and Lithuania.

		100–150 kV				220–330 kV				380–420 kV			
Regions	Country	Number of faults	km	# faults / 100 km	10-yr avg # faults / 100 km	Number of faults	km	# faults / 100 km	10-yr avg # faults / 100 km	Number of faults	km	# faults / 100 km	10-yr avg # faults / 100 km
Baltic	Estonia	0	78	0.00	0.69	0	0	0.00	0.00	0	0	0.00	0.00
	Latvia	0	82	0.00	0.17	0	17	0.00	0.89	0	0	0.00	0.00
	Lithuania	0	93	0.00	0.32	0	0	0.00	0.00	0	0	0.00	0.00
	Total	0	254	0.00	0.39	0	18	0.00	0.88	0	0	0.00	0.00
Nordic	Denmark	3	1 663	0.18	0.26	1	331	0.30	0.29	0	204	0.00	0.08
	Finland	1	10	10.00	0.57	0	0	0.00	0.00	0	0	0.00	0.00
	Iceland	0	90	0.00	0.09	0	0	0.00	0.00	0	0	0.00	0.00
	Norway	3	422	0.71	1.24	0	98	0.00	0.00	4	25	16.00	2.80
	Sweden	0	481	0.00	0.56	0	139	0.00	1.26	0	14	0.00	3.75
	Total	7	2 666	0.26	0.47	1	568	0.18	0.57	4	243	1.64	0.75
Grand Total		7	2 920	0.24	0.46	1	585	0.17	0.58	4	243	1.64	0.75

Table 6.11: Percentage distribution of cable faults per cause in the Nordic and Baltic countries in 2019. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	0%	0%	0%	0%	0%	0%	0%
	Latvia	0%	0%	0%	0%	0%	0%	0%
	Lithuania	0%	0%	0%	0%	0%	0%	0%
	Total	0%	0%	0%	0%	0%	0%	0%
Nordic	Denmark	0%	0%	0%	0%	100%	0%	0%
	Finland	0%	0%	100%	0%	0%	0%	0%
	Iceland	0%	0%	0%	0%	0%	0%	0%
	Norway	0%	43%	0%	0%	43%	0%	14%
	Sweden	0%	0%	0%	0%	0%	0%	0%
	Total	0%	25%	8%	0%	58%	0%	8%
Grand Total		0%	25%	8%	0%	58%	0%	8%

Table 6.12: Average distribution of cable faults per cause for 2010–2019 in each Nordic country and Estonia and for 2012–2019 in Latvia and Lithuania. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	0%	0%	50%	0%	50%	0%	0%
	Latvia	0%	0%	0%	0%	100%	0%	0%
	Lithuania	0%	0%	50%	0%	50%	0%	0%
	Total	0%	0%	38%	0%	63%	0%	0%
Nordic	Denmark	0%	0%	12%	12%	74%	0%	3%
	Finland	0%	0%	8%	25%	25%	25%	17%
	Iceland	0%	0%	0%	100%	0%	0%	0%
	Norway	2%	23%	5%	7%	35%	19%	9%
	Sweden	5%	0%	2%	5%	66%	2%	20%
	Total	2%	7%	6%	10%	54%	9%	12%
Grand Total		2%	7%	8%	9%	54%	8%	11%

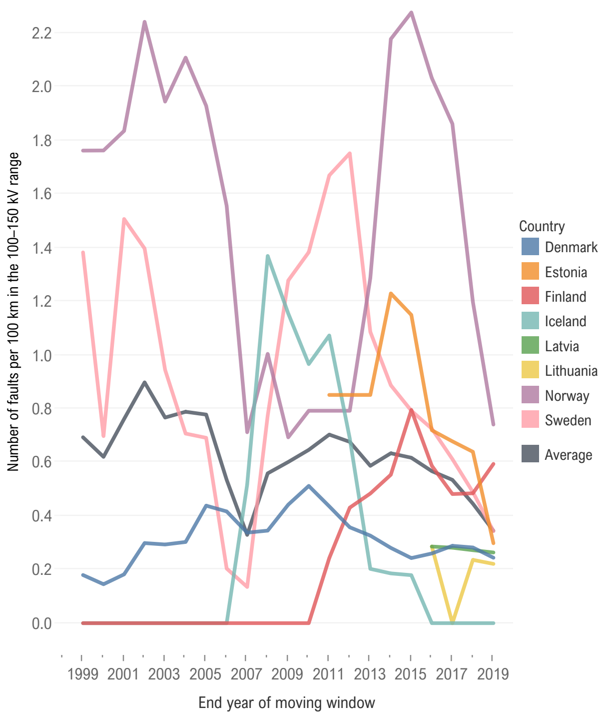

Figure 6.1: 5-year moving average of faults per 100 km 100–150 kV cable in each Nordic and Baltic country.

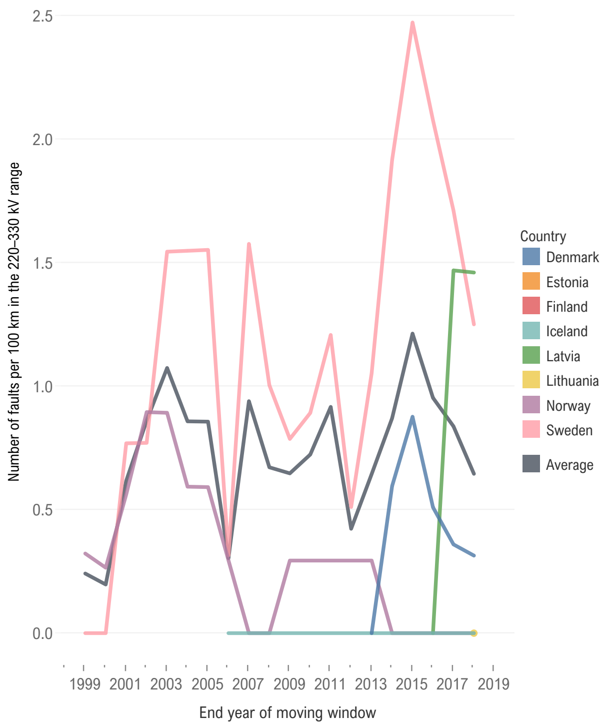

Figure 6.2: 5-year moving average of faults per 100 km 220–330 kV cable in each Nordic and Baltic country. Estonia, Finland and Lithuania do not own 220–330 kV cables.

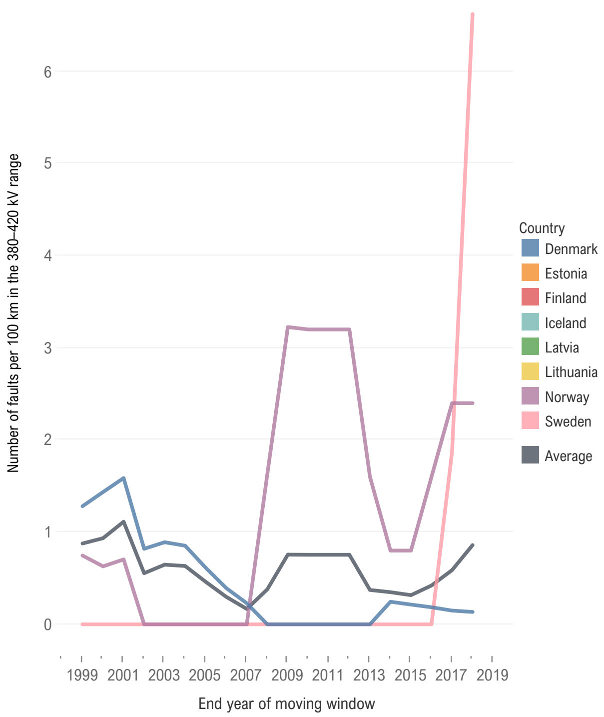

Figure 6.3: 5-year moving average of faults per 100 km 380–420 kV cable in each Nordic and Baltic country. Estonia has data since 2007, and Latvia and Lithuania have data since 2012. Estonia, Finland, Iceland, Latvia and Lithuania do not own 380–420 kV cables, as can be seen in Table 6.9.

6.4 Faults on overhead lines

This section presents overhead line faults in 2019 and for 2010–2019 at the voltage levels 100–150 kV, 220–330 kV and 380–420 kV.

Table 6.13 presents the installed length of overhead lines in kilometres, the number of faults, the 10-year average number of faults for 2010–2019 and the number of permanent faults in 2019. Table 6.14 presents additionally the number of faults per 100 km of overhead line in 2019 and the average for 2010–2019.

Table 6.15 shows the percentage distribution of faults per cause in 2019. Table 6.16 presents the respective average values for the period 2010–2019 in the Nordic countries and Estonia and for 2012–2019 in Latvia and Lithuania. The used causes are lightning, other environmental causes, external influences, operation and maintenance, technical equipment, other and unknown. The fault categories used are explained in more detail in Section 1.4.1. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

Figure 6.4, Figure 6.5 and Figure 6.6 present the 5-year moving average of 100–150 kV, 220–330 kV and 380–420 kV overhead line faults per 100 km in each Nordic and Baltic country. Trend curves are used to filter out the annual deviation and make it easier to follow on trends and decide on whether actions have to be taken in the future.

Figure 6.7 presents the 5-year moving average of the permanent faults to number of faults ratio, for all voltage level ranges, in each Nordic and Baltic country.

Table 6.13: Length of line (in km) and the number of faults separated by voltage level. The average number of faults is presented for 2010–2019 for the Nordic countries and Estonia and for 2012–2019 for Latvia and Lithuania. Furthermore, the number of permanent faults in 2019 is shown.

		100–150 kV				220–330 kV				380–420 kV			
Regions	Country	km	Number of faults	10-year average # faults	Number of permanent faults	km	Number of faults	10-year average # faults	Number of permanent faults	km	Number of faults	10-year average # faults	Number of permanent faults
Baltic	Estonia	3 415	62	56.8	10	1 878	9	14.3	2	0	0	0.0	0
	Latvia	3 790	89	45.4	30	1 535	13	10.4	5	0	0	0.0	0
	Lithuania	4 984	88	50.8	18	1 864	13	12.1	8	103	1	0.6	1
	Total	12 189	239	152.9	58	5 277	35	36.8	15	103	1	0.6	1
Nordic	Denmark	2 802	27	12.5	1	55	0	0.4	0	1 317	1	2.9	0
	Finland	17 216	312	172.8	28	1 290	11	15.0	1	5 463	10	10.2	1
	Iceland	1 247	11	7.5	2	919	4	3.4	2	0	0	0.0	0
	Norway	10 736	79	46.5	14	5 355	22	38.1	0	3 266	46	35.8	3
	Sweden	14 876	184	116.6	15	3 634	37	31.7	2	10 938	31	37.4	0
	Total	46 877	613	355.8	60	11 253	74	88.6	5	20 984	88	86.3	4
Grand Total		59 066	852	508.7	118	16 530	109	125.4	20	21 087	89	86.9	5

Table 6.14: Number of overhead line faults, length of overhead line (in km) and the number of faults per 100 km overhead line in 2019, grouped by voltage level. Furthermore, the 10-year average number of faults per 100 km of overhead line is presented for 2010–2019 for the Nordic countries and Estonia and for 2012–2019 for Latvia and Lithuania.

