2022 NORDIC AND BALTIC GRID DISTURBANCE STATISTICS

18 October 2023 (corrected on 2 January 2025)

From: Regional Group Nordic

Corrections made on 2 January 2025:

1. Corrected length of installed 380–420 kV overhead line for Finland in 2022.

2022 Nordic and Baltic Grid Disturbance Statistics

Report rendered 2 January 2025

ENTSO-E Mission Statement

Who we are

ENTSO-E, the European Network of Transmission System Operators for Electricity, is the association for the cooperation of the European transmission system operators (TSOs). The 39 member TSOs, representing 35 countries, are responsible for the secure and coordinated operation of Europe's electricity system, the largest interconnected electrical grid in the world. In addition to its core, historical role in technical cooperation, ENTSO-E is also the common voice of TSOs.

ENTSO-E brings together the unique expertise of TSOs for the benefit of European citizens by keeping the lights on, enabling the energy transition, and promoting the completion and optimal functioning of the internal electricity market, including via the fulfilment of the mandates given to ENTSO-E based on EU legislation.

Our mission

ENTSO-E and its members, as the European TSO community, fulfil a common mission: Ensuring the security of the interconnected power system in all time frames at pan-European level and the optimal functioning and development of the European interconnected electricity markets, while enabling the integration of electricity generated from renewable energy sources and of emerging technologies.

Our vision

ENTSO-E plays a central role in enabling Europe to become the first climate-neutral continent by 2050 by creating a system that is secure, sustainable and affordable, and that integrates the expected amount of renewable energy, thereby offering an essential contribution to the European Green Deal. This endeavour requires sector integration and close cooperation among all actors.

Europe is moving towards a sustainable, digitalised, integrated and electrified energy system with a combination of centralised and distributed resources. ENTSO-E acts to ensure that this energy system keeps consumers at its centre and is operated and developed with climate objectives and social welfare in mind.

ENTSO-E is committed to use its unique expertise and system-wide view – supported by a responsibility to maintain the system's security – to deliver a comprehensive roadmap of how a climate-neutral Europe looks.

Our values

ENTSO-E acts in solidarity as a community of TSOs united by a shared responsibility.

As the professional association of independent and neutral regulated entities acting under a clear legal mandate, ENTSO-E serves the interests of society by optimising social welfare in its dimensions of safety, economy, environment, and performance.

ENTSO-E is committed to working with the highest technical rigour as well as developing sustainable and innovative responses to prepare for the future and overcoming the challenges of keeping the power system secure in a climate-neutral Europe. In all its activities, ENTSO-E acts with transparency and in a trustworthy dialogue with legislative and regulatory decision makers and stakeholders.

Our contributions

ENTSO-E supports the cooperation among its members at European and regional levels. Over the past decades, TSOs have undertaken initiatives to increase their cooperation in network planning, operation and market integration, thereby successfully contributing to meeting EU climate and energy targets.

To carry out its legally mandated tasks, ENTSO-E's key responsibilities include the following:

› Development and implementation of standards, network codes, platforms and tools to ensure secure system and market operation as well as integration of renewable energy; › Assessment of the adequacy of the system in different timeframes;

› Coordination of the planning and development of infrastructures at the European level (Ten-Year Network Development Plans, TYNDPs);

› Coordination of research, development and innovation activities of TSOs;

› Development of platforms to enable the transparent sharing of data with market participants.

ENTSO-E supports its members in the implementation and monitoring of the agreed common rules.

ENTSO-E is the common voice of European TSOs and provides expert contributions and a constructive view to energy debates to support policymakers in making informed decisions.

Executive Summary

The 2022 Nordic and Baltic Grid Disturbance Statistics gives both an overview of the grid disturbances, faults, and energy not supplied (ENS) in the Nordic and Baltic 100–420 kV alternating current grids, as well as a deeper dive into the statistics of individual components used in the grids.

The year 2022 was good; disturbances had much smaller effect on the end-users compared to average years. ENS was only 54 % in Baltic and only 55 % in Nordic countries of the corresponding ten-year annual averages.

Year 2022 compared to ten-year annual averages:

- The number of faults and the number of disturbances was about 5 % smaller in Baltic and about 10 % higher in Nordic.
- The number of disturbances that caused ENS was only half in Baltic and on the same level in Nordic.

The grid components that caused the largest share of ENS in 2022 was overhead line in Finland 99 %, Iceland 59 %, Sweden 57 %, Lithuania 56 %, and Norway 45 %. In Estonia it was circuit breakers 91 %, in Latvia control equipment 74 %, and in Denmark busbars 49 %.

The causes of the overhead line faults are usually *lightning* and *environmental causes*.

In 2022 there were also external causes (Lithuania and Denmark) and unknown (Sweden and Finland). Unknown includes also causes not well enough examined and reported. Also these faults are most likely lightning and environmental causes. Policies for examining the cause of line faults are listed in Appendix B on page 51.

Table 1 shows the key figures of this report for each participating country.

Table 1: The number of faults, the number of disturbances, the fault to disturbance ratio, and ENS in 2022 and the corresponding annual averages for the 10-year period 2013–2022.

	Number of faults		No. of disturbances		Ratio		ENS (MWh)	
Country	2022	Annual avg. 2013–2022	2022	Annual avg. 2013–2022	2022	2013–2022	2022	Annual avg. 2013–2022
Estonia	149	172	144	165	1.0	1.0	50	74
Latvia	131	141	118	126	1.1	1.1	13	78
Lithuania	168	162	162	151	1.0	1.1	39	37
Baltic total	448	475	424	443	1.1	1.1	102	189
Denmark	85	72	80	65	1.1	1.1	37	34
Finland	596	436	572	418	1.0	1.0	125	256
Iceland	85	66	58	44	1.5	1.5	1269	797
Norway	323	341	292	301	1.1	1.1	418	2151
Sweden	435	456	426	438	1.0	1.0	650	1343
Nordic total	1524	1372	1428	1266	1.1	1.1	2498	4581
Baltic & Nordic total	1972	1847	1852	1708	1.1	1.1	2600	4770

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Glossary

Disturbance See grid disturbance.
DSO Distribution System Operator.
End-user "Buyers of electrical energy who do not resell all the energy" [1, p. 11].
Energy not supplied "The estimated energy which would have been supplied to end-users if no interruption and no transmission restrictions had occurred" [1, p. 12].
ENS Energy not supplied.
ENTSO-E European Network of Transmission System Operators for Electricity.
Fault "The inability of a component to perform its required function" [1, p. 3–4].
Fault cause "Cause relating to design, production, installation, operation or maintenance which results in a fault" [1, p. 7].
Grid disturbance "Outages, forced or unintended disconnection or failed re-connection (of a component) as a result of faults in the power grid" [1, p. 5].
HVAC High-voltage alternating current. As explained in Section 1.3, this report encompasses HVAC components in the 100–420 kV voltage range.
HVDC High-voltage direct current.
kV Kilovolt.
MWh Megawatt hour.
Nominal voltage "Value of the voltage by which the electrical installation or part of the electrical installation is designated and identified" [2].
ppm Parts per million.
Primary cause (of a fault) "Event or circumstance which leads to a fault" [1, p. 7].
Primary fault "A fault which initiates a grid disturbance" [1, p. 4].
RGN Regional Group Nordic.
Secondary fault A fault that aggravates a grid disturbance [1, p. 3–4].
SGU Significant Grid User.
Statistical area The area inside a country's borders. The statistical area is further limited to central components, as shown in Figure 1.2.
Statistical voltage level This report groups the voltage levels into three statistical voltage levels. The statistical voltage levels are 100–150 kV, 220–330 kV and 380–420 kV.
SVC Static var compensator.
TSO Transmission System Operator.
TWh Terawatt hour.

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1 Introduction

1.1 Description of the report

The 2022 Nordic and Baltic Grid Disturbance Statistics gives an overview of the faults, disturbances, and energy not supplied (ENS) in the Nordic and Baltic 100–420 kV alternating current power grids for the year 2022. Transmission System Operators (TSOs) 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.

All of Denmark is included in the disturbance data of this report, although only the grid of eastern Denmark belongs to the Nordic synchronous system.

The report includes faults causing grid disturbances or ENS in the 100–420 kV grids and it is made according to *Nordel's Guidelines for the Classification of Grid Disturbances* [1].

The report is organised into six chapters. Chapter 2 summarises the statistics, covering the consequences of disturbances in the form of ENS and covering the total number of disturbances in the Nordic and Baltic 100–420 kV grids. Besides, each TSO presents the key events of the year 2022.

Chapter 3 presents the grid disturbances and focuses on the allocation of their causes.

Chapter 4 presents the tables and figures of ENS for each country.

Chapter 5 presents secondary faults and their impact on the Nordic and Baltic transmission grids.

Chapter 6 presents an overview of faults causing grid disturbances in the Nordic and Baltic power grids and faults in the following components: cables, overhead lines, circuit breakers, control equipment, instrument transformers, power transformers, and compensation devices.

Appendices A–D describe how the TSO of each country calculates ENS, examines line fault causes, and contacts for TSOs as well as distribution network statistics. Appendix E includes additional figures.

1.2 History

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

In 2007, the language of the statistics was changed 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 the name of the report today.

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

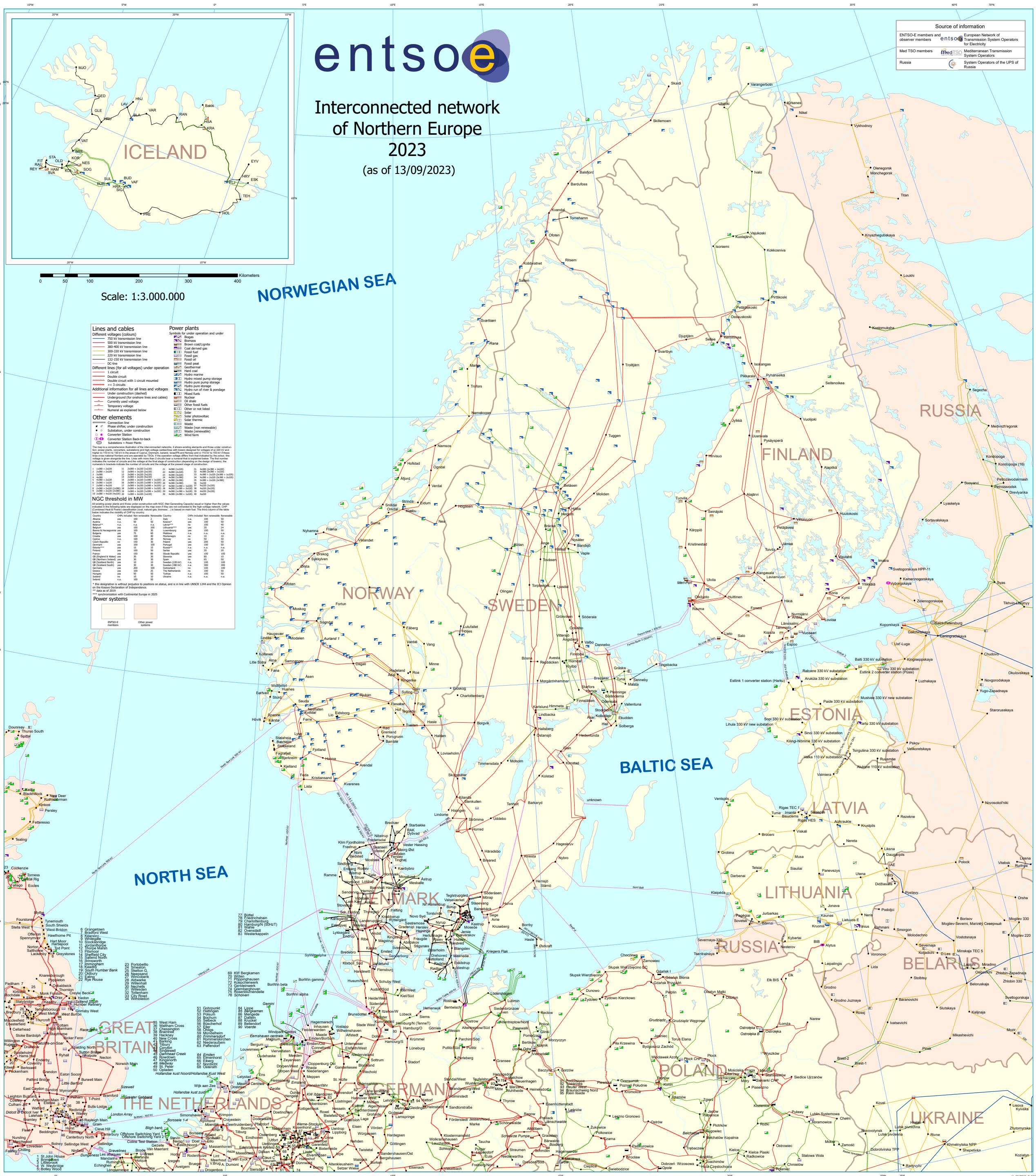

Figure 1.1: The Nordic and Baltic main grids [3] in 2023. All of Denmark is included in the disturbance data of this report although only the grid of eastern Denmark belongs to the Nordic synchronous area.

1.3 The scope and limitations of the statistics

The statistics comprise grid disturbances, faults causing ENS, and the amounts of ENS in the Nordic and Baltic 100–420 kV grids.

When a table or figure in these statistics does not explicitly state voltages, all voltages 100–420 kV are included.