		100–150 kV				220–330 kV				380–420 kV			
Regions	Country	Number of faults	km	# faults / 100 km	10-yr avg # faults / 100 km	Number of faults	km	# faults / 100 km	10-yr avg # faults / 100 km	Number of faults	km	# faults / 100 km	10-yr avg # faults / 100 km
Baltic	Estonia	62	3 415	1.82	3.31	9	1 878	0.48	0.80	0	0	0.00	0.00
	Latvia	89	3 790	2.35	2.38	13	1 535	0.85	0.75	0	0	0.00	0.00
	Lithuania	88	4 984	1.77	2.04	13	1 864	0.70	0.69	1	103	0.97	1.22
	Total	239	12 189	1.96	2.56	35	5 277	0.66	0.75	1	103	0.97	1.22
Nordic	Denmark	27	2 802	0.96	0.77	0	55	0.00	0.55	1	1 317	0.08	0.23
	Finland	312	17 216	1.81	2.06	11	1 290	0.85	0.69	10	5 463	0.18	0.19
	Iceland	11	1 247	0.88	1.20	4	919	0.44	0.39	0	0	0.00	0.00
	Norway	79	10 736	0.74	0.87	22	5 355	0.41	0.70	46	3 266	1.41	1.21
	Sweden	184	14 876	1.24	1.54	37	3 634	1.02	0.79	31	10 938	0.28	0.35
	Total	613	46 877	1.31	1.51	74	11 253	0.66	0.70	88	20 984	0.42	0.43
Grand Total		852	59 066	1.44	1.70	109	16 530	0.66	0.72	89	21 087	0.42	0.43

Table 6.15: Percentage distribution of overhead line faults per cause in the Nordic and Baltic countries in 2019. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	32%	3%	35%	10%	6%	0%	14%
	Latvia	13%	30%	26%	1%	0%	0%	29%
	Lithuania	19%	1%	51%	2%	1%	1%	25%
	Total	20%	12%	38%	4%	2%	0%	24%
Nordic	Denmark	25%	4%	61%	0%	0%	0%	11%
	Finland	28%	51%	0%	1%	0%	3%	17%
	Iceland	0%	93%	0%	0%	0%	7%	0%
	Norway	44%	42%	3%	1%	7%	1%	2%
	Sweden	65%	1%	2%	2%	1%	0%	28%
	Total	42%	32%	4%	1%	2%	2%	17%
Grand Total		37%	27%	13%	2%	2%	1%	19%

Table 6.16: Average distribution of overhead line faults per cause for 2010–2019 in each Nordic country and Estonia and for 2012–2019 in Latvia and Lithuania. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	17%	33%	9%	14%	6%	0%	21%
	Latvia	14%	29%	29%	1%	1%	0%	25%
	Lithuania	13%	5%	31%	2%	3%	1%	46%
	Total	15%	23%	21%	7%	4%	0%	29%
Nordic	Denmark	20%	14%	38%	4%	0%	1%	22%
	Finland	26%	36%	1%	2%	1%	13%	22%
	Iceland	5%	81%	3%	1%	5%	4%	1%
	Norway	35%	56%	1%	1%	2%	3%	2%
	Sweden	52%	5%	2%	4%	3%	2%	32%
	Total	36%	29%	2%	2%	2%	7%	21%
Grand Total		31%	28%	7%	3%	2%	5%	23%

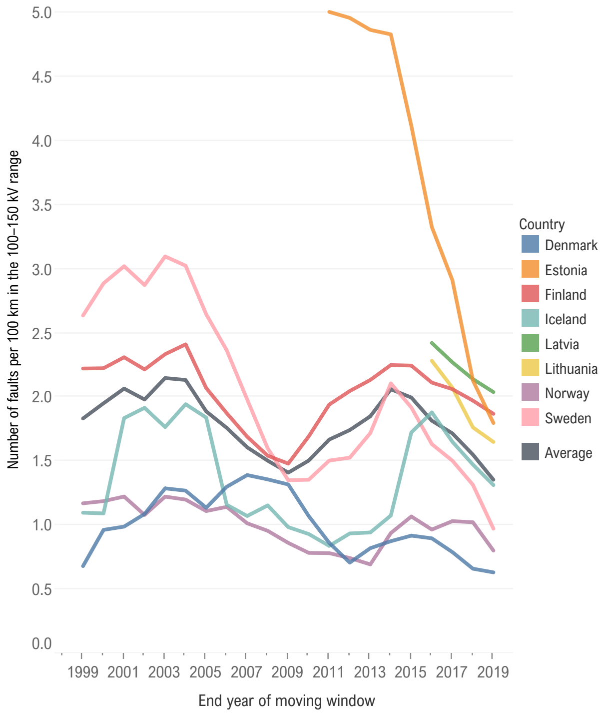

Figure 6.4: 5-year moving average of 100–150 kV overhead line faults per 100 km in each Nordic and Baltic country. Estonia has data since 2007, and Latvia and Lithuania have data since 2012.

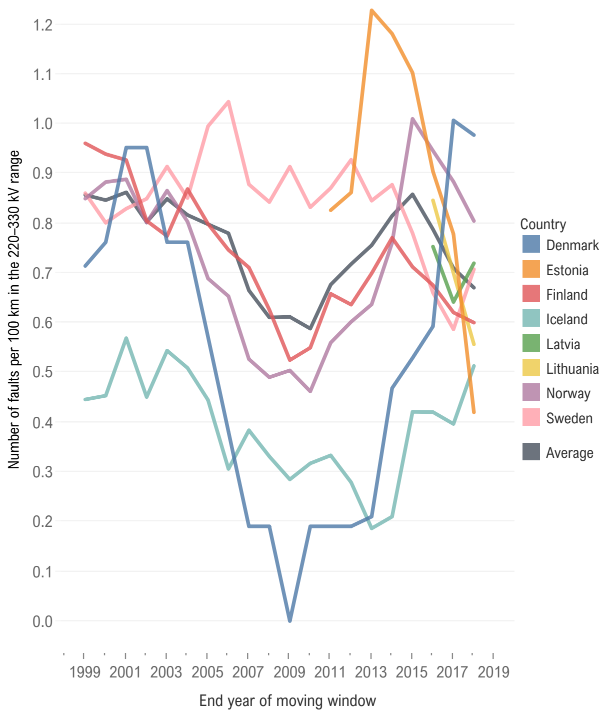

Figure 6.5: 5-year moving average of 220–330 kV overhead line faults per 100 km in each Nordic and Baltic country. Estonia has data since 2007, and Latvia and Lithuania have data since 2012.

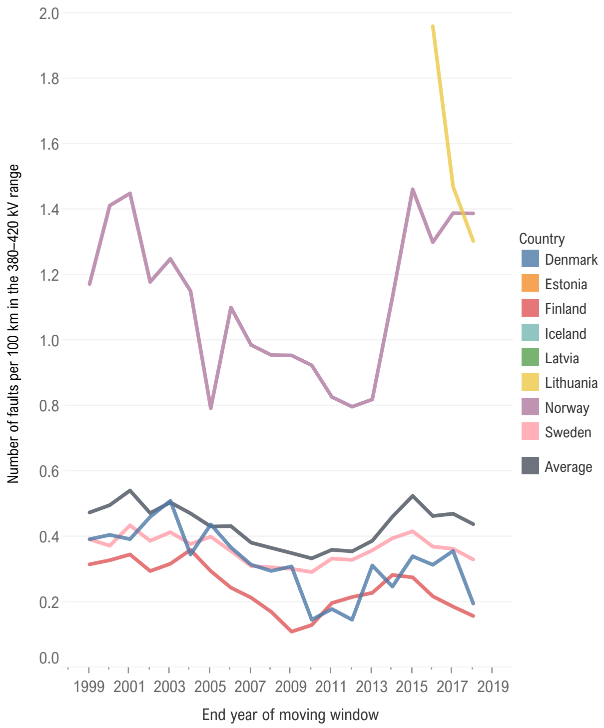

Figure 6.6: 5-year moving average of 380–420 kV overhead line faults per 100 km in each Nordic and Baltic country. Estonia has data since 2007, and Latvia and Lithuania have data since 2012. 380–420 kV trend lines are missing for Estonia, Iceland and Latvia because they do not own overhead lines in the 380–420 kV voltage range, as can be seen in Table 6.13.

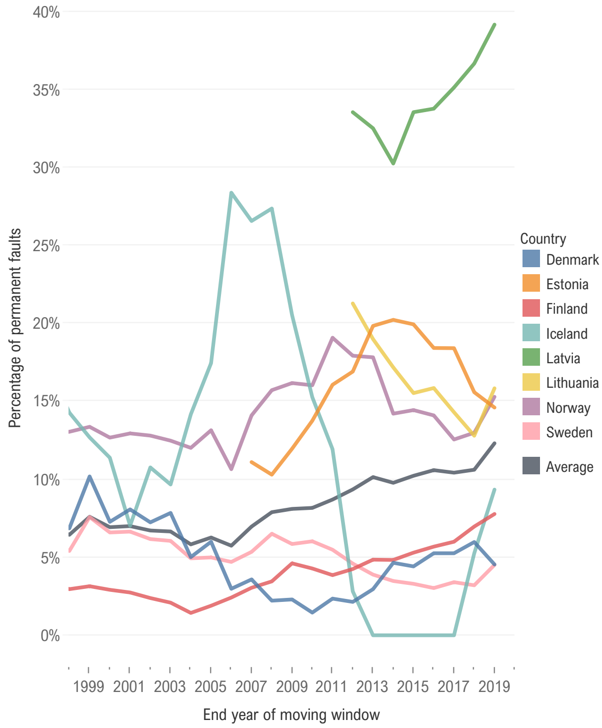

Figure 6.7: 5-year moving average of the permanent faults to the number of faults ratio in each Nordic and Baltic country. Estonia has data since 2007, and Latvia and Lithuania have data since 2012.

6.5 Faults in circuit breakers

This section presents circuit breaker faults in 2019 and during 2010–2019 at the voltage levels 100–150 kV, 220–330 kV and 380–420 kV. Circuit breakers are used to protect the grid when it is experiencing faults. When functioning correctly, they isolate a faulty part of the network from the healthy, thus preventing an outage from spreading further into the grid. Therefore, it is essential to keep the circuit breakers in good working condition.

Table 6.17 presents the number of installed circuit breakers, the number of faults, and the average number of faults for 2010–2019. Table 6.18 presents additionally the number of faults per 100 devices in 2019 and the average for 2010–2019.

Table 6.19 presents the percentage distribution of faults per cause in 2019. Table 6.20 presents the respective average values for the period 2010–2019 in the Nordic countries and Estonia and during 2012–2019 in Latvia and Lithuania. The used causes are lightning, other environmental causes, external influences, operation and maintenance, technical equipment, other and unknown. The fault categories used are explained in more detail in Section 1.4.1. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

Figure 6.8, Figure 6.9 and Figure 6.10 present the 5-year moving average of 100–150 kV, 220–330 kV and 380–420 kV circuit breaker faults per 100 devices in each Nordic and Baltic country. Trend curves are used to filter out the annual deviation and make it easier to follow on trends and decide on whether actions have to be taken in the future.

Table 6.17: Number of circuit breakers and faults, separated by voltage level, in each Nordic and Baltic country in 2019. The average number of faults is presented for 2010–2019 for the Nordic countries and Estonia and for 2012–2019 for Latvia and Lithuania.

		100–150 kV			220–330 kV			380–420 kV		
Regions	Country	Number of devices	Number of faults	10-year average # faults	Number of devices	Number of faults	10-year average # faults	Number of devices	Number of faults	10-year average # faults
Baltic	Estonia	662	3	4.8	131	2	2.2	0	0	0.0
	Latvia	631	4	2.6	106	0	0.1	0	0	0.0
	Lithuania	862	5	7.1	113	1	0.8	5	1	0.1
	Total	2 155	12	14.6	350	3	3.1	5	1	0.1
Nordic	Denmark	951	0	2.2	38	0	0.0	224	1	0.5
	Finland	2 655	1	4.2	74	0	0.0	365	0	0.6
	Iceland	125	4	2.2	86	0	0.7	0	0	0.0
	Norway	2 491	6	9.1	730	3	4.3	453	1	2.1
	Sweden	2 659	3	3.9	341	0	1.1	640	3	3.5
	Total	8 881	14	21.6	1 269	3	6.1	1 682	5	6.7
Grand Total		11 036	26	36.2	1 619	6	9.2	1 687	6	6.8

Table 6.18: Number of circuit breakers, faults, and the number of faults per 100 devices in 2019, grouped by voltage level. Furthermore, the 10-year average number of faults per 100 devices is presented for 2010–2019 for the Nordic countries and Estonia and for 2012–2019 for Latvia and Lithuania.

		100–150 kV				220–330 kV				380–420 kV			
Regions	Country	Number of faults	Number of devices	# faults / 100 devs	10-yr avg # faults / 100 devs	Number of faults	Number of devices	# faults / 100 devs	10-yr avg # faults / 100 devs	Number of faults	Number of devices	# faults / 100 devs	10-yr avg # faults / 100 devs
Baltic	Estonia	3	662	0.45	0.83	2	131	1.53	1.83	0	0	0.00	0.00
	Latvia	4	631	0.63	0.43	0	106	0.00	0.12	0	0	0.00	0.00
	Lithuania	5	862	0.58	0.83	1	113	0.88	0.72	1	5	20.00	5.00
	Total	12	2 155	0.56	0.72	3	350	0.86	1.01	1	5	20.00	5.00
Nordic	Denmark	0	951	0.00	0.27	0	38	0.00	0.00	1	224	0.45	0.27
	Finland	1	2 655	0.04	0.18	0	74	0.00	0.00	0	365	0.00	0.21
	Iceland	4	125	3.20	1.36	0	86	0.00	0.87	0	0	0.00	0.00
	Norway	6	2 491	0.24	0.40	3	730	0.41	0.59	1	453	0.22	0.61
	Sweden	3	2 659	0.11	0.18	0	341	0.00	0.33	3	640	0.47	0.61
	Total	14	8 881	0.16	0.28	3	1 269	0.24	0.49	5	1 682	0.30	0.48
Grand Total		26	11 036	0.24	0.36	6	1 619	0.37	0.59	6	1 687	0.36	0.49

Table 6.19: Percentage distribution of circuit breakers faults per cause in the Nordic and Baltic countries in 2019. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	0%	0%	0%	20%	80%	0%	0%
	Latvia	0%	0%	0%	25%	75%	0%	0%
	Lithuania	0%	0%	0%	43%	57%	0%	0%
	Total	0%	0%	0%	31%	69%	0%	0%
Nordic	Denmark	0%	0%	0%	0%	100%	0%	0%
	Finland	0%	0%	100%	0%	0%	0%	0%
	Iceland	0%	50%	0%	0%	0%	50%	0%
	Norway	0%	0%	0%	30%	60%	10%	0%
	Sweden	33%	0%	0%	0%	67%	0%	0%
	Total	9%	9%	5%	14%	50%	14%	0%
Grand Total		5%	5%	3%	21%	58%	8%	0%

Table 6.20: Average distribution of faults in circuit breakers per cause during 2010–2019 in each Nordic country and Estonia and during 2012–2019 in Latvia and Lithuania.