The statistics do not comprise:

- Faults in production units;
- Faults having nominal voltages below 100 kV;
- Faults detected during maintenance or testing;
- Planned outages 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.
- High-voltage direct current (HVDC) units are not included in this report. ENTSO-E produces a separate report called *ENTSO-E HVDC Utilisation and Unavailability Statistics* [4].

Control equipment and installations for reactive compensation are included in the statistics if they control 100–420 kV systems. A graphical interpretation of the grid components included in the statistics is presented in Figure 1.2.

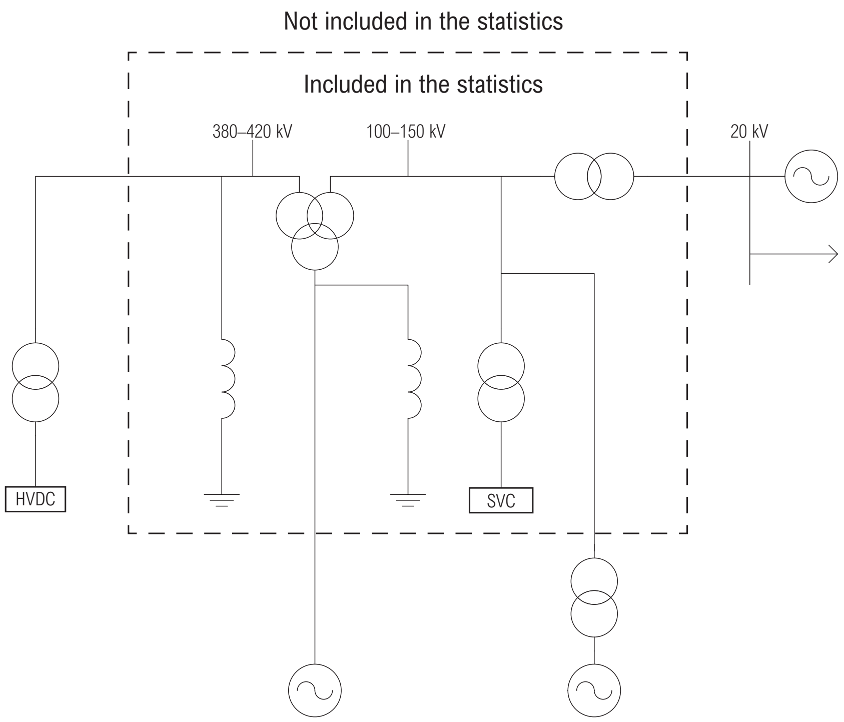

Figure 1.2: A graphical representation of the included grid components in the statistics.

Although the statistics are built upon common guidelines [1], there are slight differences in the interpretations between different countries and companies. These differences are considered to have a minor impact on the statistical material.

1.4 Available data in the report

Many figures and tables present data for 2022 or for 2013–2022. Some figures use data from longer periods. For example, moving average figures for component faults in Chapter 6 use data from 1995. However, not all participating TSO's have data since 1995. In these cases, the figures and tables show all the available data.

Many of the reported values are presented in percentages. When the calculations are done, the percentage values are rounded to the nearest decimal and may result in the total sum deviating slightly from 100 %.

1.5 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.

1.6 Fault causes

Each grid disturbance and fault has a cause connected to it. The used causes in this report are detailed in Table 1.1.

There are minor differences in the fault cause groupings between countries. This report uses the fault causes presented in Table 1.1. Appendix B describes how each Nordic and Baltic TSO examines the cause of line faults.

Table 1.1: The fault causes used in these statistics, the explanations being similar as in the Nordel guidelines [1, Tab. 5.1]. 'Other natural causes' has been renamed to 'environmental causes'.

Fault cause	Explanation
Lightning	Lightning is separated from the environmental causes because it causes a large share of overhead line faults in some countries and is therefore insignificant from a maintenance perspective.
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 causes	Operating problems, faults at customers', faults in other networks, issues in conjunction with faults in other components, system causes, other
Unknown	Unknown causes

1.7 Voltage levels in the Nordic and Baltic grids

Because slightly different voltage levels are used in each country, this report groups the voltage levels into three statistical voltage ranges. The statistical voltage in this report is the same as the nominal grid voltage at the fault.

When a table or figure in these statistics does not explicitly state voltages, all voltages 100–420 kV are included.

Table 1.2 presents the statistical voltage levels used in this report and their percentage allocation. Table 1.3 presents the coverage of the statistics in each country. The network statistics of each country cover data from several grid owners (TSOs and DSOs).

Table 1.2: Nominal voltage levels (U_N) included in this report and their percentage (p) allocation. Because slightly different voltage levels are used in each country, this report groups the voltage levels into the ranges below.

		Statistical voltage range, kV		
Country		100–150 kV	220–330 kV	380–420 kV
Denmark	U_N / p %	150 kV / 64 % 132 kV / 36 %	220 kV / 100 %	400 kV / 100 %
Estonia	U_N / p %	110 kV / 100 %	330 kV / 100 %	–
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[1]	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 %

[1] 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.

Table 1.3: Percentage of networks included in the statistics per statistical voltage level. The percentage is estimated per line length.

	Voltage level		
Country	100–150 kV	220–330 kV	380–420 kV
Denmark	100 %	100 %	100 %
Estonia	100 %	100 %	–
Finland	87 %	100 %	100 %
Iceland	100 %	100 %	–
Latvia	100 %	100 %	–
Lithuania	100 %	100 %	100 %
Norway	100 %	100 %	100 %
Sweden	76 %	99 %	100 %

2 Summary

In 2022, 1852 grid disturbances occurred in the Nordic and Baltic 100–420 kV grids, which is below the 10-year annual average of 1708 disturbances. The energy not supplied (ENS) due to faults in the Nordic grids amounted to 2498 MWh and 102 MWh in the Baltic. There were 2600 MWh of ENS in the Nordic and Baltic grids, which is only 55 % of the 10-year annual average. Out of all 1852 disturbances, 371 caused ENS in 2022.

The following sections present the summaries for each Nordic and Baltic country including the most significant issues in 2022.

2.1 Summary of Denmark

In Denmark, the ENS caused by grid disturbances was 37 MWh in 2022 (10-year annual average 34 MWh). There were 80 grid disturbances (10-year annual average 65) and 4 of them caused ENS.

In 2022, 50 % of the total ENS was caused by substation faults, and 50 % by overhead line faults. The most significant reasons for ENS caused by disturbances were environmental causes (85 %) and operation and maintenance (15 %). Disturbances were caused most by technical equipment (29 %) and and external influences (26 %).

Secondary faults in Denmark accounted for 6 % of all faults in 2022 and caused 45 % of the total ENS. Secondary faults were primarily caused by technical equipment (60 %) and operation and maintenance (40 %).

The three most significant disturbances in 2022 were the following:

- Due to a storm insulator on different substations got polluted with salt causing flashovers and components tripping in many places. This includes a complete substation due to a busbar fault. Furthermore, due to faulty protection settings at a nearby substation, another cable tripped leading to a total of two substations being disconnected from the grid. The resulting ENS was 31.4 MWh.
- After maintenance work at a substation the substation is being released to the control center which energize the substation. Unfortunately, maintenance contractor forgot to remove a temporary grounding, causing the total substation to trip. The resulting ENS was 3.1 MWh.
- A human error during coupling causes a substation to be disconnected from the grid. The resulting ENS was 2.0 MWh.

2.2 Summary of Estonia

In Estonia, the ENS caused by grid disturbances was 49,7 MWh in 2022 (10-year annual average is 74 MWh). There were 144 grid disturbances (10-year annual average 165) and 6 of them caused ENS.

In 2022, 98 % of the total ENS was caused by 110 kV substation faults, and 2 % by 110 kV overhead line faults. The most significant reasons for ENS caused by disturbances was external influences (91 %) and the other reason was technical equipment (2 %) and unknown (1 %). Disturbances were caused mostly by technical equipment (37 %) and environmental causes (22 %).

Secondary faults in Estonia accounted for 3 % of all faults in 2022 and did not cause ENS. Majority of secondary faults were caused by technical equipment (60 %).

The three most significant disturbances in the 110–400 kV grid in 2022 were the following:

- All the 110 kV cirquit breakers of 110 kV substation feeding the city and its surroundings were swiched off by an unknown person. ENS was 45.18 MWh.
- Because of the critical need to repair the terminals of the 110 kV disconnector it was necessary to make an interruption to the consumers. ENS was 2.07 MWh.
- 110 kV transformer tripped from non-selective back-up current protection due to failure of main protection. ENS was 0.9 MWh.

2.3 Summary of Finland

In Finland, the ENS caused by grid disturbances was 125 MWh in 2022 (10-year annual average 256 MWh). There were 572 grid disturbances (10-year annual average 418) and 73 (73) of them caused ENS.

In 2022, 99 % of the total ENS was caused by overhead line faults. The most significant reasons for ENS caused by technical equipment (26 %). Lightning and environmental causes formed 24 %. Disturbances were caused most by lightning and environmental causes (47 %). There were also lots of unknown and causes not reported by DSOs.

Secondary faults in Finland accounted for 3 % of all faults in 2022 and caused 6 % of the total ENS. Secondary faults were primarily caused by operation and maintenance 79 % (10-year annual average 43 %).

The three most significant disturbances in the 110–400 kV grid in 2022 were:

- One-phase fault on the 110 kV line. The post insulator of 110 kV disconnector broken. ENS 28 MWh.
- One-phase fault on 110 kV line. Outsider project. The piling machine was working too close to the line. ENS 20 MWh.
- One-phase fault on 110 kV line. The line protection relay fault. ENS 8 MWh.

2.4 Summary of Iceland

In Iceland, the ENS caused by grid disturbances was 1269 MWh in 2022 (10-year annual average 749 MWh). There were 58 grid disturbances (10-year annual average 41) and 31 of them caused ENS.

In 2022, 59 % of the total ENS was caused by overhead line faults, and 41 % of by substation faults. The most significant reasons for ENS caused disturbances were weather (43 %) and technical equipment (10 %).

Secondary faults in Iceland accounted for 12,9 % of all faults in 2022 and caused approximately 1 % of the total ENS. Secondary faults were primarily caused by technical equipment (73 %) and environmental cause (27 %), and the majority of ENS due to secondary fault was mainly caused by technical equipment (86 %).

The most significant disturbances in 2022 were the following:

- On 21 February 2022, one 220 kV overhead line BU3 disconnected 4 times during stormy weather with ice and high wind power. The total ENS was 86 MWh.
- On 25 February 2022, an extreme weather condition hit the country, one 220 kV transmission line BU2 tripped due to lighting strike. Geothermal station tripped 7 units and cause a widespread disturbance causing ENS at power intensive users. Total ENS was 514 MWh.
- On 25 February 2022, a fault occurred in PowerStation Sigalda and 220 kV busbar tripped. Four geothermal units disconnected, and system protection split the system in two islands. Total ENS in this disturbance was 163 MWh.

2.5 Summary of Latvia

In Latvia, the ENS caused by grid disturbances was 13,2 MWh in 2021 (10-year annual average 78 MWh). There were 118 grid disturbances (10-year annual average 126) and 8 of them caused ENS.

In 2022, 92 % of the total ENS was caused by substation faults, and 8 % by overhead line faults. The most significant reasons for ENS caused by disturbances were external influences (46 %) and technical equipment (43 %). Disturbances were caused most by environmental causes (53 %) and external influences (24 %).

Secondary faults in Latvia accounted for 10 % of all faults in 2022 and caused approximately 49 % of the total ENS. Secondary faults were primarily caused by operation and maintenance (54 %) and technical equipment (46 %), and all most ENS of the secondary faults was due to operation and maintenance.

The most significant disturbances in 2022 were the following:

- A tree gnawed by a beaver fell in overhead line and caused a secondary fault in the other lines control equipment. The disconnection of both lines resulted of one substation blackout. Underlying fault in communications did not allow dispatchers to reconnect undamaged line remotely. Overall result was 6,2 MWh of ENS.
- A fault from winds torn off roof part on 110 kV disconnector induced two secondary faults in independent control equipment – one was connected to differences in magnetizing curves of instrument transformers and other was due to mistake in primary operations. In summary it took outages of two overhead lines and two power transformers.
- Short-circuit in distribution grid caused a secondary fault in the control equipment of a power transformer. The disturbance resulted in 3,3 MWh of ENS due to planned outage of backup transformer.

2.6 Summary of Lithuania

In Lithuania, the ENS caused by grid disturbances was 38,7 MWh in 2022 (10-year annual average 37,3 MWh). There were 162 grid disturbances (10-year annual average 151) and 15 of them caused ENS.

In 2022, 56 % of the total ENS was caused by overhead line faults, and 44 % by substation faults. The most significant reasons for ENS caused by disturbances were external influences (58 %) and technical equipment (18 %). Disturbances were caused most by external influences (40 %) and unknown causes (19 %).

Secondary faults in Lithuania accounted for 2 % of all faults in 2022 and caused approximately 18 % of the total ENS. Secondary faults were primarily caused by technical equipment (75 %) and operation and maintenance (25 %).

The most significant disturbances in 2022 were the following:

- On 14 January 2022, multiple 110 kV overhead lines were disconnected due to very high winds which caused trees to fall on the lines. ENS was 13.3 MWh.
- On 11 May 2022, during construction works in Cukrus substation the last 110 kV overhead line of these substation was disconnected by short circuit caused by personnel of contractor. ENS was 3.5 MWh.
- On 4 Augus 2022, due to maintenance personnel mistake the 110 kV busbar tripped in Telšiai substation. ENS was 2.2 MWh.

2.7 Summary of Norway

In Norway, the ENS caused by grid disturbances was 418 MWh in 2022 (10-year annual average 2151 MWh). There were 292 grid disturbances (10-year annual average 301) and 76 of them caused ENS.

In 2022, 45 % of the total ENS was caused by overhead line faults, and 32 % by substation faults. The most significant reasons for ENS caused by disturbances were environmental causes (46 %) and operation and maintenance (36 %).

Secondary faults in Norway accounted for 10 % of all faults in 2022 and caused approximately 14 % of the total ENS. Secondary faults were primarily caused by technical equipment (42 %) and operation and maintenance (29 %), and the majority of ENS due to secondary faults was mainly caused by technical equipment (61 %).

The most significant disturbances in 2022 were a few events that led to separate network areas (islanding), e.g. this event:

- In January, two 420 kV overhead lines serving the most northern part of Norway both disconnected nearly simultaneously during stormy weather, leading to islanding of the area with a large production surplus. The frequency increased to more than 52 Hz, leading to automatic disconnection of practically all wind power in the area, and the frequency then decreased to 48 Hz. Frequency controlled system protection schemes took out about 100 MW load and the separate network then stabilized at 50 Hz. The 420 kV lines were reconnected after 15 minutes, and the disconnected load was uploaded.

2.8 Summary of Sweden

In Sweden, the ENS caused by grid disturbances was 650 MWh in 2022 (10-year annual average 1343 MWh). There were 426 grid disturbances (10-year annual average 438) and 158 of them caused ENS.

In 2022, 57 % of the total ENS was caused by overhead line faults, and 27 % by substation faults. The most significant reasons for ENS caused by disturbances were lightning (54 %) and other (25 %). Disturbances were caused most by unknown causes (35 %) and lightning (31 %).

Secondary faults in Sweden accounted for 2 % of all faults in 2022 and did not cause any ENS. Secondary faults were caused by technical equipment (44 %) and others (44 %).

In 2022, there were no notable grid disturbances that distinguished themselves from others. However, a few disturbances occurred on overhead lines, particularly on transmission towers. These disturbances were primarily caused by damaged parts resulting from strong winds and the natural wear and tear associated with an aging transmission network.

3 Disturbances

3.1 Overview

This chapter presents grid disturbances. The presentation includes an overview in Section 3.1, disturbances by month in Section 3.2, and disturbances by cause in Section 3.3.

Table 3.1 presents the number of grid disturbances in 2022 by country and the annual averages for 2013–2022, and Figure 3.1 shows the annual number of disturbances for 2013–2022, both in the 100–420 kV grids.

A grid disturbance is defined as:

> "Outages, forced or unintended disconnection or failed re-connection (of a component) as a result of faults in the power grid" [1, p. 5].

It is essential to note the difference between a grid disturbance and a fault. A grid disturbance is initiated by a fault, called the primary fault, and may be followed by consequential faults, called secondary faults. Only secondary faults that extend or aggravate a disturbance are included in this report.

The voltage level of a grid disturbance is determined by the voltage level of its primary fault.

Table 3.1: The number of disturbances and disturbances causing ENS in 2022, and their annual averages for 2013–2022 in the 100–420 kV grids.

	Disturbances		Disturbances causing ENS	
Country	Number 2022	Annual average 2013–2022	Number 2022	Annual average 2013–2022
Estonia	144	165.3	6	24.7
Latvia	118	126.5	8	14.4
Lithuania	162	151.0	15	16.7
Baltic total	424	442.8	29	55.8
Denmark	80	64.7	4	6.1
Finland	572	418.1	73	72.7
Iceland	58	44.5	31	19.7
Norway	292	300.9	76	79.1
Sweden	426	437.5	158	149.0
Nordic total	1428	1265.7	342	326.6
Baltic & Nordic total	1852	1708.5	371	382.4

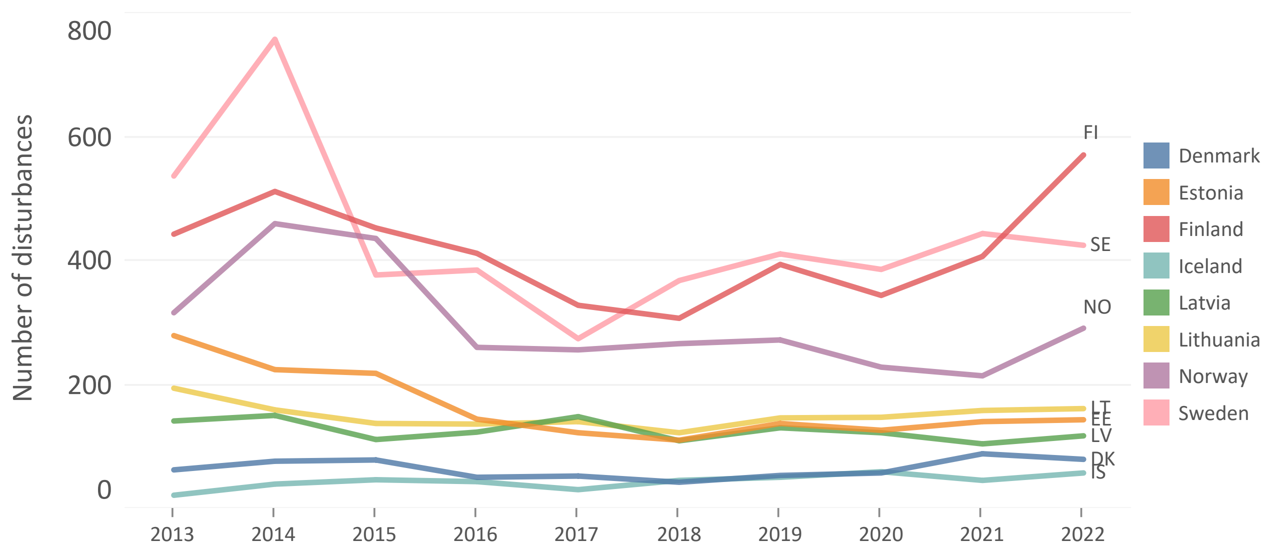

Figure 3.1: Annual number of grid disturbances in the 100–420 kV grids.

3.2 Disturbances by month

Table 3.2 presents the percentage allocation of grid disturbances in the 100–420 kV grids by month in 2022. Table 3.3 presents percentage allocation by month over 2013–2022.

Table 3.2: Percentage allocation of grid disturbances in the 100–420 kV grids by month in 2022. Proportionately higher percentage values are highlighted in yellow and red.

Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Estonia	11%	11%	6%	6%	11%	7%	10%	9%	8%	4%	3%	13%
Latvia	14%	3%	15%	3%	3%	10%	12%	17%	6%	6%	5%	6%
Lithuania	10%	4%	9%	5%	5%	12%	18%	24%	4%	2%	2%	3%
Denmark	19%	5%	4%	6%	8%	8%	8%	11%	15%	4%	5%	9%
Finland	14%	2%	6%	5%	7%	10%	16%	14%	5%	3%	3%	15%
Iceland	10%	41%	7%	2%	9%	0%	3%	2%	12%	9%	0%	5%
Norway	23%	16%	3%	3%	4%	7%	7%	9%	4%	9%	6%	9%
Sweden	5%	4%	3%	5%	7%	17%	16%	27%	4%	4%	3%	5%

Table 3.3: Percentage allocation of grid disturbances in the 100–420 kV grids by month over 2013–2022. Proportionately higher percentage values are highlighted in yellow and red.

Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Estonia	4%	4%	5%	6%	10%	13%	16%	19%	7%	7%	4%	5%
Latvia	4%	3%	7%	5%	8%	14%	12%	21%	8%	7%	4%	7%
Lithuania	4%	2%	7%	6%	9%	12%	17%	27%	5%	4%	3%	4%
Denmark	9%	6%	6%	6%	7%	8%	8%	11%	9%	9%	7%	14%
Finland	7%	3%	3%	6%	10%	14%	21%	14%	6%	4%	3%	7%
Iceland	11%	18%	13%	5%	5%	6%	6%	3%	8%	7%	5%	14%
Norway	16%	9%	8%	4%	4%	8%	11%	9%	6%	6%	8%	11%
Sweden	5%	4%	4%	4%	7%	14%	23%	19%	7%	5%	4%	5%

3.3 Disturbances by cause

This section presents grid disturbances in the 100–420 kV grids by cause, the cause defined as the cause of the disturbance's primary fault. The used causes are lightning, environmental causes, external influences, operation and maintenance, technical equipment, other causes and unknown. The causes are explained in more detail in Section 1.6.

Table 3.4 presents the percentage allocation of grid disturbances by cause in terms of the primary fault in 2022. Table 3.5 shows the respective percentages over 2013–2022.

Table 3.6 presents the percentage allocation of grid disturbances that caused ENS by cause in terms of the primary fault in 2022. Table 3.7 shows the respective percentages over 2013–2022.

Table 3.4: Grid disturbances (%) by cause for 2022. Proportionately higher percentage values are highlighted in yellow and red.

Country	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Unknown
Estonia	22%	8%	17%	38%	15%
Latvia	53%	24%	2%	14%	7%
Lithuania	17%	40%	6%	19%	19%
Denmark	24%	26%	15%	29%	6%
Finland	47%	3%	3%	4%	44%
Iceland	67%	2%	0%	31%	0%
Norway	51%	4%	11%	29%	4%
Sweden	33%	3%	3%	27%	35%

Table 3.5: Percentage allocation of grid disturbances by cause over 2013–2022. Proportionately higher percentage values are highlighted in yellow and red.

Country	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Unknown
Estonia	32%	8%	14%	37%	8%
Latvia	35%	24%	6%	18%	17%
Lithuania	13%	26%	7%	21%	33%
Denmark	19%	22%	19%	31%	9%
Finland	52%	2%	6%	21%	19%
Iceland	41%	2%	9%	45%	3%
Norway	53%	2%	14%	27%	4%
Sweden	40%	2%	7%	24%	28%

Table 3.6: Percentage allocation of grid disturbances that caused ENS by cause in 2022. Proportionately higher percentage values are highlighted in yellow and red.

Country	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Unknown
Estonia	0%	17%	0%	67%	17%
Latvia	63%	13%	0%	25%	0%
Lithuania	13%	67%	20%	0%	0%
Denmark	25%	0%	75%	0%	0%
Finland	33%	10%	10%	7%	41%
Iceland	81%	0%	0%	19%	0%
Norway	39%	5%	18%	30%	7%
Sweden	44%	0%	1%	31%	23%

Table 3.7: Percentage allocation of grid disturbances that caused ENS by cause over 2013–2022. Proportionately higher percentage values are highlighted in yellow and red.

Country	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Unknown
Estonia	12%	10%	26%	45%	8%
Latvia	35%	26%	17%	19%	3%
Lithuania	14%	41%	24%	14%	7%
Denmark	11%	0%	49%	34%	5%
Finland	31%	3%	10%	21%	34%
Iceland	54%	2%	11%	31%	1%
Norway	52%	2%	20%	23%	3%
Sweden	40%	2%	8%	23%	27%

4 Energy not supplied

This chapter presents energy not supplied (ENS) caused by grid disturbances. The presentation includes the amount of ENS in 2022 by country and the annual averages for 2013–2022. Furthermore, ENS is compared to consumption in Section 4.2, allocated by month in Section 4.3, allocated by cause in Section 4.4, allocated by voltage level in Section 4.5, and examined at component level in Section 4.6.

4.1 Overview

Table 4.1 shows the amount of ENS in 2022 by country and the annual averages for 2013–2022.

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” [1].

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.

Table 4.1: ENS in 2022 and the annual averages for 2013–2022.

	ENS (MWh)	
Country	2022	Annual average 2013–2022
Estonia	49.7	74.0
Latvia	13.2	77.9
Lithuania	38.7	37.3
Baltic total	101.5	189.2
Denmark	36.8	33.9
Finland	125.1	256.3
Iceland	1268.6	796.9
Norway	418.0	2150.7
Sweden	649.6	1343.2
Nordic total	2498.1	4580.9
Baltic & Nordic total	2599.6	4770.1

4.2 Energy not supplied and total consumption

This section presents ENS normalised by the total electricity consumption. Table 4.2 shows the consumption, ENS, and the ENS to consumption ratio.

Figure 4.1 presents the 5-year moving average of ENS scaled to consumption since 2000 in the Nordic countries, since 2007 in Estonia, and since 2012 in Latvia and Lithuania.

There is a considerable annual variance due to occasional events, such as storms. These events have a significant effect on each country's annual statistics.

More information on past events are available in the previous Nordic and Baltic statistics and from the contact persons in Appendix C. Iceland's high values, seen in Table 4.2 and Figure 4.1, are a result of power intensive industries that cause substantial amounts of ENS even during short interruptions.

Table 4.2: Electricity consumption, ENS, and their ratio in 2022 and the corresponding annual averages for 2013–2022. Ppm (parts per million) represents ENS (MWh) as a proportional value of the consumed energy (TWh).