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	1%	0%	0%	10%	80%	0%	9%
	Latvia	0%	0%	5%	9%	86%	0%	0%
	Lithuania	2%	0%	3%	31%	42%	5%	17%
	Total	1%	0%	2%	19%	65%	2%	11%
Nordic	Denmark	0%	0%	0%	74%	22%	0%	4%
	Finland	6%	2%	4%	21%	31%	10%	25%
	Iceland	0%	14%	3%	14%	48%	21%	0%
	Norway	3%	2%	2%	43%	30%	7%	14%
	Sweden	14%	1%	1%	12%	64%	0%	8%
	Total	6%	3%	2%	32%	39%	6%	12%
Grand Total		4%	2%	2%	28%	47%	5%	12%

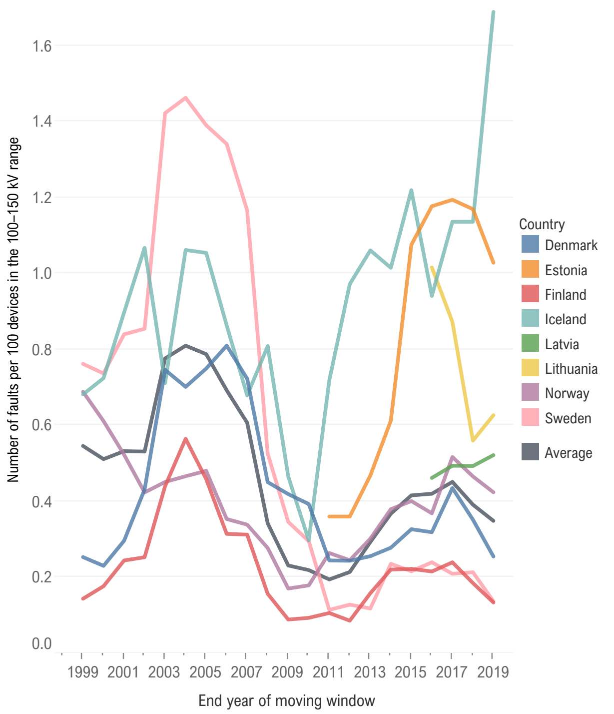

Figure 6.8: 5-year moving average of faults per 100 devices of 100–150 kV circuit breakers in each Nordic and Baltic country. Estonia has data since 2007, and Latvia and Lithuania have data since 2012.

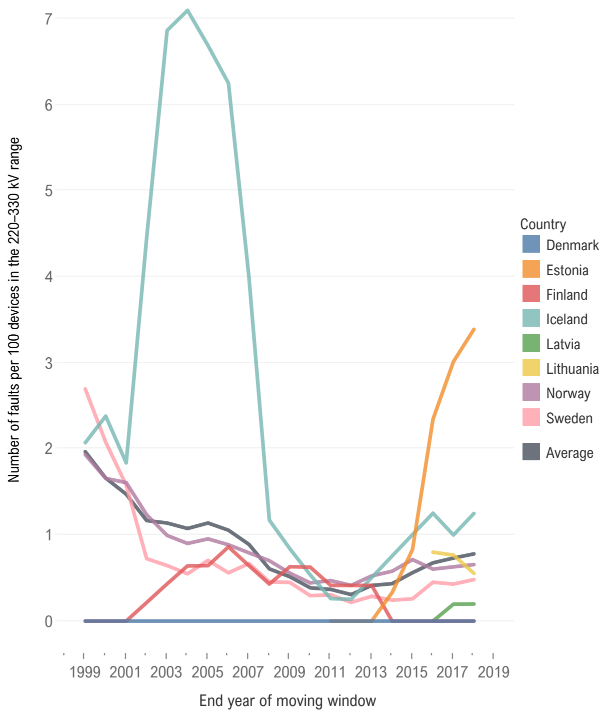

Figure 6.9: 5-year moving average of faults per 100 devices of 220–330 kV circuit breakers in each Nordic and Baltic country. Estonia has data since 2007, and Latvia and Lithuania have data since 2012.

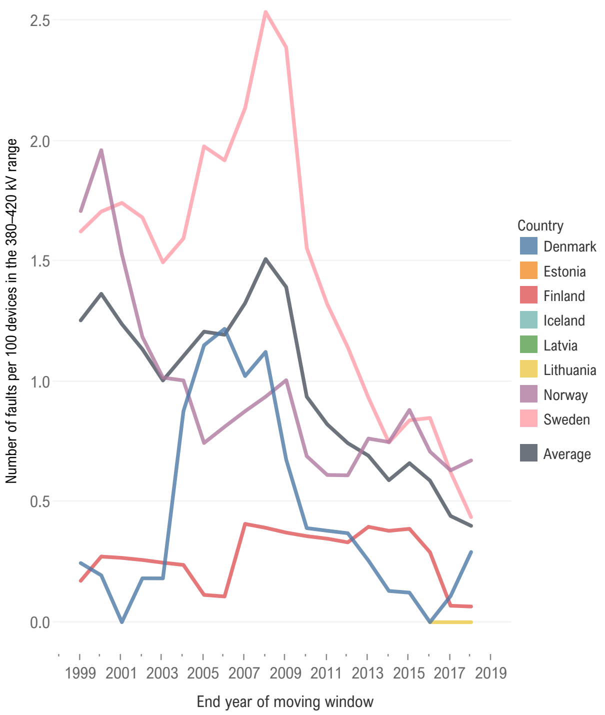

Figure 6.10: 5-year moving average of faults per 100 devices of 380–420 kV circuit breakers in each Nordic and Baltic country. Estonia, Iceland, Latvia and Lithuania do not own circuit breakers in the 380–420 kV voltage range, as can be seen in Table 6.17.

6.6 Faults in control equipment

This section presents control equipment faults in 2019 and during 2010–2019 at the voltage levels 100–150 kV, 220–330 kV and 380–420 kV. Grid owners use control equipment to monitor and control their power grid. It should be noted that control equipment embedded in other components are not included in this category as they are deemed to be a part of the other component.

For control equipment, it is essential to distinguish between faults in technical equipment and faults made by human errors. Human errors include, for example, incorrect settings in an Intelligent Electronic Device (IED). In these statistics, human errors are registered under operation and maintenance, separated from the category technical equipment.

In devices where the control equipment is integrated, which is typical for SVCs, there is uncertainty whether faults are registered in the control equipment or the actual device. When the control equipment is embedded in another installation, faults should generally be categorised as faults in the installation and not in the control equipment. However, this definition is not yet fully applied in all countries.

Table 6.21 presents the number of installed control equipment, the number of faults, and the average number of faults for 2010–2019. Table 6.22 presents additionally the number of faults per 100 devices in 2019 and the average for 2010–2019.

Table 6.23 presents the percentage distribution of faults per cause in 2019. Table 6.24 presents the respective average values for the period 2010–2019 in the Nordic countries and Estonia and during 2012–2019 in Latvia and Lithuania. The used causes are lightning, other environmental causes, external influences, operation and maintenance, technical equipment, other and unknown. The fault categories used are explained in more detail in Section 1.4.1. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

Figure 6.11, Figure 6.12 and Figure 6.13 present the 5-year moving average of 100–150 kV, 220–330 kV and 380–420 kV control equipment faults per 100 devices in each Nordic and Baltic country. Trend curves are used to filter out the annual deviation and make it easier to follow on trends and decide on whether actions have to be taken in the future.

Table 6.21: Number of control equipment and faults, separated by voltage level, in each Nordic and Baltic country in 2019. The average number of faults is presented for 2010–2019 for the Nordic countries and Estonia and for 2012–2019 for Latvia and Lithuania.

		100–150 kV			220–330 kV			380–420 kV		
Regions	Country	Number of devices	Number of faults	10-year average # faults	Number of devices	Number of faults	10-year average # faults	Number of devices	Number of faults	10-year average # faults
Baltic	Estonia	662	18	7.5	131	4	1.3	0	0	0.0
	Latvia	631	22	18.8	106	2	2.9	0	0	0.0
	Lithuania	862	18	14.0	113	3	3.0	5	0	0.0
	Total	2 155	58	40.3	350	9	7.2	5	0	0.0
Nordic	Denmark	951	6	6.5	38	1	0.2	224	3	2.0
	Finland	2 655	1	23.0	74	30	4.9	365	1	5.7
	Iceland	125	6	5.0	86	2	3.2	0	0	0.0
	Norway	2 491	27	29.1	730	22	19.4	453	14	12.7
	Sweden	2 659	42	15.1	341	5	10.2	640	15	20.4
	Total	8 881	82	78.7	1 269	60	37.9	1 682	33	40.8
Grand Total		11 036	140	119.0	1 619	69	45.1	1 687	33	40.8

Table 6.22: Number of control equipment, faults, and the number of faults per 100 devices in 2019, grouped by voltage level. Furthermore, the 10-year average number of faults per 100 devices is presented for 2010–2019 for the Nordic countries and Estonia and for 2012–2019 for Latvia and Lithuania.

		100–150 kV				220–330 kV				380–420 kV			
Regions	Country	Number of faults	Number of devices	# faults / 100 devs	10-yr avg # faults / 100 devs	Number of faults	Number of devices	# faults / 100 devs	10-yr avg # faults / 100 devs	Number of faults	Number of devices	# faults / 100 devs	10-yr avg # faults / 100 devs
Baltic	Estonia	18	662	2.72	1.31	4	131	3.05	1.15	0	0	0.00	0.00
	Latvia	22	631	3.49	3.07	2	106	1.89	2.82	0	0	0.00	0.00
	Lithuania	18	862	2.09	1.64	3	113	2.65	2.86	0	5	0.00	0.00
	Total	58	2 155	2.69	1.93	9	350	2.57	2.15	0	5	0.00	0.00
Nordic	Denmark	6	951	0.63	0.78	1	38	2.63	1.59	3	224	1.34	1.11
	Finland	1	2 655	0.04	0.96	30	74	40.54	5.79	1	365	0.27	1.95
	Iceland	6	125	4.80	3.10	2	86	2.33	3.99	0	0	0.00	0.00
	Norway	27	2 491	1.08	1.30	22	730	3.01	2.67	14	453	3.09	3.70
	Sweden	42	2 659	1.58	0.70	5	341	1.47	3.08	15	640	2.34	3.56
	Total	82	8 881	0.92	1.01	60	1 269	4.73	3.07	33	1 682	1.96	2.94
Grand Total		140	11 036	1.27	1.18	69	1 619	4.26	2.90	33	1 687	1.96	2.93

Table 6.23: Percentage distribution of faults in control equipment per cause in the Nordic and Baltic countries in 2019. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	0%	0%	0%	14%	50%	18%	18%
	Latvia	4%	0%	0%	42%	54%	0%	0%
	Lithuania	0%	0%	0%	43%	5%	19%	33%
	Total	1%	0%	0%	33%	37%	12%	16%
Nordic	Denmark	0%	0%	0%	50%	10%	40%	0%
	Finland	0%	9%	0%	78%	3%	3%	6%
	Iceland	0%	0%	0%	50%	0%	50%	0%
	Norway	0%	0%	2%	52%	24%	16%	6%
	Sweden	6%	3%	2%	23%	40%	8%	18%
	Total	2%	3%	1%	46%	24%	14%	10%
Grand Total		2%	2%	1%	43%	28%	13%	12%

Table 6.24: Average distribution of faults in control equipment per cause during 2010–2019 in each Nordic country and Estonia and during 2012–2019 in Latvia and Lithuania.

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	0%	0%	0%	39%	48%	5%	9%
	Latvia	1%	1%	1%	48%	43%	1%	6%
	Lithuania	0%	0%	7%	40%	14%	7%	32%
	Total	0%	0%	3%	43%	34%	4%	16%
Nordic	Denmark	5%	3%	3%	49%	23%	11%	5%
	Finland	1%	1%	1%	58%	21%	7%	12%
	Iceland	0%	1%	0%	40%	45%	13%	0%
	Norway	2%	4%	3%	47%	29%	11%	4%
	Sweden	2%	4%	0%	27%	51%	5%	9%
	Total	2%	3%	2%	43%	34%	9%	7%
Grand Total		1%	3%	2%	43%	34%	8%	9%

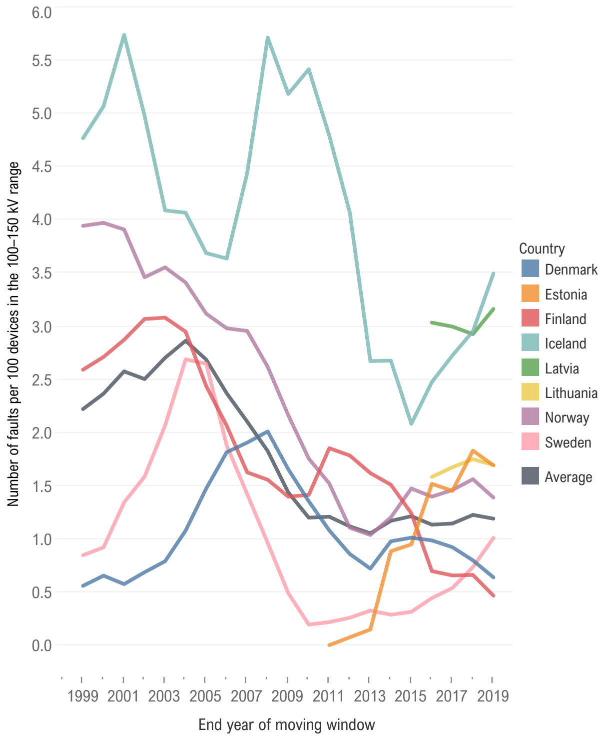

Figure 6.11: 5-year moving average of 100–150 kV control equipment faults per 100 devices in each Nordic and Baltic country. Estonia has data since 2007, and Latvia and Lithuania have data since 2012.