Country	Consumption (TWh) 2022	ENS (MWh) 2022	ENS / consumption (ppm) 2022	ENS / consumption (ppm) Annual average 2013–2022
Estonia	9.0	49.7	5.5	8.8
Latvia	7.4	13.2	1.8	11.0
Lithuania	12.0	38.7	3.2	3.3
Baltic total	28.4	101.5	3.6	7.1
Denmark	35.5	36.8	1.0	1.0
Finland	79.2	125.1	1.6	3.1
Iceland	19.1	1268.6	66.4	43.6
Norway	131.6	418.0	3.2	16.4
Sweden	136.7	649.6	4.8	9.7
Nordic total	402.1	2498.1	6.2	11.3
Baltic & Nordic total	430.5	2599.6	6.0	11.0

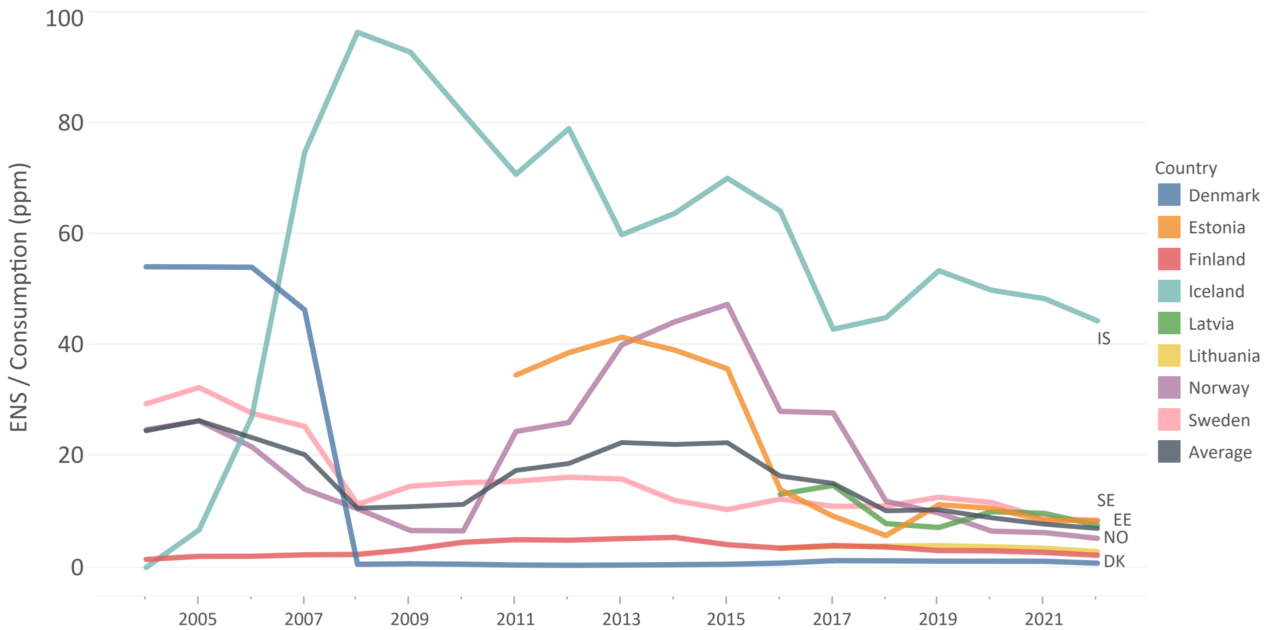

Figure 4.1: 5-year moving average for the amount of ENS divided by consumption (ppm) since 2000. Estonia has data since 2007 and since Latvia and Lithuania have data since 2012. Ppm (parts per million) represents ENS (MWh) as a proportional value of the consumed energy (TWh).

4.3 Energy not supplied by month

This section presents ENS due to disturbances that occurred in the 100–420 kV grids by month. Table 4.3 shows the percentage allocation of ENS by month in 2022 and Table 4.4 presents the respective percentage values over 2013–2022.

Table 4.3: ENS (%) by month in 2022. Proportionately higher percentage values are highlighted in yellow and red.

Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Estonia	0%	0%	2%	91%	0%	1%	0%	0%	1%	1%	0%	4%
Latvia	3%	3%	4%	0%	0%	0%	0%	0%	0%	25%	64%	0%
Lithuania	50%	2%	6%	5%	9%	21%	1%	6%	0%	1%	0%	0%
Denmark	85%	0%	0%	0%	0%	0%	0%	8%	6%	0%	0%	0%
Finland	22%	1%	25%	1%	0%	8%	24%	1%	1%	0%	1%	17%
Iceland	10%	72%	3%	0%	1%	0%	0%	0%	3%	12%	0%	1%
Norway	21%	4%	0%	39%	3%	5%	5%	4%	1%	4%	6%	7%
Sweden	1%	0%	0%	4%	3%	19%	12%	34%	0%	5%	10%	12%

Table 4.4: Percentage allocation of ENS by month over 2013–2022. Proportionately higher percentage values are highlighted in yellow and red.

Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Estonia	10%	6%	5%	8%	7%	4%	6%	4%	10%	31%	5%	4%
Latvia	2%	0%	2%	0%	4%	23%	7%	9%	7%	36%	4%	6%
Lithuania	6%	8%	13%	6%	7%	24%	17%	7%	2%	6%	3%	2%
Denmark	14%	14%	4%	4%	3%	5%	1%	11%	9%	26%	3%	8%
Finland	8%	2%	11%	6%	4%	8%	17%	16%	3%	6%	5%	15%
Iceland	17%	27%	6%	1%	2%	7%	4%	1%	3%	3%	2%	27%
Norway	9%	10%	48%	5%	1%	5%	3%	3%	3%	2%	7%	4%
Sweden	6%	6%	4%	3%	7%	15%	23%	15%	5%	7%	5%	4%

4.4 Energy not supplied by cause

This section presents ENS by the cause of each fault. The used causes are lightning, environmental causes, external influences, operation and maintenance, technical equipment, other causes and unknown. The causes are explained in more detail in Section 1.6.

Table 4.5 presents the percentage allocation of ENS by cause in 2022. Table 4.6 shows the respective percentages over 2013–2022.

Table 4.5: ENS (%) by cause in 2022. Proportionately higher percentage values are highlighted in yellow and red.

Country	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Unknown
Estonia	0%	91%	0%	8%	1%
Latvia	8%	0%	46%	46%	0%
Lithuania	7%	58%	17%	18%	0%
Denmark	41%	0%	59%	0%	0%
Finland	24%	17%	4%	26%	29%
Iceland	75%	0%	0%	25%	0%
Norway	41%	1%	8%	49%	1%
Sweden	61%	0%	4%	29%	6%

Table 4.6: Percentage allocation of ENS by cause over 2013–2022. Proportionately higher percentage values are highlighted in yellow and red.

Country	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Unknown
Estonia	1%	7%	14%	77%	1%
Latvia	41%	12%	39%	8%	0%
Lithuania	11%	37%	14%	37%	2%
Denmark	12%	0%	58%	29%	1%
Finland	26%	4%	10%	49%	12%
Iceland	41%	1%	15%	43%	0%
Norway	62%	1%	5%	29%	2%
Sweden	31%	5%	6%	40%	19%

The reason behind 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.

4.5 Energy not supplied by voltage level

Table 4.7 and Table 4.8 show the amount of ENS and its allocation by voltage level in 2022 and for 2013–2022.

Table 4.7: ENS in 2022 and its annual average for 2013–2022, and the annual average amount of ENS by voltage level for 2013–2022.

	ENS (MWh)		Average annual ENS (MWh) by voltage level over 2013–2022			
Country	2022	Annual average 2013–2022	100–150 kV	220–330 kV	380–420 kV	Other[1]
Estonia	49.7	74.0	51.8	5.9	0.0	24.2
Latvia	13.2	77.9	60.3	17.5	0.0	0.1
Lithuania	38.7	37.3	36.7	0.1	0.0	0.6
Baltic total	101.5	189.2	148.8	23.5	0.0	24.9
Denmark	36.8	33.9	31.9	0.0	1.0	1.2
Finland	125.1	256.3	235.7	0.9	0.0	35.1
Iceland	1268.6	796.9	308.6	367.6	0.0	218.9
Norway	418.0	2150.7	846.0	258.4	1030.5	15.8
Sweden	649.6	1343.2	1080.0	111.5	52.8	127.4
Nordic total	2498.1	4580.9	2502.2	738.4	1084.3	398.3
Baltic & Nordic total	2599.6	4770.1	2651.0	761.9	1084.3	423.2

[1] The category *Other* contains ENS from, for example, system faults, lower voltage level networks and connections to foreign countries.

Table 4.8: ENS (MWh) by statistical voltage level in 2022.

Country	100–150 kV	220–330 kV	380–420 kV
Estonia	49,7	0,0	0,0
Latvia	13,2	0,0	0,0
Lithuania	38,7	0,0	0,0
Denmark	36,8	0,0	0,0
Finland	124,8	0,3	0,0
Iceland	179,4	807,5	0,0
Norway	360,3	33,8	0,2
Sweden	300,2	247,6	0,1
Baltic & Nordic	1103,0	1089,1	0,3

4.6 Energy not supplied by component

Table 4.9 presents the percentage allocation of ENS by component in 2022, and Table 4.10 shows the respective percentages over 2013–2022. The ENS is allocated to the component where each fault occurred. The total amount of ENS in 2022 and the annual average values for 2013–2022 are in Table 4.7.

Table 4.9: ENS (%) by component in 2022. The ENS is allocated to the component where each fault occurred. Proportionately higher percentage values are highlighted in yellow and red.

Lines
- Cables
- Overhead lines

Substation components
- Busbars
- Circuit breakers
- Common ancillary equipment
- Control equipment
- Disconnectors
- Instrument transformers
- Power transformers
- Surge arresters and spark gaps
- Other high voltage appliances

Compensation devices
- Reactors
- Series capacitors
- Shunt capacitors
- SVC and statcom
- Synchronous compensators

Other
- Adjoining grid
- System faults

	Lines			Substation components										Compensation devices						Other		
	Cables	Overhead lines	Total	Busbars	Circuit breakers	Common ancillary equipment	Control equipment	Disconnectors	Instrument transformers	Power transformers	Surge arresters and spark gaps	Other high voltage appliances	Total	Reactors	Series capacitors	Shunt capacitors	SVC	Synchronous compensators	Total	Adjoining grid	System faults	Total
Estonia	0%	2%	2%	0%	91%	0%	2%	4%	0%	1%	0%	0%	98%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Latvia	0%	8%	8%	0%	0%	0%	74%	0%	18%	0%	0%	0%	92%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Lithuania	0%	56%	56%	21%	0%	0%	24%	0%	0%	0%	0%	0%	44%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Denmark	45%	5%	50%	49%	0%	0%	0%	0%	0%	1%	0%	0%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Finland	0%	99%	99%	0%	0%	0%	0%	0%	1%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Iceland	0%	59%	59%	0%	0%	0%	2%	0%	13%	1%	3%	0%	18%	0%	0%	0%	0%	0%	0%	22%	0%	22%
Norway	17%	45%	62%	0%	8%	0%	13%	3%	5%	2%	0%	2%	32%	0%	0%	0%	0%	0%	0%	0%	6%	6%
Sweden	0%	57%	57%	0%	12%	0%	7%	0%	0%	8%	0%	0%	27%	0%	0%	0%	0%	0%	0%	16%	0%	16%

Table 4.10: Percentage allocation of ENS by component over 2013–2022. The ENS is allocated to the component where each fault occurred. Proportionately higher percentage values are highlighted in yellow and red. The symbols are presented in Table 4.9.

	Lines			Substation components										Compensation devices						Other		
	Cables	Overhead lines	Total	Busbars	Circuit breakers	Common ancillary equipment	Control equipment	Disconnectors	Instrument transformers	Power transformers	Surge arresters and spark gaps	Other high voltage appliances	Total	Reactors	Series capacitors	Shunt capacitors	SVC	Synchronous compensators	Total	Adjoining grid	System faults	Total
Estonia	0%	11%	11%	0%	9%	0%	17%	2%	1%	2%	0%	21%	52%	0%	0%	4%	0%	0%	4%	33%	0%	33%
Latvia	0%	52%	52%	3%	1%	0%	37%	3%	1%	3%	0%	0%	47%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Lithuania	1%	51%	52%	3%	6%	0%	26%	8%	2%	0%	1%	0%	47%	0%	0%	0%	0%	0%	0%	2%	0%	2%
Denmark	5%	3%	7%	52%	10%	0%	12%	3%	7%	6%	0%	0%	89%	0%	0%	0%	0%	0%	0%	4%	0%	4%
Finland	0%	59%	60%	2%	4%	0%	6%	1%	6%	4%	0%	2%	25%	0%	1%	0%	0%	0%	1%	13%	1%	14%
Iceland	1%	20%	21%	0%	6%	0%	15%	0%	2%	17%	1%	10%	51%	0%	0%	0%	0%	0%	0%	18%	10%	27%
Norway	5%	58%	63%	3%	2%	1%	13%	4%	4%	1%	4%	3%	36%	0%	0%	0%	0%	0%	0%	0%	1%	1%
Sweden	1%	48%	49%	4%	3%	1%	8%	3%	6%	6%	2%	5%	39%	1%	0%	1%	0%	0%	2%	9%	0%	9%

5 Secondary faults

5.1 Overview

This chapter presents statistics about secondary faults, that is, faults that extend or aggravate a grid disturbance.

The number of disturbances with secondary faults is significantly smaller than the number of disturbances with only one fault. However, these disturbances may cause more ENS.

Table 5.1 presents an overview of faults connected to grid disturbances as well as the secondary faults.

Table 5.1: The number of faults (including secondary faults), the number of faults that caused ENS, total ENS, the number of secondary faults, and the amount of ENS caused by secondary faults in 2022.

	Faults in 2022			Secondary faults in 2022	
Country	Number	causing ENS	ENS (MWh)	Number	ENS (MWh)
Estonia	149	6	49.7	5	0.0
Latvia	131	8	13.2	13	6.5
Lithuania	168	16	38.7	4	7.0
Baltic total	448	30	101.5	22	13.5
Denmark	85	5	36.8	5	16.4
Finland	596	76	125.1	19	7.7
Iceland	85	30	1268.6	11	13.8
Norway	323	80	418.0	31	60.1
Sweden	435	158	649.6	9	0.0
Nordic total	1524	349	2498.1	75	98.1
Baltic & Nordic total	1972	379	2599.6	97	111.6

5.2 Statistics of secondary faults

Table 5.2 presents the percentage allocation of secondary faults by cause in 2022, and Table 5.3 shows the respective values over 2017–2022. Table 5.4 presents the annual number of secondary faults for 2017–2022.

Table 5.5 presents the percentage allocation of ENS due to secondary faults in 2022, and Table 5.6 shows the respective values over 2017–2022. Table 5.7 presents the annual amounts of ENS caused by the secondary faults for 2017–2022.

Data about secondary faults have been collected since 2017.

Table 5.2: Percentage allocation of secondary faults by cause in 2022. Proportionately higher percentage values are highlighted in yellow and red.

Country	Environmental causes	External influences	Operation and maintenance	Technical equipment	Unknown
Estonia	0%	0%	60%	0%	40%
Latvia	0%	0%	54%	46%	0%
Lithuania	0%	0%	25%	75%	0%
Denmark	0%	0%	40%	60%	0%
Finland	11%	0%	79%	5%	5%
Iceland	27%	0%	0%	73%	0%
Norway	16%	0%	29%	52%	3%
Sweden	0%	11%	0%	89%	0%

Table 5.3: Percentage allocation of secondary faults by cause over 2017–2022. Proportionately higher percentage values are highlighted in yellow and red.

Country	Environmental causes	External influences	Operation and maintenance	Technical equipment	Unknown
Estonia	6%	6%	29%	50%	8%
Latvia	0%	0%	40%	56%	4%
Lithuania	2%	0%	27%	37%	35%
Denmark	0%	3%	71%	26%	0%
Finland	20%	5%	43%	22%	10%
Iceland	13%	0%	4%	83%	0%
Norway	27%	1%	22%	44%	5%
Sweden	5%	1%	4%	80%	9%

Table 5.4: Annual number of secondary faults for 2017–2022.

Country	2017	2018	2019	2020	2021	2022	Annual average
Estonia	9	8	7	15	4	5	8,0
Latvia	20	20	23	9	16	13	10,0
Lithuania	13	19	18	6	0	4	16,8
Denmark	9	3	6	5	3	5	5,2
Finland	13	9	6	18	16	19	13,5
Iceland	8	18	26	22	14	11	16,5
Norway	30	34	26	28	36	31	30,8
Sweden	10	7	14	9	27	9	12,7
Baltic & Nordic	112	118	126	112	116	97	113,5

Table 5.5: Percentage allocation of ENS due to secondary faults by cause in 2022. Proportionately higher percentage values are highlighted in yellow and red.

Country	Environmental causes	External influences	Operation and maintenance	Technical equipment	Unknown
Estonia	0%	0%	0%	0%	0%
Latvia	0%	0%	94%	6%	0%
Lithuania	0%	0%	0%	100%	0%
Denmark	0%	0%	100%	0%	0%
Finland	0%	0%	6%	0%	94%
Iceland	14%	0%	0%	86%	0%
Norway	3%	0%	7%	90%	0%
Sweden	0%	0%	0%	0%	0%

Table 5.6: Percentage allocation of ENS due to secondary faults by cause over 2017–2022. Proportionately higher percentage values are highlighted in yellow and red.

Country	Environmental causes	External influences	Operation and maintenance	Technical equipment	Unknown
Estonia	0%	1%	19%	79%	0%
Latvia	0%	0%	95%	5%	0%
Lithuania	0%	0%	1%	99%	0%
Denmark	0%	0%	92%	8%	0%
Finland	27%	1%	10%	54%	9%
Iceland	4%	0%	0%	96%	0%
Norway	23%	27%	9%	42%	0%
Sweden	0%	0%	0%	84%	16%

Table 5.7: Annual amount of ENS (MWh) due to secondary faults for 2017–2022.

Country	2017	2018	2019	2020	2021	2022	Annual average
Estonia	0,1	0,3	0,1	0,1	1,2	0,0	0,3
Latvia	16,0	34,1	2,2	163,3	8,6	6,5	38,4
Lithuania	50,0	25,2	0,5	24,1	0,0	7,0	17,8
Denmark	4,0	0,3	4,7	0,0	0,0	16,4	4,2
Finland	6,0	48,2	12,6	12,9	15,3	7,7	17,1
Iceland	0,0	0,0	0,2	84,1	4,7	13,8	17,1
Norway	58,8	131,3	71,3	167,2	130,9	60,1	103,3
Sweden	32,0	0,0	8,4	0,0	10,2	0,0	8,4
Baltic & Nordic	166,9	239,3	100,0	451,7	170,9	111,6	206,7

6 Faults in power system components

This chapter presents an overview of all faults related to grid disturbances. Furthermore, faults for each type of power system component are shown. Some figures and tables show values normalised by the length of overhead line or cable, or the number of installed components in each country to allow comparable results.

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

6.1 Overview of faults

This section presents an overview of faults. A fault is defined as:

> "The inability of a component to perform its required function" [1, p. 3–4].

This report includes only faults that caused, aggravated or extended a grid disturbance. The causes are presented in more detail in Section 1.6.

Table 6.1 presents the number of faults and the energy not supplied (ENS) caused by them in 2022 and for 2013–2022. Table 6.2 shows the number of faults and number of grid disturbances in 2022, their annual averages for 2013–2022, and the faults to disturbance ratio over 2013–2022.

Table 6.3 shows the percentage allocation of faults per component in 2022, and Table 6.4 shows the respective percentages over 2013–2022. The component groups used in these statistics are further described in the guidelines [1, Section 5.4.10].

Table 6.1: The number of faults, the number of faults that caused ENS and amount of ENS in 2022 and their annual averages for 2013–2022.

	Number of faults		No. of faults with ENS		ENS (MWh)	
Country	2022	Annual avg. 2013–2022	2022	Annual avg. 2013–2022	2022	Annual avg. 2013–2022
Estonia	149	172.2	6	24.8	49.7	74.0
Latvia	131	140.8	8	15.4	13.2	77.9
Lithuania	168	161.9	16	16.9	38.7	37.3
Baltic total	448	474.9	30	57.1	101.5	189.2
Denmark	85	72.4	5	6.8	36.8	33.9
Finland	596	436.0	76	78.0	125.1	256.3
Iceland	85	66.0	30	21.6	1268.6	796.9
Norway	323	341.1	80	88.4	418.0	2150.7
Sweden	435	456.4	158	174.3	649.6	1343.2
Nordic total	1524	1371.9	349	369.1	2498.1	4580.9
Baltic & Nordic total	1972	1846.8	379	426.2	2599.6	4770.1

Table 6.2: The number of faults and the number of grid disturbances in 2022, their annual averages for 2013–2022, and the fault to disturbance ratio in 2022 and over 2013–2022.

	Number of faults		No. of disturbances		Ratio	
Country	2022	Annual avg. 2013–2022	2022	Annual avg. 2013–2022	2022	Annual avg. 2013–2022
Estonia	149	172.2	144	165.3	1.0	1.0
Latvia	131	140.8	118	126.5	1.1	1.1
Lithuania	168	161.9	162	151.0	1.0	1.1
Baltic total	448	474.9	424	442.8	1.1	1.1
Denmark	85	72.4	80	64.7	1.1	1.1
Finland	596	436.0	572	418.1	1.0	1.0
Iceland	85	66.0	58	44.5	1.5	1.5
Norway	323	341.1	292	300.9	1.1	1.1
Sweden	435	456.4	426	437.5	1.0	1.0
Nordic total	1524	1371.9	1428	1265.7	1.1	1.1
Baltic & Nordic total	1972	1846.8	1852	1708.5	1.1	1.1

Table 6.3: Percentage allocation of faults by component in 2022. Proportionately higher percentage values are highlighted in yellow and red.

Lines
- Cables
- Overhead lines

Substation components
- Busbars
- Circuit breakers
- Common ancillary equipment
- Control equipment
- Disconnectors
- Instrument transformers
- Power transformers
- Surge arresters and spark gaps
- Other high voltage appliances

Compensation devices
- Reactors
- Series capacitors
- Shunt capacitors
- SVC and statcom
- Synchronous compensators

Other
- Adjoining grid
- System faults

	Lines			Substation components										Compensation devices						Other		
	Cables	Overhead lines	Total	Busbars	Circuit breakers	Common ancillary equipment	Control equipment	Disconnectors	Instrument transformers	Power transformers	Surge arresters and spark gaps	Other high voltage appliances	Total	Reactors	Series capacitors	Shunt capacitors	SVC	Synchronous compensators	Total	Adjoining grid	System faults	Total
Estonia	1%	44%	45%	1%	10%	1%	10%	4%	3%	12%	1%	0%	42%	1%	0%	0%	0%	0%	1%	11%	0%	11%
Latvia	1%	75%	76%	0%	1%	0%	12%	1%	4%	1%	0%	0%	18%	0%	0%	0%	0%	0%	0%	6%	0%	6%
Lithuania	0%	73%	73%	1%	2%	0%	8%	0%	0%	0%	1%	0%	11%	0%	0%	0%	0%	0%	0%	16%	0%	16%
Denmark	9%	59%	68%	7%	1%	0%	0%	0%	0%	8%	0%	0%	16%	4%	0%	4%	0%	0%	7%	8%	0%	8%
Finland	0%	83%	83%	0%	1%	0%	5%	0%	2%	1%	0%	7%	15%	0%	2%	0%	0%	0%	2%	0%	0%	0%
Iceland	0%	47%	47%	0%	1%	0%	9%	2%	1%	6%	1%	6%	27%	0%	0%	1%	0%	0%	1%	25%	0%	25%
Norway	3%	51%	54%	0%	2%	1%	20%	2%	4%	2%	1%	2%	35%	1%	0%	0%	3%	1%	5%	0%	6%	6%
Sweden	0%	71%	71%	0%	2%	0%	6%	0%	0%	2%	0%	0%	11%	0%	3%	0%	0%	0%	4%	13%	1%	14%

Table 6.4: Percentage allocation of faults by component over 2013–2022. Proportionately higher percentage values are highlighted in yellow and red. The symbols are presented in Table 6.3.

	Lines			Substation components										Compensation devices						Other		
	Cables	Overhead lines	Total	Busbars	Circuit breakers	Common ancillary equipment	Control equipment	Disconnectors	Instrument transformers	Power transformers	Surge arresters and spark gaps	Other high voltage appliances	Total	Reactors	Series capacitors	Shunt capacitors	SVC	Synchronous compensators	Total	Adjoining grid	System faults	Total
Estonia	0%	51%	52%	2%	6%	1%	9%	4%	2%	7%	0%	5%	36%	1%	0%	1%	0%	0%	2%	11%	0%	11%
Latvia	0%	67%	67%	1%	2%	0%	14%	1%	2%	4%	0%	0%	24%	0%	0%	0%	0%	0%	0%	9%	0%	9%
Lithuania	0%	68%	68%	1%	4%	1%	9%	1%	1%	1%	1%	0%	18%	0%	0%	0%	0%	0%	0%	13%	0%	13%
Denmark	6%	44%	50%	4%	4%	0%	12%	1%	2%	7%	1%	3%	35%	2%	0%	1%	1%	3%	6%	10%	0%	10%
Finland	0%	82%	82%	0%	1%	0%	6%	0%	1%	2%	0%	2%	13%	0%	1%	0%	0%	0%	2%	3%	0%	3%
Iceland	0%	33%	33%	0%	5%	0%	13%	1%	0%	4%	0%	4%	28%	0%	0%	1%	0%	0%	1%	21%	16%	38%
Norway	2%	50%	52%	1%	4%	2%	19%	1%	2%	2%	1%	7%	39%	0%	0%	1%	5%	1%	7%	0%	2%	2%
Sweden	1%	61%	62%	1%	2%	0%	12%	2%	1%	5%	0%	1%	25%	1%	1%	0%	1%	0%	4%	9%	0%	9%

6.2 Faults by cause

This section presents faults according to cause, with the cause of a fault defined as the primary cause of the fault. The used causes are lightning, environmental causes, external influences, operation and maintenance, technical equipment, other causes and unknown. The causes are explained in more detail in Section 1.6.

There are minor differences in the fault cause groupings between countries. This report uses the fault causes presented in Table 1.1. Appendix B describes how each Nordic and Baltic TSO examines the cause of line faults.

Table 6.5 presents the percentage allocation of faults by cause in 2022. Table 6.6 shows the respective percentages over 2013–2022.

Table 6.7 presents the percentage allocation of faults that caused ENS by cause in 2022. Table 6.8 shows the respective percentages over 2013–2022.

Table 6.5: Percentage allocation of the number of faults by cause in 2022. Proportionately higher percentage values are highlighted in yellow and red.