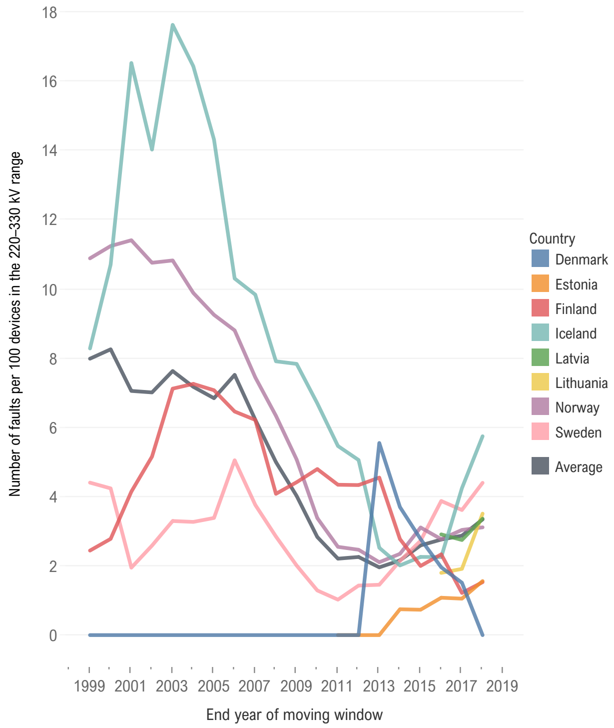

Figure 6.12: 5-year moving average of 220–330 kV control equipment faults per 100 devices in each Nordic and Baltic country. Estonia has data since 2007, and Latvia and Lithuania have data since 2012.

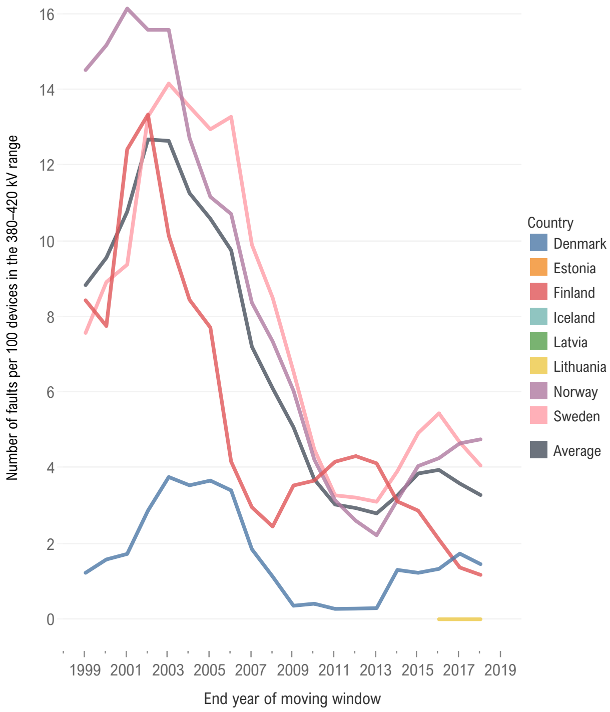

Figure 6.13: 5-year moving average of 380–420 kV control equipment faults per 100 devices in each Nordic and Baltic country. Lithuania has data since 2012. Estonia, Iceland and Latvia do not own control equipment in the 380–420 kV voltage range, as can be seen in Table 6.21.

6.7 Faults in instrumental transformers

This section presents instrumental transformer faults in 2019 and during 2010–2019 at the voltage levels 100–150 kV, 220–330 kV and 380–420 kV. Instrumental transformers provide the necessary power to metering and protection devices in the power grid. These, in turn, trigger the protection relays when needed and allow the grid owner to monitor the state of the system. Both current and voltage transformers are included in instrumental transformers.

Table 6.25 presents the number of instrumental transformers, the number of faults, and the average number of faults for 2010–2019. Table 6.26 presents additionally the number of faults per 100 devices in 2019 and the average for 2010–2019.

Table 6.27 presents the percentage distribution of faults per cause in 2019. Table 6.28 presents the respective average values for the period 2010–2019 in the Nordic countries and Estonia and during 2012–2019 in Latvia and Lithuania. The used causes are lightning, other environmental causes, external influences, operation and maintenance, technical equipment, other and unknown. The fault categories used are explained in more detail in Section 1.4.1. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

Figure 6.14, Figure 6.15 and Figure 6.16 present the 5-year moving average of 100–150 kV, 220–330 kV and 380–420 kV instrumental transformer faults per 100 devices in each Nordic and Baltic country. Trend curves are used to filter out the annual deviation and make it easier to follow on trends and decide on whether actions have to be taken in the future.

Table 6.25: Number of instrumental transformers and faults, separated by voltage level, in each Nordic and Baltic country in 2019. The average number of faults is presented for 2010–2019 for the Nordic countries and Estonia and for the period 2012–2019 for Latvia and Lithuania. The number of instrumental transformers in Sweden is not accurate due to missing data from some regional grid owners.

		100–150 kV			220–330 kV			380–420 kV		
Regions	Country	Number of devices	Number of faults	10-year average # faults	Number of devices	Number of faults	10-year average # faults	Number of devices	Number of faults	10-year average # faults
Baltic	Estonia	2 925	3	1.2	840	1	0.7	0	0	0.0
	Latvia	2 814	3	1.1	462	0	0.1	0	0	0.0
	Lithuania	3 375	1	0.9	645	0	0.4	27	0	0.0
	Total	9 114	7	3.2	1 947	1	1.2	27	0	0.0
Nordic	Denmark	4 452	0	1.4	150	0	0.1	1 118	0	0.4
	Finland	9 789	3	2.8	434	0	0.1	2 057	0	0.2
	Iceland	375	0	0.1	258	0	0.0	0	0	0.0
	Norway	7 768	3	3.4	2 805	2	2.0	930	1	1.6
	Sweden	7 413	7	4.2	1 894	1	0.2	3 440	0	1.8
	Total	29 797	13	11.9	5 541	3	2.4	7 545	1	4.0
Grand Total		38 911	20	15.1	7 488	4	3.6	7 572	1	4.0

Table 6.26: Number of instrumental transformers, faults, and the number of faults per 100 devices in 2019, grouped by voltage level. Furthermore, the 10-year average number of faults per 100 devices is is presented for 2010–2019 for the Nordic countries and Estonia and for 2012–2019 for Latvia and Lithuania.

		100–150 kV				220–330 kV				380–420 kV			
Regions	Country	Number of faults	Number of devices	# faults / 100 devs	10-yr avg # faults / 100 devs	Number of faults	Number of devices	# faults / 100 devs	10-yr avg # faults / 100 devs	Number of faults	Number of devices	# faults / 100 devs	10-yr avg # faults / 100 devs
Baltic	Estonia	3	2 925	0.10	0.09	1	840	0.12	0.21	0	0	0.00	0.00
	Latvia	3	2 814	0.11	0.08	0	462	0.00	0.05	0	0	0.00	0.00
	Lithuania	1	3 375	0.03	0.05	0	645	0.00	0.12	0	27	0.00	0.00
	Total	7	9 114	0.08	0.08	1	1 947	0.05	0.14	0	27	0.00	0.00
Nordic	Denmark	0	4 452	0.00	0.06	0	150	0.00	0.33	0	1 118	0.00	0.09
	Finland	3	9 789	0.03	0.06	0	434	0.00	0.04	0	2 057	0.00	0.02
	Iceland	0	375	0.00	0.02	0	258	0.00	0.00	0	0	0.00	0.00
	Norway	3	7 768	0.04	0.04	2	2 805	0.07	0.07	1	930	0.11	0.17
	Sweden	7	7 413	0.09	0.10	1	1 894	0.05	0.02	0	3 440	0.00	0.11
	Total	13	29 797	0.04	0.06	3	5 541	0.05	0.05	1	7 545	0.01	0.11
Grand Total		20	38 911	0.05	0.06	4	7 488	0.05	0.07	1	7 572	0.01	0.11

Table 6.27: Percentage distribution of faults in instrumental transformers per cause in the Nordic and Baltic countries in 2019. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	0%	0%	0%	0%	100%	0%	0%
	Latvia	0%	0%	0%	0%	100%	0%	0%
	Lithuania	0%	0%	0%	0%	100%	0%	0%
	Total	0%	0%	0%	0%	100%	0%	0%
Nordic	Denmark	0%	0%	0%	0%	0%	0%	0%
	Finland	0%	0%	0%	33%	67%	0%	0%
	Iceland	0%	0%	0%	0%	0%	0%	0%
	Norway	0%	0%	0%	0%	100%	0%	0%
	Sweden	0%	0%	0%	0%	63%	13%	25%
	Total	0%	0%	0%	6%	76%	6%	12%
Grand Total		0%	0%	0%	4%	84%	4%	8%

Table 6.28: Average distribution of faults in instrumental transformers per cause during 2010–2019 in each Nordic country and Estonia and during 2012–2019 in Latvia and Lithuania.

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	0%	0%	0%	11%	89%	0%	0%
	Latvia	0%	0%	0%	0%	100%	0%	0%
	Lithuania	0%	0%	0%	10%	90%	0%	0%
	Total	0%	0%	0%	8%	92%	0%	0%
Nordic	Denmark	0%	0%	5%	11%	63%	5%	16%
	Finland	6%	0%	0%	6%	61%	10%	16%
	Iceland	0%	0%	0%	0%	0%	100%	0%
	Norway	11%	3%	1%	19%	43%	19%	4%
	Sweden	6%	0%	2%	6%	77%	2%	6%
	Total	8%	1%	2%	11%	60%	10%	8%
Grand Total		6%	1%	1%	11%	65%	9%	7%

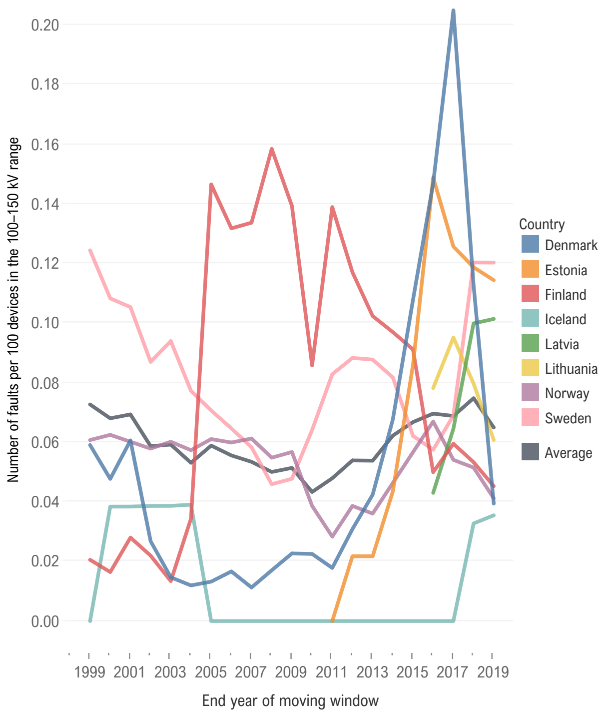

Figure 6.14: 5-year moving average of 100–150 kV instrumental transformer faults per 100 devices in each Nordic and Baltic country. Estonia has data since 2007, and Latvia and Lithuania have data since 2012. The number of instrumental transformers in Sweden is not accurate due to missing data from some regional grid owners.

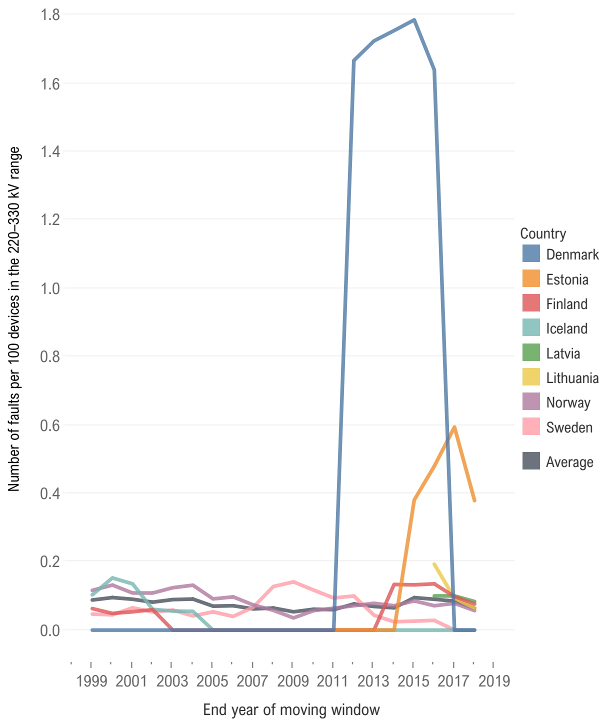

Figure 6.15: 5-year moving average of 220–330 kV instrumental transformer faults per 100 devices in each Nordic and Baltic country. Estonia has data since 2007, and Latvia and Lithuania have data since 2012. Denmark's high values during 2007–2016 are caused by 1 fault in 2012. The values seem to be extreme because Denmark owns significantly less instrumental transformers than the other countries, as can be seen in Table 6.25.