Country	Environmental causes	External influences	Operation and maintenance	Technical equipment	Unknown
Estonia	21%	7%	19%	37%	15%
Latvia	48%	21%	7%	18%	6%
Lithuania	16%	38%	7%	21%	18%
Denmark	22%	25%	16%	31%	6%
Finland	45%	3%	5%	4%	43%
Iceland	49%	1%	0%	49%	0%
Norway	47%	4%	13%	32%	4%
Sweden	32%	3%	3%	28%	34%

Table 6.6: Percentage allocation of the number of faults by cause over 2013–2022. Proportionately higher percentage values are highlighted in yellow and red.

Country	Environmental causes	External influences	Operation and maintenance	Technical equipment	Unknown
Estonia	31%	8%	15%	38%	8%
Latvia	31%	21%	10%	22%	16%
Lithuania	12%	24%	9%	22%	33%
Denmark	19%	20%	21%	32%	8%
Finland	51%	2%	7%	21%	19%
Iceland	33%	1%	6%	59%	1%
Norway	50%	2%	15%	29%	4%
Sweden	38%	2%	7%	27%	26%

Table 6.7: Percentage allocation of the number of faults that caused ENS by cause in 2022. Proportionately higher percentage values are highlighted in yellow and red.

Country	Environmental causes	External influences	Operation and maintenance	Technical equipment	Unknown
Estonia	0%	17%	0%	67%	17%
Latvia	50%	0%	13%	38%	0%
Lithuania	13%	63%	19%	6%	0%
Denmark	20%	0%	80%	0%	0%
Finland	32%	9%	12%	7%	41%
Iceland	83%	0%	0%	17%	0%
Norway	36%	4%	20%	34%	6%
Sweden	44%	0%	1%	31%	23%

Table 6.8: Percentage allocation of the number of faults that caused ENS by cause over 2013–2022. Proportionately higher percentage values are highlighted in yellow and red.

Country	Environmental causes	External influences	Operation and maintenance	Technical equipment	Unknown
Estonia	12%	10%	26%	44%	8%
Latvia	26%	15%	32%	24%	3%
Lithuania	12%	39%	25%	18%	6%
Denmark	10%	0%	49%	37%	4%
Finland	30%	3%	12%	21%	34%
Iceland	52%	1%	10%	36%	0%
Norway	50%	2%	20%	25%	3%
Sweden	37%	2%	8%	28%	26%

6.3 Faults in cables

This section presents cable faults in 2022 and for 2013–2022.

Table 6.9 presents the length of cables and the number of faults in 2022, and the 10-year annual average of the number of faults for 2013–2022. Table 6.10 presents the number of faults per 100 km of cable in 2022 and the annual averages for 2013–2022.

Table 6.11 shows the percentage allocation of cable faults by cause in 2022. Table 6.12 presents the respective percentages over 2013–2022.

Figure 6.1 presents the 5-year moving average of cable faults per 100 km.

Table 6.9: Length of cable (km) and the number of cable faults in 2022, and the annual average number of faults for 2013–2022, grouped by voltage level.

Country	100–150 kV			220–330 kV			380–420 kV		
	km in 2022	Number of faults in 2022	10-year ann. avg of faults	km in 2022	Number of faults in 2022	10-year ann. avg of faults	km in 2022	Number of faults in 2022	10-year ann. avg of faults
Estonia	112	1	0.5	0	0	0.0	0	0	0.0
Latvia	83	1	0.2	22	0	0.2	0	0	0.0
Lithuania	112	0	0.1	0	0	0.0	0	0	0.0
Denmark	1 672	8	3.5	366	0	0.3	222	0	0.2
Finland	46	0	1.0	0	0	0.0	22	0	0.0
Iceland	111	0	0.2	10	0	0.0	0	0	0.0
Norway	571	5	4.1	108	4	0.4	22	0	0.8
Sweden	322	1	2.3	52	1	1.5	28	0	0.4
Baltic & Nordic	3 028	16	11.9	559	5	2.4	294	0	1.4

Table 6.10: Number of cable faults per 100 km in 2022 and the annual average for 2013–2022, grouped by voltage level.

Country	100–150 kV		220–330 kV		380–420 kV	
	Number of faults / 100 km in 2022	10-year ann. avg no. of faults / 100 km	Number of faults / 100 km in 2022	10-year ann. avg no. of faults / 100 km	Number of faults / 100 km in 2022	10-year ann. avg no. of faults / 100 km
Estonia	0.89	0.66	0.00	0.00	0.00	0.00
Latvia	1.21	0.26	0.00	1.20	0.00	0.00
Lithuania	0.00	0.11	0.00	0.00	0.00	0.00
Denmark	0.48	0.25	0.00	0.14	0.00	0.12
Finland	0.00	0.55	0.00	0.00	0.00	0.00
Iceland	0.00	0.18	0.00	0.00	0.00	0.00
Norway	0.88	0.81	3.70	0.43	0.00	3.28
Sweden	0.31	0.52	1.92	1.17	0.00	2.42
Baltic & Nordic	0.53	0.41	0.89	0.53	0.00	0.66

Table 6.11: Percentage allocation of cable faults by cause in 2022. Proportionately higher percentage values are highlighted in yellow and red.

Country	Environmental causes	External influences	Operation and maintenance	Technical equipment	Unknown
Estonia	0%	0%	100%	0%	0%
Latvia	0%	100%	0%	0%	0%
Lithuania	0%	0%	0%	0%	0%
Denmark	0%	13%	38%	50%	0%
Finland	0%	0%	0%	0%	0%
Iceland	0%	0%	0%	0%	0%
Norway	11%	33%	0%	56%	0%
Sweden	0%	0%	0%	50%	50%

Table 6.12: Percentage allocation of cable faults by cause over 2013–2022. Proportionately higher percentage values are highlighted in yellow and red.

Country	Environmental causes	External influences	Operation and maintenance	Technical equipment	Unknown
Estonia	0%	60%	20%	20%	0%
Latvia	0%	25%	0%	75%	0%
Lithuania	0%	0%	0%	100%	0%
Denmark	0%	10%	20%	65%	5%
Finland	10%	10%	30%	50%	0%
Iceland	50%	0%	0%	50%	0%
Norway	23%	11%	4%	58%	4%
Sweden	5%	0%	11%	68%	16%

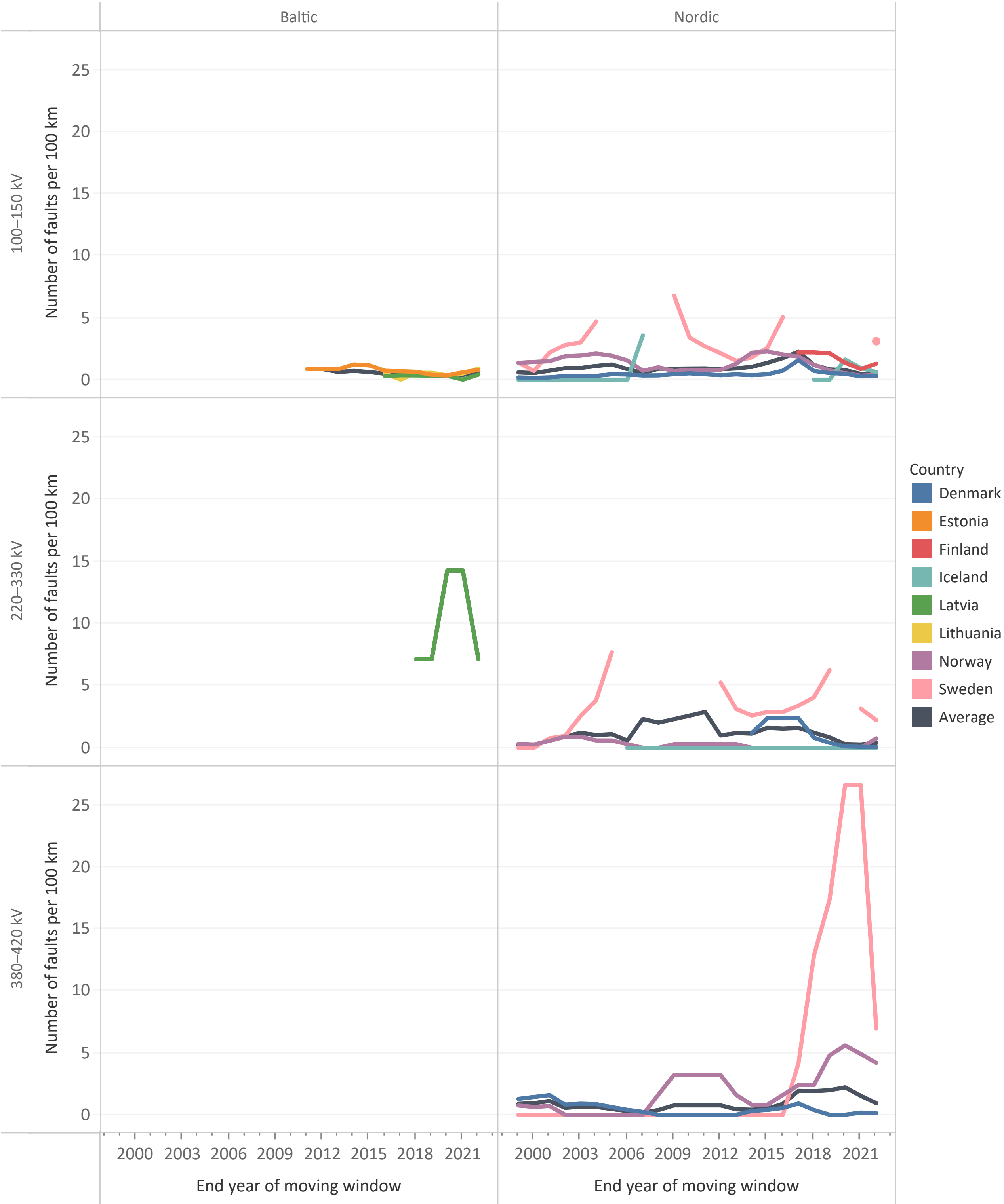

Figure 6.1: 5-year moving average of cable faults per 100 km. Estonia has data since 2007, and Latvia and Lithuania have data since 2012. Estonia, Finland and Lithuania do not own 220–330 kV cables. Estonia, Finland, Iceland, Latvia and Lithuania do not own 380–420 kV cables.

6.4 Faults on overhead lines

This section presents overhead line faults in 2022 and for 2013–2022.

Table 6.13 presents the length of overhead lines and the number of faults in 2022, and the 10-year annual average of the number of faults for 2013–2022. Table 6.14 presents the number of faults per 100 km of overhead line in 2022 and the annual averages for 2013–2022.

Table 6.15 presents the number of faults and the number of permanent faults for 2022 and their 10-year respective average values for 2013–2022.

Table 6.16 shows the percentage allocation of overhead line faults by cause in 2022. Table 6.17 presents the respective percentages over 2013–2022.

Figure 6.2 presents the 5-year moving average of overhead line faults per 100 km.

Table 6.13: Length of overhead line (km) and number faults in 2022, and the annual average number of faults for 2013–2022, grouped by voltage level.

Country	100–150 kV			220–330 kV			380–420 kV		
	km in 2022	Number of faults in 2022	10-year ann. avg of faults	km in 2022	Number of faults in 2022	10-year ann. avg of faults	km in 2022	Number of faults in 2022	10-year ann. avg of faults
Estonia	3 361	51	76.1	1 634	15	12.1	0	0	0.0
Latvia	3 777	96	85.5	1 720	2	8.6	0	0	0.0
Lithuania	4 968	115	100.1	1 896	8	10.1	103	0	0.6
Denmark	2 781	44	26.5	0	0	0.3	1 472	6	5.1
Finland	17 066	464	334.4	1 061	22	13.5	5 750*	9	9.1
Iceland	1 273	30	17.6	1 002	10	3.9	0	0	0.0
Norway	10 999	79	93.5	4 095	26	34.5	4 766	59	42.8
Sweden	12 044	242	213.2	3 261	35	28.3	8 423	32	36.4
Baltic & Nordic	56 269	1 121	946.9	14 669	118	111.3	20 870	106	94.0

* Correction on 2 January 2025: corrected to 5750 km from 6106 km.

Table 6.14: Number of overhead line faults per 100 km in 2022 and the annual average for 2013–2022, grouped by voltage level.

Country	100–150 kV		220–330 kV		380–420 kV	
	Number of faults / 100 km in 2022	10-year ann. avg no. of faults / 100 km	Number of faults / 100 km in 2022	10-year ann. avg no. of faults / 100 km	Number of faults / 100 km in 2022	10-year ann. avg no. of faults / 100 km
Estonia	1.52	2.23	0.92	0.66	0.00	0.00
Latvia	2.54	2.24	0.12	0.58	0.00	0.00
Lithuania	2.31	2.01	0.42	0.56	0.00	0.84
Denmark	1.58	0.89	0.00	0.68	0.41	0.38
Finland	2.72	2.03	2.07	0.76	0.16*	0.16
Iceland	2.36	1.41	1.00	0.44	0.00	0.00
Norway	0.72	0.86	0.63	0.67	1.24	1.24
Sweden	2.01	1.42	1.07	0.74	0.38	0.36
Baltic & Nordic	1.99	1.61	0.80	0.66	0.51	0.46

* Correction on 2 January 2025: updated calculation of faults per 100 km based on the corrected length of installed overhead line (was 0.15).

Table 6.15: Number of overhead lines faults and permanent faults in 2022 and their 10-year annual average values for 2013–2022, grouped by voltage level.

	100–150 kV				220–330 kV				380–420 kV			
	Faults		Permanent faults		Faults		Permanent faults		Faults		Permanent faults	
Country	Number in 2022	10-year ann. avg	Number in 2022	10-year ann. avg	Number in 2022	10-year ann. avg	Number in 2022	10-year ann. avg	Number in 2022	10-year ann. avg	Number in 2022	10-year ann. avg
Estonia	51	76.1	15	14.4	15	12.1	7	3.9	0	0.0	0	0.0
Latvia	96	85.5	40	32.9	2	8.6	0	1.1	0	0.0	0	0.0
Lithuania	115	100.1	14	14.8	8	10.1	1	1.8	0	0.6	0	0.4
Denmark	44	26.5	6	2.5	0	0.3	0	0.0	6	5.1	1	0.8
Finland	464	334.4	66	27.4	22	13.5	4	1.4	9	9.1	2	1.2
Iceland	30	17.6	0	1.6	10	3.9	0	0.8	0	0.0	0	0.0
Norway	79	93.5	21	21.3	26	34.5	5	3.0	59	42.8	3	1.8
Sweden	242	213.2	5	7.9	35	28.3	2	1.7	32	36.4	7	2.1
Baltic & Nordic	1 121	946.9	167	122.8	118	111.3	19	13.7	106	94.0	13	6.3

Table 6.16: Percentage allocation of overhead line faults by cause in 2022.

Country	Environmental causes	External influences	Operation and maintenance	Technical equipment	Unknown
Estonia	42%	14%	15%	12%	17%
Latvia	63%	28%	0%	1%	8%
Lithuania	22%	51%	2%	2%	24%
Denmark	30%	38%	10%	16%	6%
Finland	53%	3%	2%	0%	42%
Iceland	98%	3%	0%	0%	0%
Norway	89%	4%	1%	5%	1%
Sweden	44%	3%	0%	7%	46%

Table 6.17: Percentage allocation of overhead line faults by cause over 2013–2022.

Country	Environmental causes	External influences	Operation and maintenance	Technical equipment	Unknown
Estonia	57%	14%	12%	7%	9%
Latvia	47%	29%	1%	1%	22%
Lithuania	17%	34%	2%	4%	43%
Denmark	34%	40%	5%	7%	14%
Finland	60%	2%	2%	16%	21%
Iceland	90%	3%	0%	6%	1%
Norway	91%	1%	1%	4%	2%
Sweden	55%	2%	2%	5%	36%

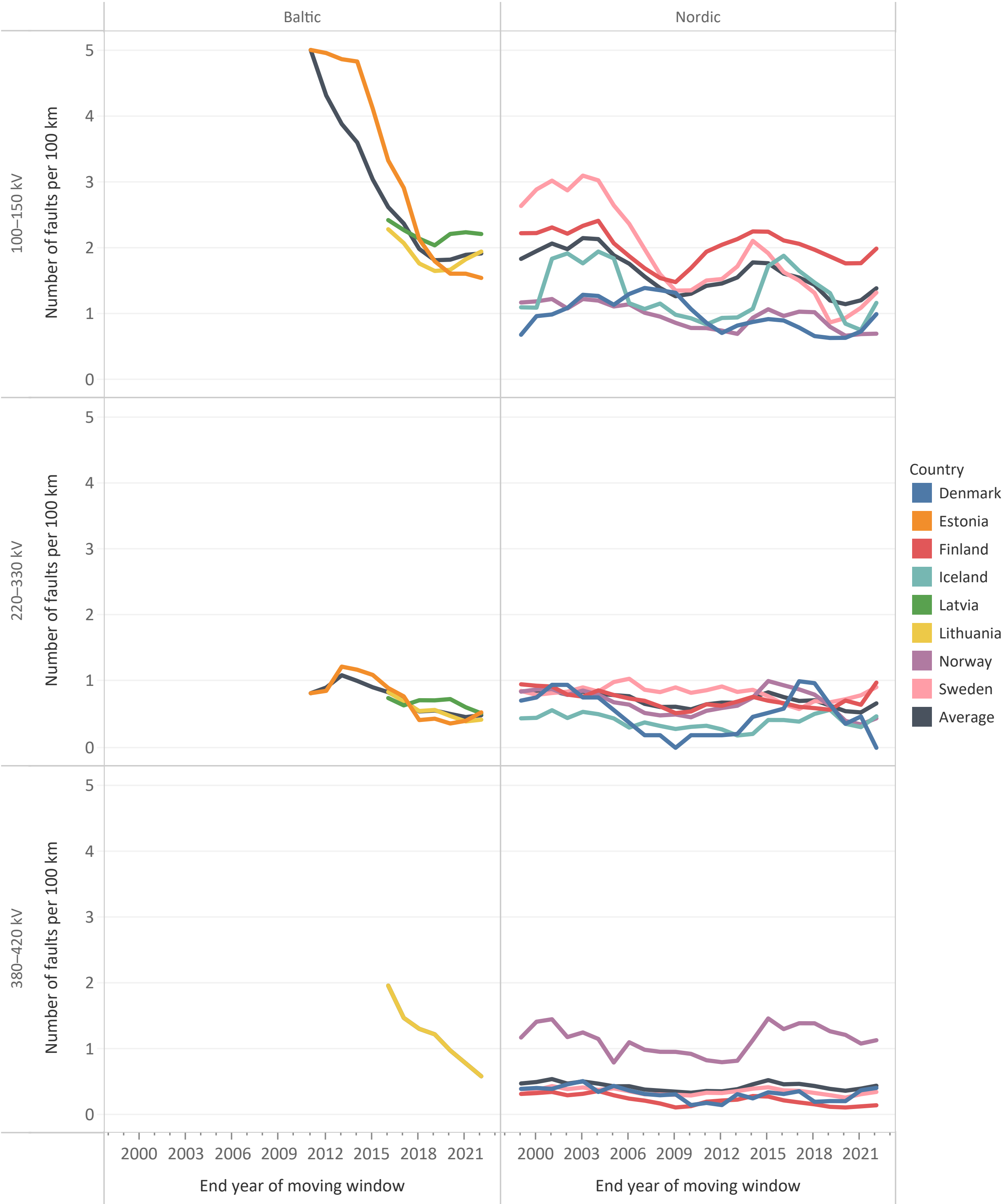

Figure 6.2: 5-year moving average of overhead line faults per 100 km. Estonia has data since 2007, and Latvia and Lithuania have data since 2012. Estonia, Iceland and Latvia do not own 380–420 kV transmission grids.

6.5 Faults in circuit breakers

This section presents circuit breaker faults in 2022 and for 2013–2022.

Table 6.18 presents the number of circuit breakers and the number of faults in 2022, and the 10-year annual average of the number of faults for 2013–2022. Table 6.19 presents the number of faults per 100 devices in 2022 and the annual averages for 2013–2022.

Table 6.20 presents the percentage allocation of circuit breaker faults by cause in 2022. Table 6.21 presents the respective percentages over 2013–2022.

Figure 6.3 presents the 5-year moving average of circuit breaker faults per 100 devices.

Table 6.18: Number of circuit breakers and their faults in 2022, and the annual average number of faults for 2013–2022, grouped by voltage level.

Country	100–150 kV			220–330 kV			380–420 kV		
	Number of devices in 2022	Number of faults in 2022	10-year ann. avg of faults	Number of devices in 2022	Number of faults in 2022	10-year ann. avg of faults	Number of devices in 2022	Number of faults in 2022	10-year ann. avg of faults
Estonia	679	11	7.0	133	4	2.7	0	0	0.0
Latvia	602	1	2.7	100	0	0.1	0	0	0.0
Lithuania	870	3	5.2	115	0	0.7	11	0	0.1
Denmark	979	1	2.3	37	0	0.1	270	0	0.4
Finland	2 989	2	4.3	61	0	0.0	403	1	0.3
Iceland	142	1	2.2	87	0	1.0	0	0	0.0
Norway	2 693	5	7.9	684	2	4.4	630	1	2.2
Sweden	2 257	5	4.3	292	2	1.4	715	1	4.3
Baltic & Nordic	11 211	29	35.9	1 509	8	10.4	2 029	3	7.3

Table 6.19: Number of circuit breaker faults per 100 devices in 2022 and the annual average for 2013–2022, grouped by voltage level.

Country	100–150 kV		220–330 kV		380–420 kV	
	Number of faults / 100 devices in 2022	10-year ann. avg no. of faults / 100 devices	Number of faults / 100 devices in 2022	10-year ann. avg no. of faults / 100 devices	Number of faults / 100 devices in 2022	10-year ann. avg no. of faults / 100 devices
Estonia	1.62	1.14	3.01	2.18	0.00	0.00
Latvia	0.17	0.44	0.00	0.10	0.00	0.00
Lithuania	0.34	0.61	0.00	0.63	0.00	2.08
Denmark	0.10	0.26	0.00	0.43	0.00	0.19
Finland	0.07	0.17	0.00	0.00	0.25	0.09
Iceland	0.70	1.40	0.00	1.21	0.00	0.00
Norway	0.19	0.33	0.29	0.61	0.16	0.51
Sweden	0.22	0.18	0.68	0.42	0.14	0.69
Baltic & Nordic	0.26	0.34	0.53	0.66	0.15	0.45

Table 6.20: Percentage allocation of circuit breakers faults by cause in 2022. Proportionately higher percentage values are highlighted in yellow and red.

Country	Environmental causes	External influences	Operation and maintenance	Technical equipment	Unknown
Estonia	0%	7%	7%	80%	7%
Latvia	0%	0%	0%	100%	0%
Lithuania	0%	0%	67%	33%	0%
Denmark	0%	0%	100%	0%	0%
Finland	0%	0%	0%	100%	0%
Iceland	0%	0%	0%	100%	0%
Norway	0%	0%	25%	63%	13%
Sweden	25%	0%	0%	75%	0%

Table 6.21: Percentage allocation of circuit breaker faults over 2013–2022. Proportionately higher percentage values are highlighted in yellow and red.

Country	Environmental causes	External influences	Operation and maintenance	Technical equipment	Unknown
Estonia	1%	1%	10%	79%	8%
Latvia	0%	4%	11%	86%	0%
Lithuania	2%	0%	35%	48%	15%
Denmark	0%	0%	79%	18%	4%
Finland	9%	2%	26%	39%	24%
Iceland	6%	3%	9%	81%	0%
Norway	6%	3%	34%	42%	16%
Sweden	13%	0%	11%	70%	6%

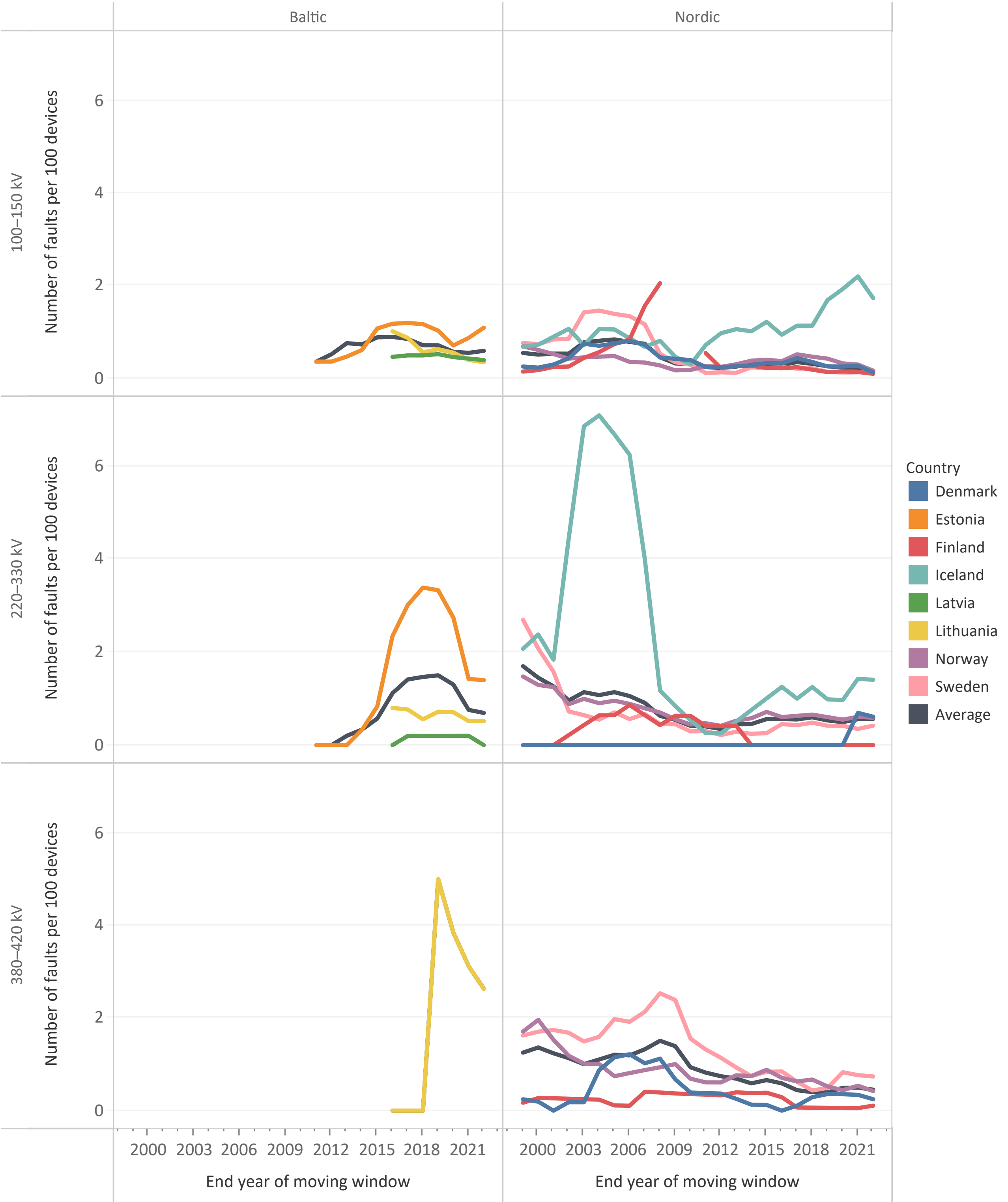

Figure 6.3: 5-year moving average of circuit breaker faults per 100 devices. Estonia has data since 2007, and Latvia and Lithuania have data since 2012. Estonia, Iceland and Latvia do not own 380–420 kV transmission grids.