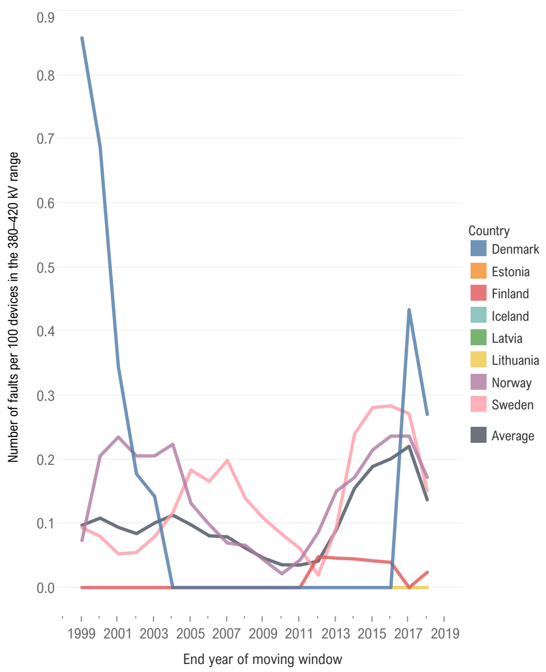

Figure 6.16: 5-year moving average of 380–420 kV instrumental transformer faults per 100 devices in each Nordic and Baltic country. Lithuania has data since 2012. Estonia, Iceland and Latvia do not own instrumental transformers in the 380–420 kV voltage range, as can be seen in Table 6.25.

6.8 Faults in power transformers

This section presents power transformer faults in 2019 and during 2010–2019 at the voltage levels 100–150 kV, 220–330 kV and 380–420 kV. Power transformers are essential when power needs to be transferred from where power is generated to where power is consumed, as they allow the grid owner to optimise the voltage level to minimise transmission losses. The rated voltage of a power transformer is defined in these statistics as the winding with the highest voltage, as stated in the guidelines in Section 6.2 [2].

Table 6.29 presents the number of power transformers, the number of faults, and the average number of faults for 2010–2019. Table 6.30 presents additionally the number of faults per 100 devices in 2019 and the average for 2010–2019.

Table 6.31 shows the percentage distribution of faults per cause in 2019. Table 6.32 presents the respective average values for the period 2010–2019 in the Nordic countries and Estonia and during 2012–2019 in Latvia and Lithuania. The used causes are lightning, other environmental causes, external influences, operation and maintenance, technical equipment, other and unknown. The fault categories used are explained in more detail in Section 1.4.1. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

Figure 6.17, Figure 6.18 and Figure 6.19 present the 5-year moving average of 100–150 kV, 220–330 kV and 380–420 kV power transformer faults per 100 devices in each Nordic and Baltic country. Trend curves are used to filter out the annual deviation and make it easier to follow on trends and decide on whether actions have to be taken in the future.

Table 6.29: Number of power transformers and faults, separated by voltage level, in each Nordic and Baltic country in 2019. The average number of faults is presented for 2010–2019 for the Nordic countries and Estonia and for 2012–2019 for Latvia and Lithuania.

		100–150 kV			220–330 kV			380–420 kV		
Regions	Country	Number of devices	Number of faults	10-year average # faults	Number of devices	Number of faults	10-year average # faults	Number of devices	Number of faults	10-year average # faults
Baltic	Estonia	207	7	7.5	25	2	2.7	0	0	0.0
	Latvia	248	1	4.9	27	0	1.4	0	0	0.0
	Lithuania	378	0	0.3	25	1	1.0	0	0	0.0
	Total	833	8	12.6	77	3	5.1	0	0	0.0
Nordic	Denmark	237	5	3.4	13	0	0.1	43	0	1.0
	Finland	1 149	8	7.0	15	4	1.3	62	0	1.2
	Iceland	14	5	1.5	16	1	0.8	0	0	0.0
	Norway	913	2	4.8	266	0	1.7	100	0	1.6
	Sweden	860	7	19.6	117	2	3.8	79	0	1.5
	Total	3 173	27	36.3	427	7	7.7	284	0	5.3
Grand Total		4 006	35	48.9	504	10	12.8	284	0	5.3

Table 6.30: Number of power transformers, faults, and the number of faults per 100 devices in 2019, grouped by voltage level. Furthermore, the 10-year average number of faults per 100 devices is presented for 2010–2019 for the Nordic countries and Estonia and for 2012–2019 for Latvia and Lithuania.

		100–150 kV				220–330 kV				380–420 kV			
Regions	Country	Number of faults	Number of devices	# faults / 100 devs	10-yr avg # faults / 100 devs	Number of faults	Number of devices	# faults / 100 devs	10-yr avg # faults / 100 devs	Number of faults	Number of devices	# faults / 100 devs	10-yr avg # faults / 100 devs
Baltic	Estonia	7	207	3.38	3.49	2	25	8.00	11.59	0	0	0.00	0.00
	Latvia	1	248	0.40	1.98	0	27	0.00	5.42	0	0	0.00	0.00
	Lithuania	0	378	0.00	0.06	1	25	4.00	4.19	0	0	0.00	0.00
	Total	8	833	0.96	1.57	3	77	3.90	7.34	0	0	0.00	0.00
Nordic	Denmark	5	237	2.11	1.43	0	13	0.00	1.67	0	43	0.00	3.16
	Finland	8	1 149	0.70	0.65	4	15	26.67	5.14	0	62	0.00	1.88
	Iceland	5	14	35.71	3.81	1	16	6.25	6.30	0	0	0.00	0.00
	Norway	2	913	0.22	0.60	0	266	0.00	0.64	0	100	0.00	2.04
	Sweden	7	860	0.81	2.56	2	117	1.71	3.73	0	79	0.00	2.24
	Total	27	3 173	0.85	1.24	7	427	1.64	1.87	0	284	0.00	2.20
Grand Total		35	4 006	0.87	1.31	10	504	1.98	2.60	0	284	0.00	2.20

Table 6.31: Percentage distribution of faults per cause in the Nordic and Baltic countries in 2019. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	0%	0%	0%	22%	44%	0%	33%
	Latvia	0%	0%	100%	0%	0%	0%	0%
	Lithuania	0%	0%	0%	0%	100%	0%	0%
	Total	0%	0%	9%	18%	45%	0%	27%
Nordic	Denmark	0%	20%	0%	20%	40%	20%	0%
	Finland	67%	0%	0%	0%	25%	8%	0%
	Iceland	0%	33%	0%	0%	0%	67%	0%
	Norway	0%	0%	0%	50%	0%	50%	0%
	Sweden	0%	11%	0%	11%	22%	0%	56%
	Total	24%	12%	0%	9%	21%	21%	15%
Grand Total		18%	9%	2%	11%	27%	16%	18%

Table 6.32: Average distribution of faults per cause during 2010–2019 in each Nordic country and Estonia and during 2012–2019 in Latvia and Lithuania. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	1%	3%	3%	22%	68%	0%	4%
	Latvia	0%	0%	30%	30%	36%	0%	4%
	Lithuania	0%	0%	0%	30%	40%	0%	30%
	Total	1%	2%	11%	25%	56%	0%	6%
Nordic	Denmark	2%	22%	0%	27%	38%	7%	4%
	Finland	15%	2%	3%	19%	23%	24%	14%
	Iceland	0%	22%	0%	9%	52%	17%	0%
	Norway	7%	22%	1%	17%	26%	20%	6%
	Sweden	20%	2%	2%	20%	21%	6%	29%
	Total	15%	8%	2%	19%	25%	13%	19%
Grand Total		11%	6%	4%	21%	33%	9%	15%

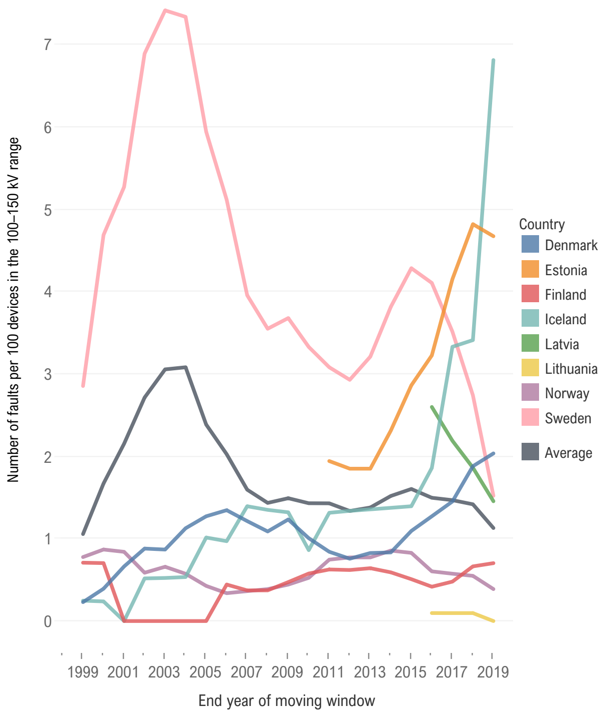

Figure 6.17: 5-year moving average of 100–150 kV power transformer faults per 100 devices in each Nordic and Baltic country. Estonia has data since 2007, and Latvia and Lithuania have data since 2012.

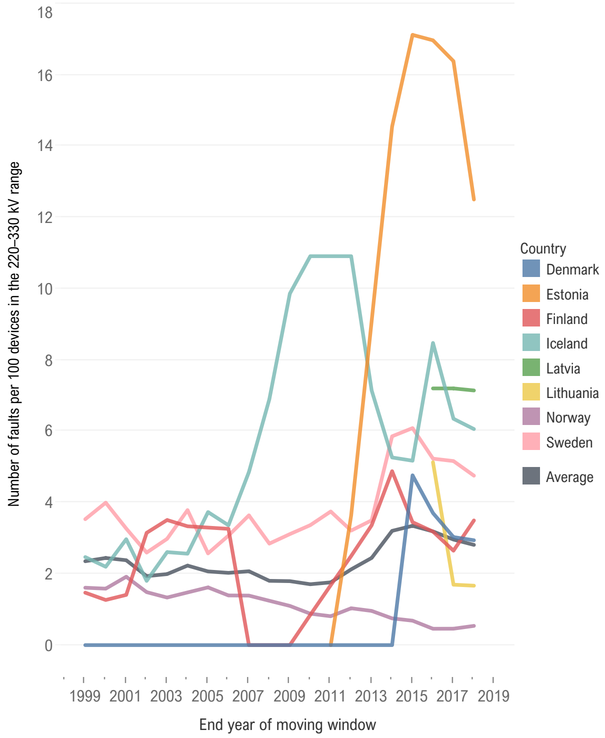

Figure 6.18: 5-year moving average of 220–330 kV power transformer faults per 100 devices in each Nordic and Baltic country. Estonia has data since 2007, and Latvia and Lithuania have data since 2012.

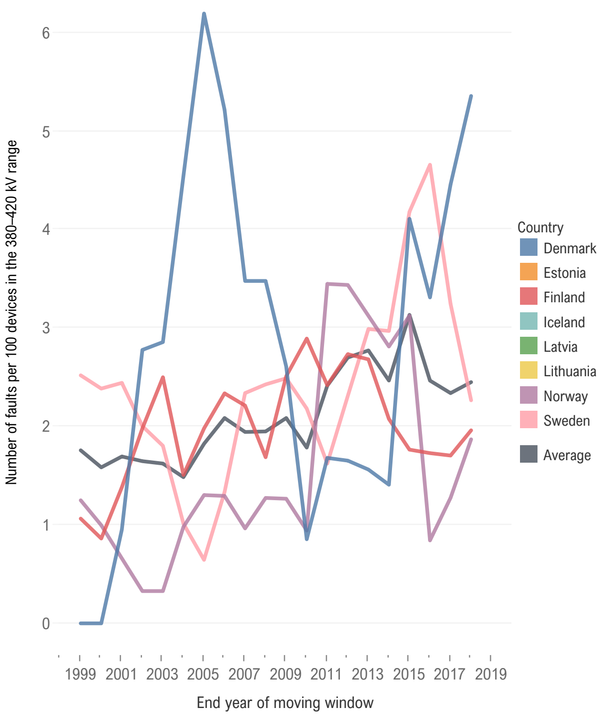

Figure 6.19: 5-year moving average of 380–420 kV power transformer faults per 100 devices in each Nordic and Baltic country. Estonia, Iceland, Latvia and Lithuania do not own power transformers in the 380–420 kV voltage range, as can be seen in Table 6.29.

6.9 Faults in compensation devices

The sections in this chapter present fault statistics for compensation devices. Compensation devices are used to reduce reactive and capacitive power and for stabilising voltage and frequency in the power system. The following compensation devices are presented in this chapter: reactors, series capacitors, shunt capacitors and SVC devices. The statistics include the number of devices and faults, the number of faults per 100 devices and energy not supplied (ENS) in 2019 and 2010–2019.

6.9.1 Faults in reactors

Reactors add reactance to the power grid and limit short circuit currents. Table 6.33 presents the number of reactors and faults, the number of faults per 100 devices, and the amount of energy not supplied (ENS).

Table 6.33: The number of reactors and faults in 2019, and the number of faults per 100 devices and the amount of ENS in 2019 and the average for 2010–2019.

	Devices	Faults	Faults per 100 devices		ENS (MWh)	
Country	2019	2019	2019	2010–2019	2019	2010–2019
Estonia	28	4	14.3	9.7	0.0	0.0
Latvia[2]	2	0	0.0	6.1	0.0	0.0
Lithuania[2]	2	0	0.0	0.0	0.0	0.0
Baltic total	32	4	12.5	7.1	0.0	0.0
Denmark	112	1	0.9	1.7	0.0	0.3
Finland[1]	182	0	0.0	0.2	0.0	1.0
Iceland	0	0	0.0	0.0	0.0	0.0
Norway	36	4	11.1	3.3	0.0	0.0
Sweden	91	9	9.9	5.7	0.0	0.0
Nordic total	421	14	3.3	3.3	0.0	1.3
Nordic & Baltic total	453	18	4.0	3.6	0.0	1.3

[1] In Finland, reactors compensating the reactive power of 380–420 kV lines are connected to the 20 kV tertiary winding of the 380–420/100–150/20 kV power transformers.
[2] The average values of Latvia and Lithuania use the period 2012–2019.

6.9.2 Faults in series capacitors

Series capacitors compensate for the inductance created by long transmission lines. The compensated inductance decreases the voltage drop and transmission losses and increases the transmission capacity and voltage stability of long lines. Table 6.34 presents the number of series capacitors and faults, the number of faults per 100 devices and the amount of energy not supplied (ENS).

Table 6.34: The number of series capacitors and faults in 2019, and the number of faults per 100 devices and the amount of ENS in 2019 and the average for 2010–2019.

	Devices	Faults	Faults per 100 devices		ENS (MWh)	
Country	2019	2019	2019	2010–2019	2019	2010–2019
Estonia	10	0	0.0	0.0	0.0	0.0
Latvia[1]	18	0	0.0	0.0	0.0	0.0
Lithuania[1]	2	0	0.0	0.0	0.0	0.0
Baltic total	30	0	0.0	0.0	0.0	0.0
Denmark	0	0	0.0	0.0	0.0	0.0
Finland	11	5	45.5	53.5	0.0	1.9
Iceland	1	0	0.0	20.0	0.0	0.0
Norway	3	0	0.0	3.3	0.0	0.0
Sweden	17	8	47.1	150.0	0.0	0.0
Nordic total	32	13	40.6	88.8	0.0	1.9
Nordic & Baltic total	62	13	21.0	74.2	0.0	1.9

[1] The average values of Latvia and Lithuania use the period 2012–2019.

6.9.3 Faults in shunt capacitors

Shunt capacitors provide the grid with reactive power to the grid, thus decreasing transmission losses and increasing transmission capacity. Table 6.35 presents the number of shunt capacitors and faults, the number of faults per 100 devices and the amount of energy not supplied (ENS).

Table 6.35: The number of shunt capacitors and faults in 2019, and the number of faults per 100 devices and the amount of ENS in 2019 and the average for 2010–2019.

	Devices	Faults	Faults per 100 devices		ENS (MWh)	
Country	2019	2019	2019	2010–2019	2019	2010–2019
Estonia	0	0	0.0	8.9	0.0	3.0
Latvia[1]	0	0	0.0	0.0	0.0	0.0
Lithuania[1]	0	0	0.0	0.0	0.0	0.0
Baltic total	0	0	0.0	6.8	0.0	3.0
Denmark	35	0	0.0	0.4	0.0	0.0
Finland	24	1	4.2	3.7	0.0	0.0
Iceland	13	0	0.0	4.1	0.0	0.0
Norway	194	4	2.1	2.1	0.0	0.0
Sweden	152	1	0.7	0.8	81.7	15.2
Nordic total	418	6	1.4	1.8	81.7	15.2
Nordic & Baltic total	418	6	1.4	1.9	81.7	18.2

[1] The average values of Latvia and Lithuania use the period 2012–2019.

6.9.4 Faults in SVC devices

SVCs, or static VAR compensators, provide the power grid with fast and dynamic reactive power to se the voltage levels, the power factor and harmonics. However, SVC devices are often subjects to temporary faults. A typical fault is an error in the control system computer that trips the SVC device's circuit breaker. The fault is then simply cleared by restarting the computer. However, the fault is recorded and is partly the reason behind the high number of SVC device faults.

Table 6.36 presents the number of shunt capacitors and faults, the number of faults per 100 devices and the amount of energy not supplied (ENS).

Table 6.36: The number of SVCs and faults in 2019, and the number of faults per 100 devices and the amount of ENS in 2019 and the average for 2010–2019.

	Devices	Faults	Faults per 100 devices		ENS (MWh)	
Country	2019	2019	2019	2010–2019	2019	2010–2019
Estonia	0	0	0.0	0.0	0.0	0.0
Latvia[1]	2026	2	0.1	0.1	0.1	0.0
Lithuania[1]	11	1	9.1	3.5	0.0	0.0
Baltic total	2037	3	0.1	0.2	0.1	0.0
Denmark	1	1	100.0	40.0	0.0	0.0
Finland	1	0	0.0	16.7	0.0	0.0
Iceland	2	0	0.0	14.3	0.0	0.0
Norway	25	27	108.0	90.5	0.0	0.0
Sweden	2	2	133.3	308.8	0.0	0.0
Nordic total	30	30	98.4	99.4	0.0	0.0
Nordic & Baltic total	2068	33	1.6	9.5	0.1	0.0

[1] The average values of Latvia and Lithuania use the period 2012–2019.

References

[1] DISTAC, "Nordic and Baltic Grid Disturbance Statistics 2018." https://eepublicdownloads.blob.core.windows.net/public-cdn-container/clean-documents/Publications/SOC/Nordic/Nordic_and_Baltic_Grid_Disturbance_Statistics_2018.pdf, December 2019.

[2] DISTAC, "Guidelines for the Classification of Grid Disturbances above 100 kV." https://docstore.entsoe.eu/Documents/Publications/SOC/Nordic/HVAC_guidelines_2017_04_13.pdf, April 2017.

[3] ENTSO-E, "The ENTSO-E Interconnected System Grid Map 2019." https://docstore.entsoe.eu/Documents/Publications/maps/2019/Map_Northern-Europe-3.000.000.pdf. [Online; accessed 31.05.2019].

[4] DISTAC, "Nordic and Baltic HVDC Utilisation and Unavailability Statistics." https://www.entsoe.eu/publications/system-operations-reports/, September 2018.

Appendices

A Calculation of energy not supplied

Every country has its own method to calculate energy not supplied (ENS). The process for each country is described below.

Denmark

In Denmark, the ENS of the transmission grid is calculated as the transformer load just before the grid disturbance or interruption multiplied by the outage duration. Transformer load covers load/consumption and generation at lower/medium voltage.

Estonia

In Estonia, ENS calculation is based on interruption time for the end-user. When the outage duration is less than two hours, ENS is calculated by cut-off power (measured straight before the outage) multiplied by the interruption time. When the outage duration is more than two hours, the load data of the previous or next day shall be taken into account, and ENS is calculated per these load profiles.

Finland

In Finland, ENS in the transmission grid is counted for those faults that caused an outage at the point of supply, which is the high voltage side of the transformer. ENS is calculated individually for all connection points and is linked to the fault that caused the outage. ENS is counted by multiplying the outage duration and the power before the fault. Outage duration is the time that the point of supply is dead or the time until the delivery of power to the customer can be arranged via another grid connection.

Iceland

In Iceland, ENS is computed per the delivery from the transmission grid. It is calculated at the points of supply in the 220 kV or 132 kV systems. ENS is linked to the fault that caused the outage. In the data of the ENTSO-E Nordic and Baltic statistics, ENS that was caused by the generation or distribution systems has been left out. However, distribution systems register ENS caused by outages in the transmission and distribution systems with end-user impact. Mutual rules for registration of faults and ENS in all grids are used in Iceland.

Latvia

In Latvia, the ENS is linked to the end-user, that is, ENS is not counted as long as the end-user receives energy through the distribution grid. Note that the distribution grid is 100 % dependent on the TSO supply due to undeveloped energy generation. The amount of ENS is calculated by multiplying the pre-outage load with the duration of the outage.

Lithuania

In Lithuania energy not delivered (END) is treated as the energy not supplied (ENS). The END of the transmission grid is calculated at the point of supply of the end customer. The point of supply means the low voltage side of the 110/35/10 kV or 110/10 kV transformer at the low voltage customer connection point. If an outage is in a radial 110 kV connection, END is calculated by the distribution system operator (DSO), who considers the possibility to supply energy from the other 35 kV or 10 kV voltage substations. The DSO then uses the average load before the outage and its duration in the calculations. All events with the energy not supplied shall be investigated together with the DSO or Significant User directly connected to 110 kV network. Both parties shall agree and confirm the amounts of not supplied energy.

Norway

In Norway, ENS is referred to the end-user. ENS is calculated at the point of supply that is located on the low voltage side of the distribution transformer (1 kV) or in some other location where the end-user is directly connected. All ENS is linked to the fault that caused the outage. ENS is calculated per a standardised method that has been established by the authority.

Sweden

In Sweden, energy not supplied is calculated by multiplying the outage duration with the detected pre-outage load. Because the pre-outage load is rarely registered, some companies multiply the rated power at the point of supply by the outage duration.

Starting in 2020, by recommendation from the regulator, the yearly average output will be used instead of the pre-outage load to calculate ENS.

B Policies for examining the cause of line faults

Denmark

In Denmark, the quality of data from disturbance recorders and other information that has been gathered is not always good enough to pinpoint the cause of the disturbance. In this case, it leads to a cause stated as unknown. It is also a fact that every line fault is not inspected, which may lead to a cause stated as unknown.

Estonia

In Estonia, the cause of a line fault is determined by inspections or by identifying possible cause origins. The fault location is usually found as disturbance recorders measure it, although the accuracy may vary a lot. The 110 kV lines have many trips with a successful automatic reclosing at nights during summer months. After investigations, it turned out that stork contamination on insulators was causing the flashovers. In these cases, the fault sites are not always inspected. Elering has access to the lightning detection system, which allows identifying the line faults caused by lightning. If no signs are referring to a particular cause, the cause for a fault is reported as unknown.

Finland

In Finland, Fingrid Oyj changed the classification policy of faults in July 2011, and more effort is put into clarifying causes. Even if the cause is not 100 % certain, but if the expert opinion is that the cause is, for example, lightning, the cause is reported as lightning. Additionally, the category 'other environmental causes' is used more often. Therefore, the number of unknown faults has decreased.

Iceland

In Iceland, disturbances in Landsnet's transmission system are classified into two categories: sudden disturbances in the transmission network and sudden disturbances in other systems. System operation staff analyses monthly interferences, and corrections are made to the data if needed. In 2016, Landsnet started to hold meetings three times a year, with representatives from the asset management and maintenance department to review the registration of interference and corrections made if the cause was something else than what was initially reported. This process also helps in understanding how disturbances are listed in the disturbance database for these parties.

Latvia

In Latvia, disturbance recorders, relay protection systems, on-sight inspections and information from witnesses are used to find the cause of a disturbance. If enough evidence is available, the cause is set accordingly. Unfortunately, there are many cases, for example, lightning, other environmental causes or external influences, where it is difficult to find the right cause. In those cases, we use our experience to pinpoint the most probable cause and mark it as such.

Lithuania

In Lithuania, disturbances in the transmission system are mainly classified into two categories: disturbances that affected the consumers (Significant users and the DSO) connected to the transmission network and disturbances that did not. All disturbances are investigated per the internal investigation procedures of Litgrid. To detect line faults, TSO analyses the data from disturbance recorders, relay protection terminals and the post-inspection of the line. Litgrid does not have access to the data of the lightning detection system.

Norway

In Norway, primarily for these statistics, the reporting TSO needs to distinguish between six fault categories and unknown. Norway has at least a single-sided distance to a fault on most lines on this reporting level, and all line faults are inspected. The fault categories external influence (people), operation and maintenance (people), technical equipment and other is usually detected during the disturbance and the post-inspection of the line. To distinguish between the remaining two categories lightning and other environmental faults, Statnett uses waveform analysis on fault records, the lightning detection system and weather information to sort out the lightning. If the weather was good and no other category is suitable, 'unknown' is used.

Sweden

In Sweden regarding lightning, data from disturbance recorders and other gathered information might not be enough to pinpoint the cause of the disturbance in many cases. Svenska kraftnät does not have full access to raw data from the lightning detection system. If a successful reclosing has taken place, Svenska kraftnät prefers to declare the cause as unknown instead of lightning, which may be the most probable cause.

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D Contact persons for the distribution network statistics

ENTSO-E Regional Group Nordic provides no statistics for distribution networks (voltage voltages lower than 100 kV). However, there are more or less developed national statistics for these voltage levels.

More detailed information regarding these statistics can be obtained from the representatives of the Nordic and Baltic countries, which are listed below:

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E Additional figures

This appendix was introduced to allow experimenting with new kinds of figures without affecting the rest of the report. Furthermore, it shows what kind of statistical data can be derived from the data collected by the DISTAC group.

Section E.1 shows fault trends for other environmental causes and operation and maintenance. Section E.2 shows fault trends for operation and maintenance faults for overhead lines.

E.1 Detailed view of faults due to other environmental causes and operation and maintenance

This section presents trend curves specifically for other environmental causes and operation and maintenance faults, to let us see if either one of them is a dominating cause of faults in a country. The cause category 'Other environmental causes' was selected because it is the main reason for higher maintenance costs and depends significantly on the weather conditions in a country. Furthermore, faults due to other environmental causes can be decreased through increased maintenance and by improving work procedures. 'Operation and maintenance' was selected because it may be interesting to see whether changes in work procedures or investments in system upgrades have impacted the fault rates of the grid.

Furthermore, trend curves for operation and maintenance might be connected to the increase in digital technology inside the substations and to number of work orders being performed in the grids. There are a total of 7 fault categories, which are defined in Section 1.4.1.

Figure E.1 shows the trend curves for other environmental causes for each Nordic and Baltic country and Figure E.2 for operation and maintenance causes. The trends are calculated using 5-year moving averages. With the help of the trend curve, it may be possible to estimate the number of faults in the future.

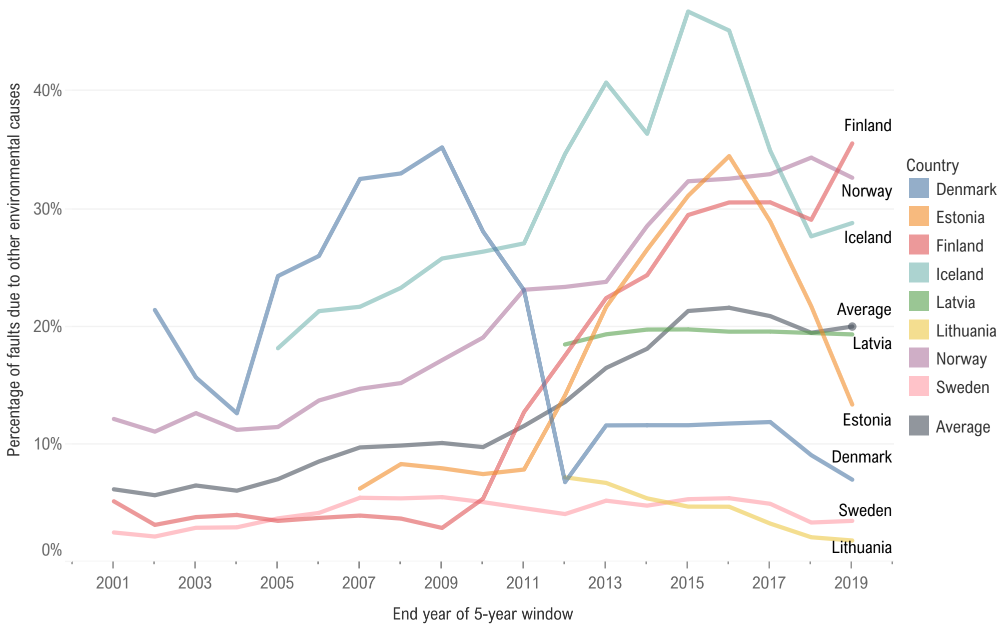

Figure E.1: 5-year moving average of other environmental faults in each Nordic and Baltic country. Other environmental causes are the main reason for higher maintenance costs and depends significantly on the weather conditions in a country. Furthermore, faults due to other environmental causes can be decreased through increased maintenance and by improving work procedures.

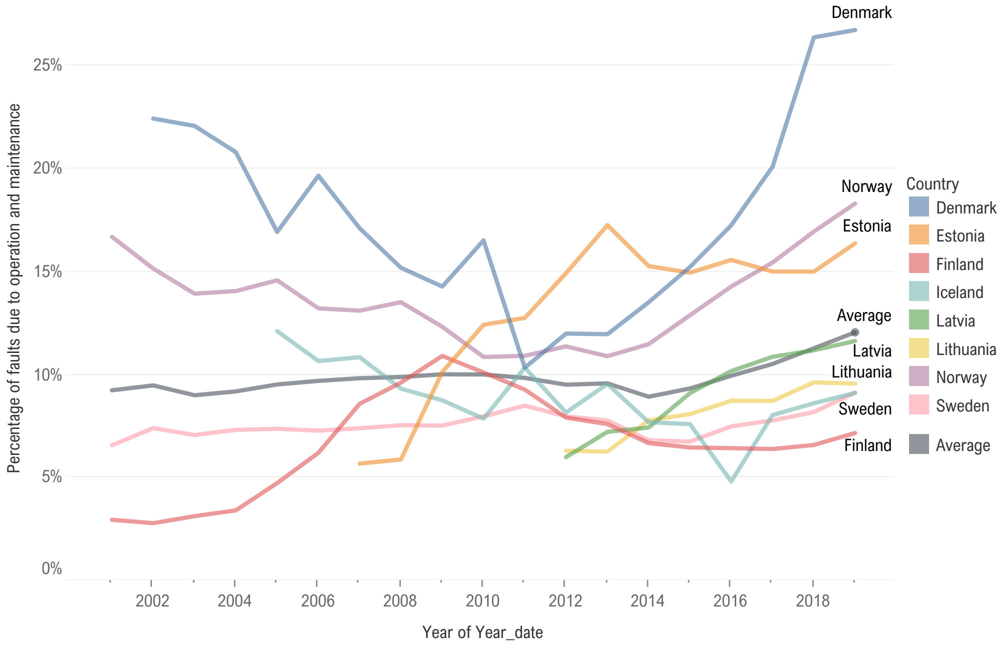

Figure E.2: 5-year moving average of operation and maintenance faults in each Nordic and Baltic country. Operation and maintenance faults are directly connected to changes in work procedures and grid investments. Furthermore, trend curves for operation and maintenance might be connected to the increase in digital technology inside the substations and to the amount of work orders being performed in the grids.

E.2 Other environmental causes and operation and maintenance faults in overhead lines

This section presents trend curves for overhead line faults according to other environmental causes and operation and maintenance, to let us see if they happen to be a dominating cause of overhead line faults in the Nordic and Baltic regions. The cause category 'Other environmental causes' was selected because it is the main reason for higher maintenance costs and depends significantly on the weather conditions in a country. Furthermore, faults due to other environmental causes can be decreased through increased maintenance and by improving work procedures. 'Operation and maintenance' was selected because it may be interesting to see whether changes in work procedures or investments in system upgrades have impacted the fault rates of the grid. Furthermore, trend curves for operation and maintenance might be connected to the increase in digital technology inside the substations and to the number of work orders being performed in the grids. There are a total of 7 fault categories, which are defined in Section 1.4.1.

Overhead line fault trends for other environmental causes and operation and maintenance causes are shown in Figure E.4 and Figure E.3, respectively. The trends are calculated using 5-year moving averages. With the help of the trend curve, it may be possible to estimate the number of faults in the future.

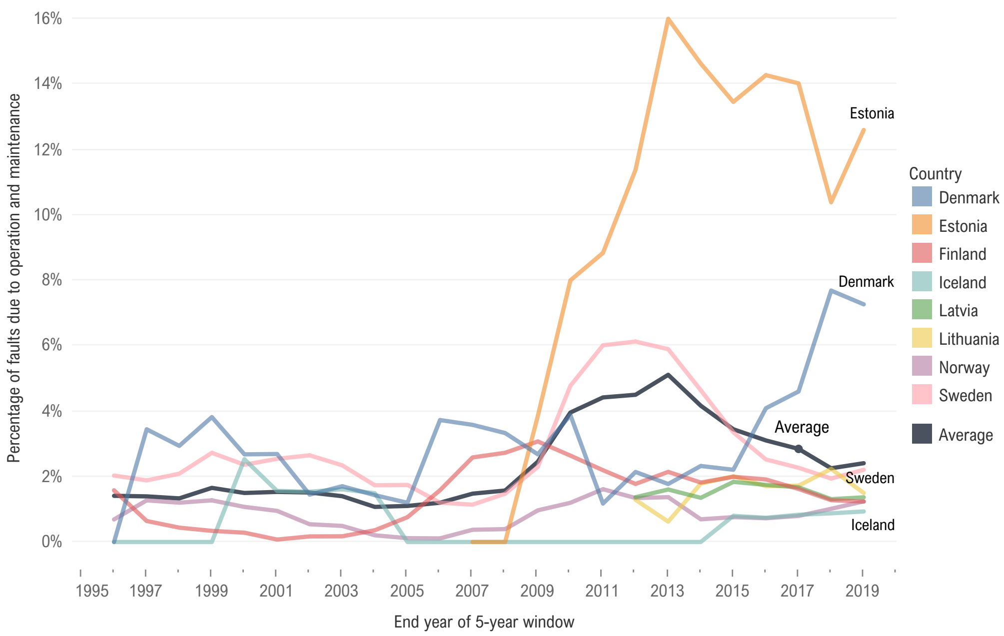

Figure E.3: 5-year moving average of overhead line faults due to operation and maintenance in each Nordic and Baltic country. Operation and maintenance faults are directly connected to changes in work procedures and grid investments. Furthermore, trend curves for operation and maintenance might be connected to the increase in digital technology inside the substations and to the amount of work orders being performed in the grids.

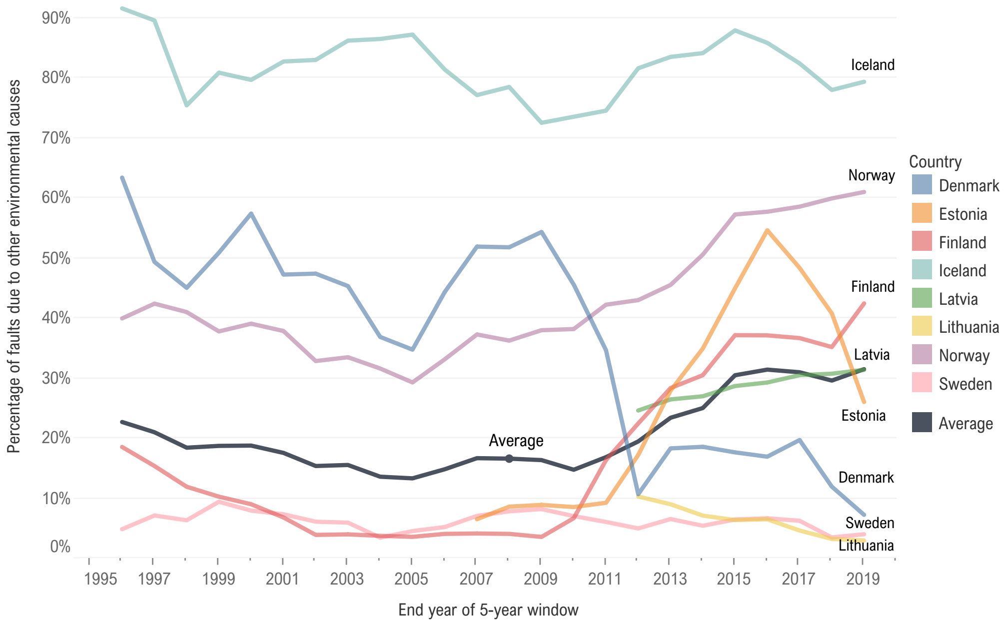

Figure E.4: 5-year moving average of overhead line faults due to other environmental causes in each Nordic and Baltic country. Other environmental causes are the main reason for higher maintenance costs and depends significantly on the weather conditions in a country. Furthermore, faults due to other environmental causes can be decreased through increased maintenance and by improving work procedures.

E.3 Annual number of units per HVAC component

This section presents the annual number of units for cables, circuit breakers, control equipment, instrumental transformers, overhead lines and power transformers. Cables and overhead lines are calculated in kilometres, and circuit breakers, control equipment and instrumental and power transformers are calculated in the number of devices.

Figure E.5 presents the length of installed cables in kilometres, with all voltage levels combined, in each Nordic and Baltic country. Figure E.6 presents the length of installed overhead lines in kilometres, with all voltage levels combined, in each Nordic and Baltic country. Figure E.7 presents the number of installed circuit breakers, with all voltage levels combined, in each Nordic and Baltic country. The number of control equipment is not presented because it is precisely the same as the number of circuit breakers. Figure E.8 presents the number of installed instrumental transformers, with all voltage levels combined, in each Nordic and Baltic country. Figure E.9 presents the number of installed power transformers, with all voltage levels combined, in each Nordic and Baltic country.

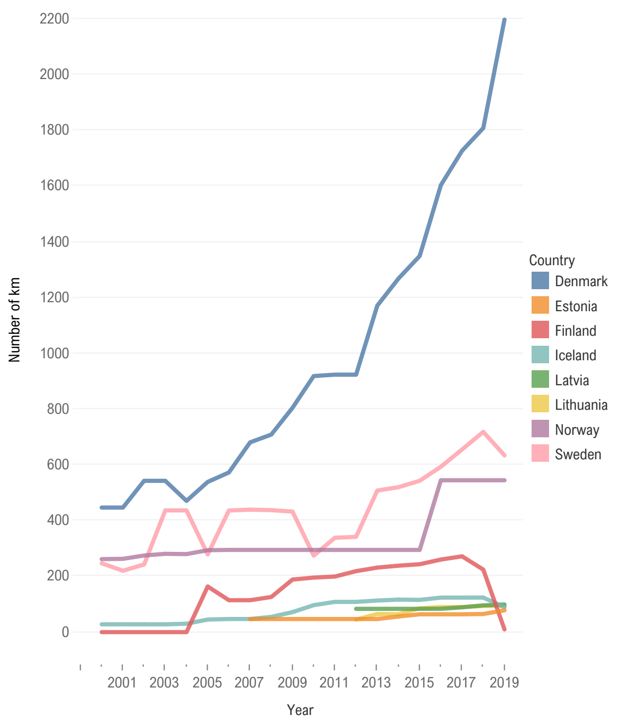

Figure E.5: Annual installed length of cables in kilometres, with all voltage levels combined, in each Nordic and Baltic country. Estonia has data since 2007, and Latvia and Lithuania have data since 2012.

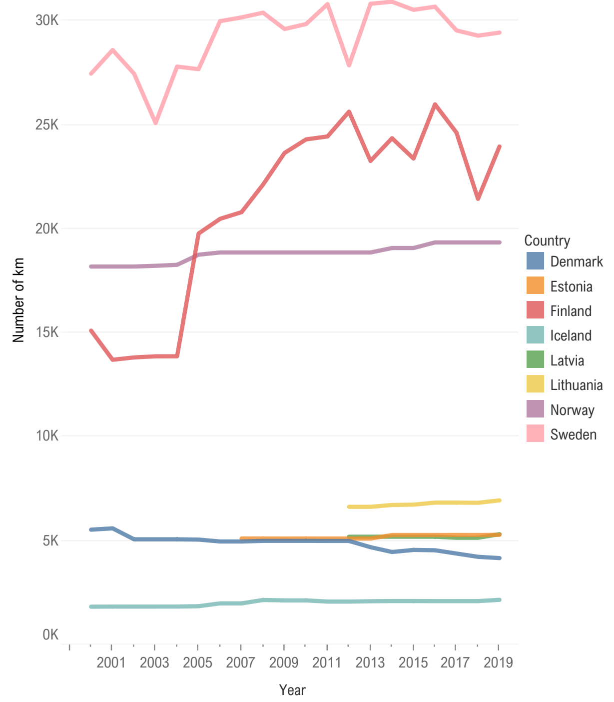

Figure E.6: Annual installed length of overhead lines in kilometres, with all voltage levels combined, in each Nordic and Baltic country. Estonia has data since 2007, and Latvia and Lithuania have data since 2012.

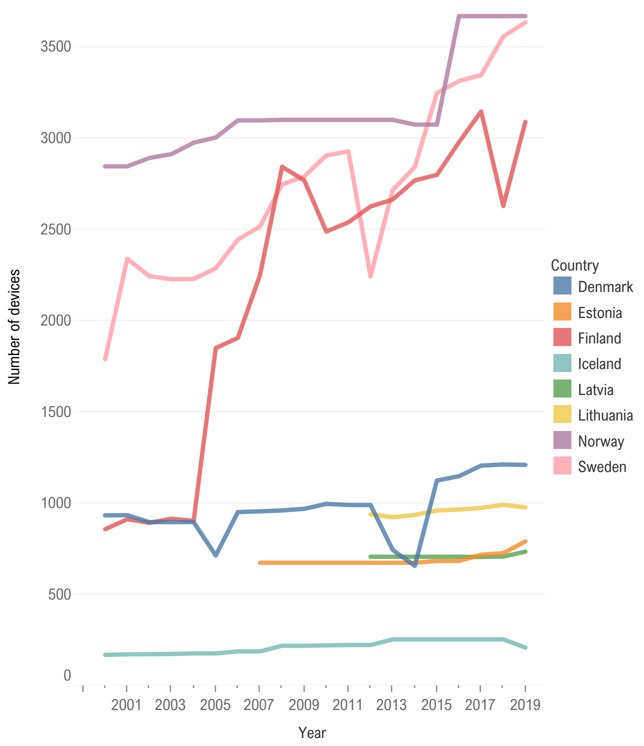

Figure E.7: Annual number of installed circuit breakers, with all voltage levels combined, in each Nordic and Baltic country. Estonia has data since 2007, and Latvia and Lithuania have data since 2012. The number of circuit breakers is equal to the number of control equipment.

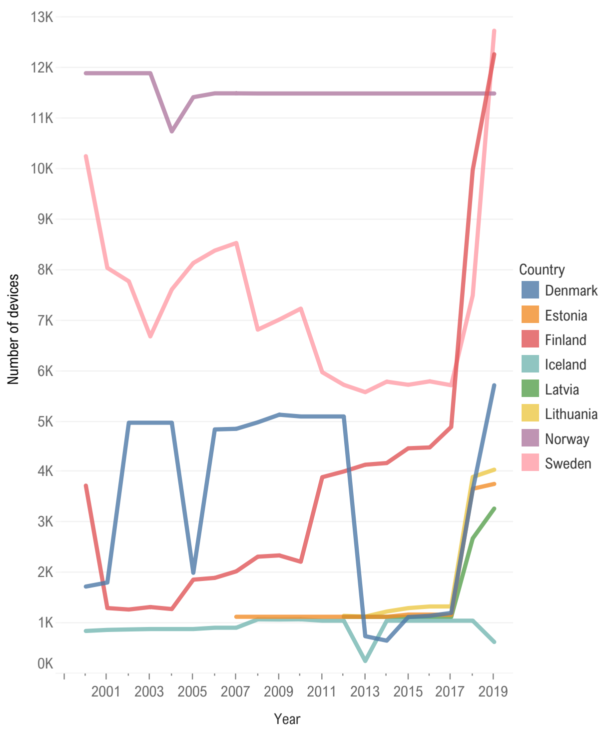

Figure E.8: Annual number of installed instrumental transformers, with all voltage levels combined, in each Nordic and Baltic country. Estonia has data since 2007, and Latvia and Lithuania have data since 2012.

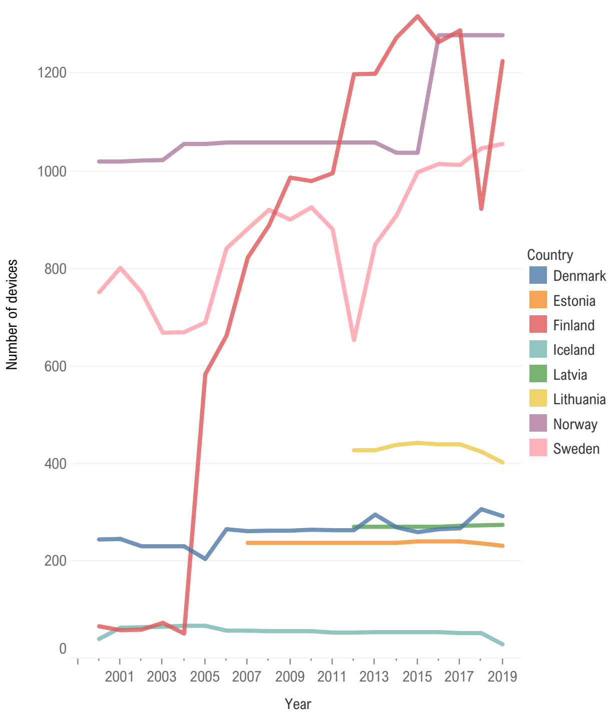

Figure E.9: Annual number of installed power transformers, with all voltage levels combined, in each Nordic and Baltic country. Estonia has data since 2007, and Latvia and Lithuania have data since 2012.

E.4 ENS compared to consumption and line length

Figure E.10 presents the annual amount of ENS compared against the total length of lines and consumption during 2010–2019 in the Nordic countries and Estonia and during 2012–2019 in Latvia and Lithuania. The total line length is the sum of the lengths of overhead lines and cables. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

One should note that there is a considerable difference from year to year depending on occasional events, such as storms. These events have a significant effect on each country's yearly statistics.

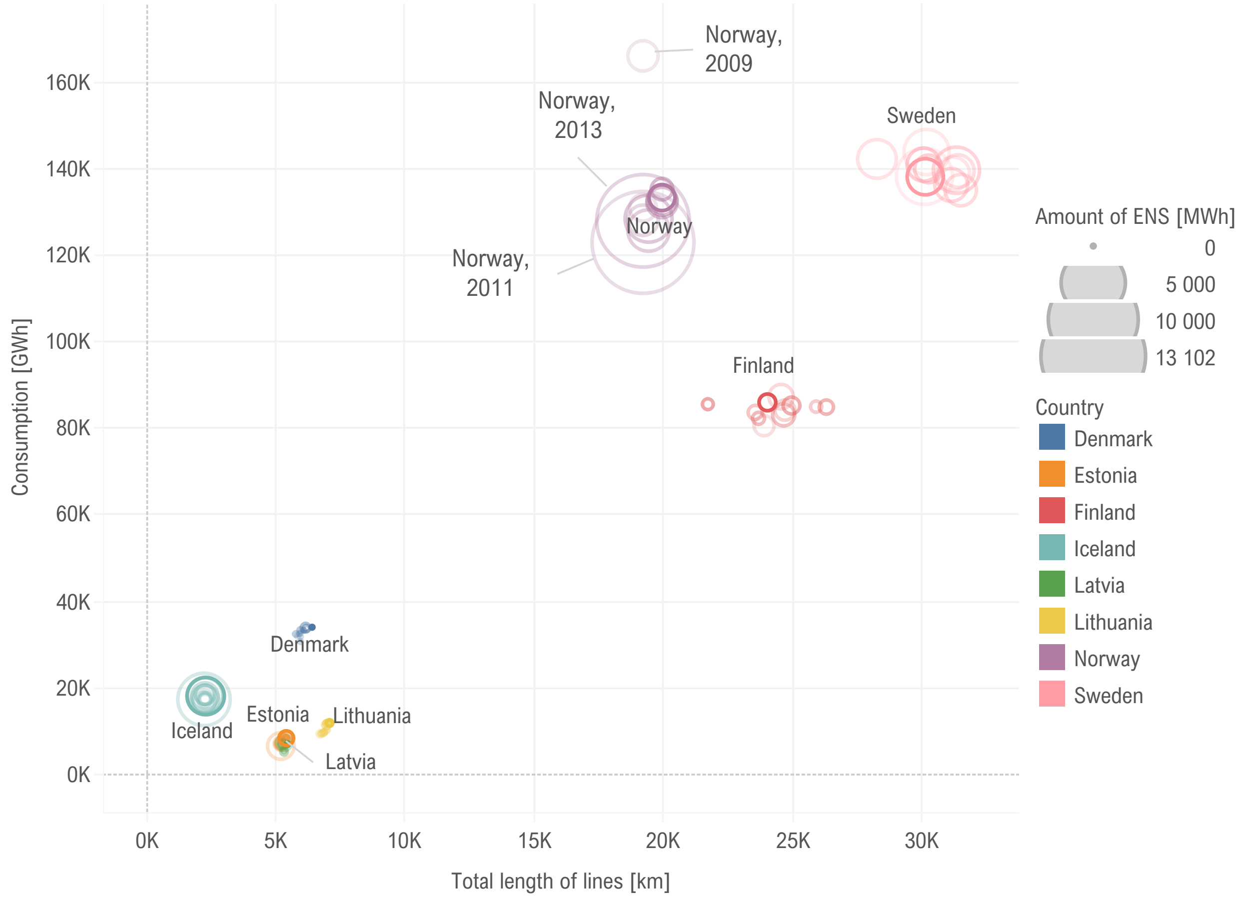

Figure E.10: The annual amount of ENS compared against the total length of lines (x-axis) and consumption (y-axis) during 2010–2019 in the Nordic countries and Estonia and during 2012–2019 in Latvia and Lithuania. The most recent statistical year 2019 is show with the darkest colour with each succeeding previous year show in a slightly lighter colour. The value of ENS is the total amount of ENS caused by all faults, that is, faults inside the statistical area and faults in adjacent grids that have caused ENS in the statistical area. This figure has the following remarks:

- Iceland's high values are a result of power intensive industries that cause substantial amounts of ENS even during short interruptions.
- The unusually high ENS divided by the consumption in 2011 in Norway was caused by extreme weather conditions in December (aka the storm named Dagmar).
- Denmark's low values are a result of various elements such as having a meshed grid and compared to the other Nordic countries, a mild climate.