6.6 Faults in control equipment

This section presents control equipment faults in 2022 and for 2013–2022. Protection devices are considered as part of the control equipment in this report. Control equipment embedded in other components are not included in this category as they are deemed to be a part of the other component.

In these statistics, human error is registered under operation and maintenance, separated from the category technical equipment. Human errors include, for example, incorrect settings in control or protection equipment.

Table 6.22 presents the number of control equipment and the number of faults in 2022, and the 10-year annual average of the number of faults for 2013–2022. Table 6.23 presents the number of faults per 100 devices in 2022 and the annual averages for 2013–2022.

Table 6.24 presents the percentage allocation of control equipment faults by cause in 2022. Table 6.25 presents the respective percentages over 2013–2022.

Figure 6.4 presents the 5-year moving average of control equipment faults per 100 devices.

Table 6.22: Number of control equipment and their faults in 2022, and the annual average number of faults for 2013–2022, grouped by voltage level. Control equipment embedded in other components are not included in this category as they are deemed to be a part of the other component.

Country	100–150 kV			220–330 kV			380–420 kV		
	Number of devices in 2022	Number of faults in 2022	10-year ann. avg of faults	Number of devices in 2022	Number of faults in 2022	10-year ann. avg of faults	Number of devices in 2022	Number of faults in 2022	10-year ann. avg of faults
Estonia	679	13	12.8	133	2	2.1	0	0	0.0
Latvia	652	13	16.7	100	3	2.7	0	0	0.0
Lithuania	870	9	11.7	115	4	3.2	11	0	0.0
Denmark	979	0	6.3	37	0	0.4	270	0	2.3
Finland	2 989	23	16.5	61	2	4.4	403	4	3.9
Iceland	142	7	5.2	87	1	3.3	0	0	0.0
Norway	2 693	29	29.5	684	20	20.5	630	15	15.8
Sweden	2 257	8	17.8	292	2	11.3	715	16	23.6
Baltic & Nordic	11 261	102	116.5	1 509	34	47.9	2 029	35	45.6

Table 6.23: Number of control equipment faults per 100 devices in 2022 and the annual average for 2013–2022, grouped by voltage level. Control equipment embedded in other components are not included in this category as they are deemed to be a part of the other component.

Country	100–150 kV		220–330 kV		380–420 kV	
	Number of faults / 100 devices in 2022	10-year ann. avg no. of faults / 100 devices	Number of faults / 100 devices in 2022	10-year ann. avg no. of faults / 100 devices	Number of faults / 100 devices in 2022	10-year ann. avg no. of faults / 100 devices
Estonia	1.91	2.09	1.50	1.73	0.00	0.00
Latvia	1.99	2.68	3.00	2.66	0.00	0.00
Lithuania	1.03	1.37	3.48	2.90	0.00	0.00
Denmark	0.00	0.72	0.00	1.74	0.00	1.08
Finland	0.77	0.63	3.28	5.71	0.99	1.18
Iceland	4.93	3.31	1.15	3.99	0.00	0.00
Norway	1.08	1.23	2.92	2.84	2.38	3.65
Sweden	0.35	0.74	0.68	3.42	2.24	3.77
Baltic & Nordic	0.91	1.11	2.25	3.05	1.72	2.83

Table 6.24: Percentage allocation of control equipment faults by cause in 2022. Proportionately higher percentage values are highlighted in yellow and red.

Country	Environmental causes	External influences	Operation and maintenance	Technical equipment	Unknown
Estonia	0%	0%	47%	20%	33%
Latvia	0%	0%	56%	44%	0%
Lithuania	0%	0%	62%	31%	8%
Denmark	0%	0%	0%	0%	0%
Finland	0%	0%	72%	21%	7%
Iceland	0%	0%	0%	100%	0%
Norway	3%	0%	50%	45%	2%
Sweden	0%	0%	35%	65%	0%

Table 6.25: Percentage allocation of control equipment faults by cause over 2013–2022. Proportionately higher percentage values are highlighted in yellow and red.

Country	Environmental causes	External influences	Operation and maintenance	Technical equipment	Unknown
Estonia	0%	0%	38%	46%	15%
Latvia	1%	0%	49%	44%	6%
Lithuania	0%	6%	43%	23%	28%
Denmark	7%	3%	52%	36%	2%
Finland	6%	1%	68%	20%	5%
Iceland	0%	0%	36%	64%	0%
Norway	6%	3%	47%	40%	4%
Sweden	5%	0%	30%	56%	9%

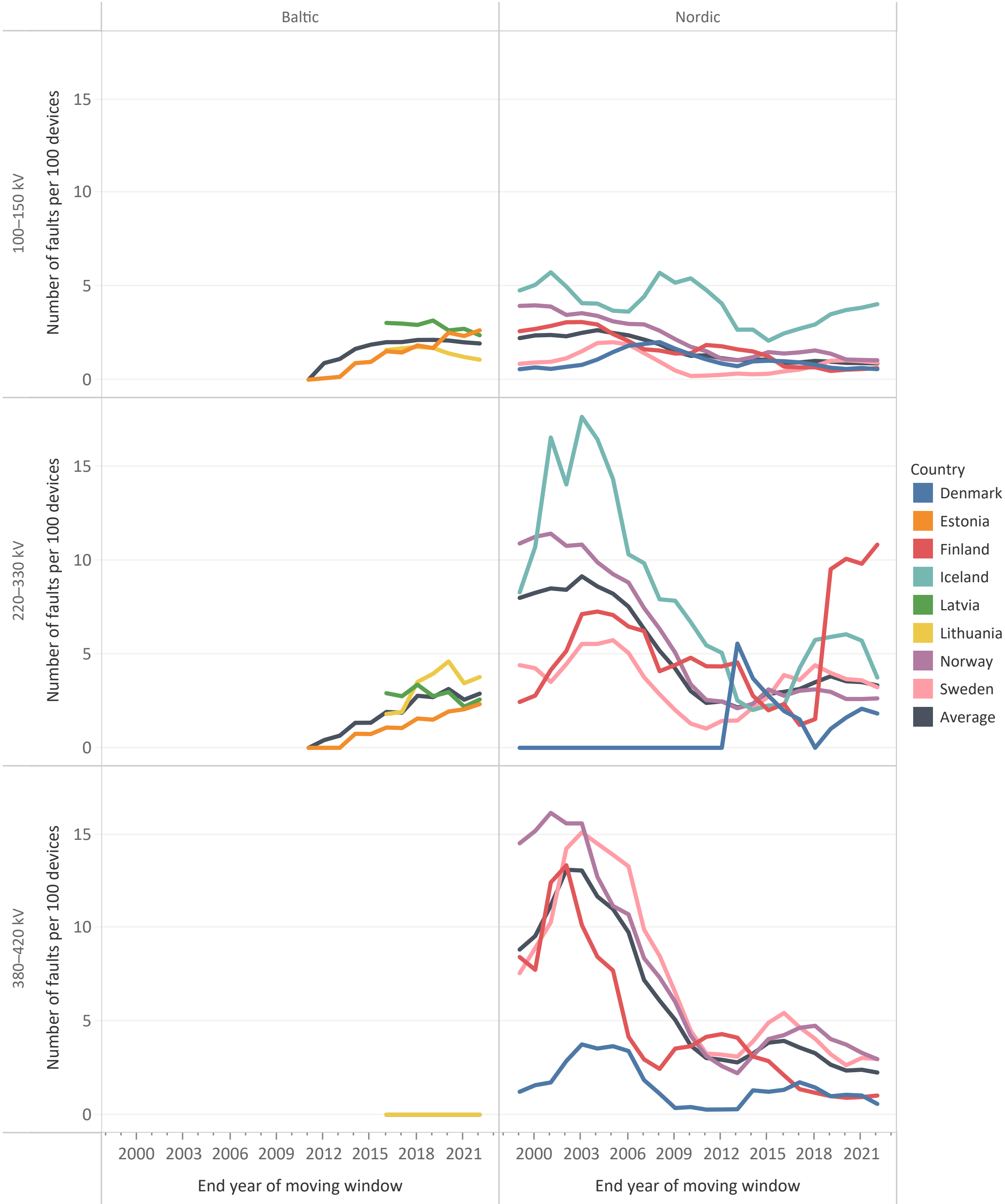

Figure 6.4: 5-year moving average of control equipment faults per 100 devices. Estonia has data since 2007, and Latvia and Lithuania have data since 2012. Estonia, Iceland and Latvia do not own 380–420 kV transmission grids. Control equipment embedded in other components are not included in this category as they are deemed to be a part of the other component.

6.7 Faults in instrument transformers

This section presents instrument transformer faults in 2022 and for 2013–2022.

Table 6.26 presents the number of instrument transformers and the number of faults in 2022, and the 10-year annual average of the number of faults for 2013–2022. Table 6.27 presents the number of faults per 100 devices in 2022 and the annual averages for 2013–2022.

Table 6.28 presents the percentage allocation of instrument transformer faults by cause in 2022. Table 6.29 presents the respective percentages over 2013–2022.

Figure 6.5 presents the 5-year moving average of instrument transformer faults per 100 devices.

Table 6.26: Number of instrument transformers and their faults in 2022, and the annual average number of faults for 2013–2022, grouped by voltage level. The number of instrument transformers in Sweden is not accurate due to missing data from some regional grid owners.

Country	100–150 kV			220–330 kV			380–420 kV		
	Number of devices in 2022	Number of faults in 2022	10-year ann. avg of faults	Number of devices in 2022	Number of faults in 2022	10-year ann. avg of faults	Number of devices in 2022	Number of faults in 2022	10-year ann. avg of faults
Estonia	3 311	2	2.3	947	3	1.2	0	0	0.0
Latvia	2 261	5	2.5	428	0	0.1	0	0	0.0
Lithuania	3 110	0	1.2	640	0	0.1	66	0	0.0
Denmark	5 848	0	1.1	243	0	0.0	1 474	0	0.6
Finland	10 631	8	2.6	308		0.1	2 071	1	0.3
Iceland	426	0	0.1	261	1	0.1	0	0	0.0
Norway	7 768	6	3.5	2 805	6	2.3	930	1	1.5
Sweden	10 002	2	3.7	1 982	0	0.1	3 756	0	1.9
Baltic & Nordic	43 357	23	17.0	7 614	10	4.0	8 297	2	4.3

Table 6.27: Number of instrument transformer faults per 100 devices in 2022 and the annual average for 2013–2022, grouped by voltage level.

Country	100–150 kV		220–330 kV		380–420 kV	
	Number of faults / 100 devices in 2022	10-year ann. avg no. of faults / 100 devices	Number of faults / 100 devices in 2022	10-year ann. avg no. of faults / 100 devices	Number of faults / 100 devices in 2022	10-year ann. avg no. of faults / 100 devices
Estonia	0.06	0.11	0.32	0.22	0.00	0.00
Latvia	0.22	0.15	0.00	0.03	0.00	0.00
Lithuania	0.00	0.06	0.00	0.02	0.00	0.00
Denmark	0.00	0.04	0.00	0.00	0.00	0.09
Finland	0.08	0.04	0.00	0.03	0.05	0.02
Iceland	0.00	0.02	0.38	0.03	0.00	0.00
Norway	0.08	0.05	0.21	0.08	0.11	0.16
Sweden	0.02	0.07	0.00	0.01	0.00	0.08
Baltic & Nordic	0.05	0.06	0.13	0.07	0.02	0.08

Table 6.28: Percentage allocation of instrument transformer faults by cause in 2022. Proportionately higher percentage values are highlighted in yellow and red.

Country	Environmental causes	External influences	Operation and maintenance	Technical equipment	Unknown
Estonia	0%	0%	20%	80%	0%
Latvia	0%	0%	0%	100%	0%
Lithuania	0%	0%	0%	0%	0%
Denmark	0%	0%	0%	0%	0%
Finland	44%	0%	0%	44%	11%
Iceland	100%	0%	0%	0%	0%
Norway	0%	0%	23%	69%	8%
Sweden	0%	0%	0%	100%	0%

Table 6.29: Percentage allocation of instrument transformer faults by cause over 2013–2022. Proportionately higher percentage values are highlighted in yellow and red.

Country	Environmental causes	External influences	Operation and maintenance	Technical equipment	Unknown
Estonia	0%	0%	9%	86%	6%
Latvia	0%	0%	0%	100%	0%
Lithuania	0%	0%	23%	77%	0%
Denmark	0%	6%	18%	71%	6%
Finland	17%	0%	10%	67%	7%
Iceland	50%	0%	0%	50%	0%
Norway	14%	1%	22%	60%	3%
Sweden	11%	0%	5%	79%	5%

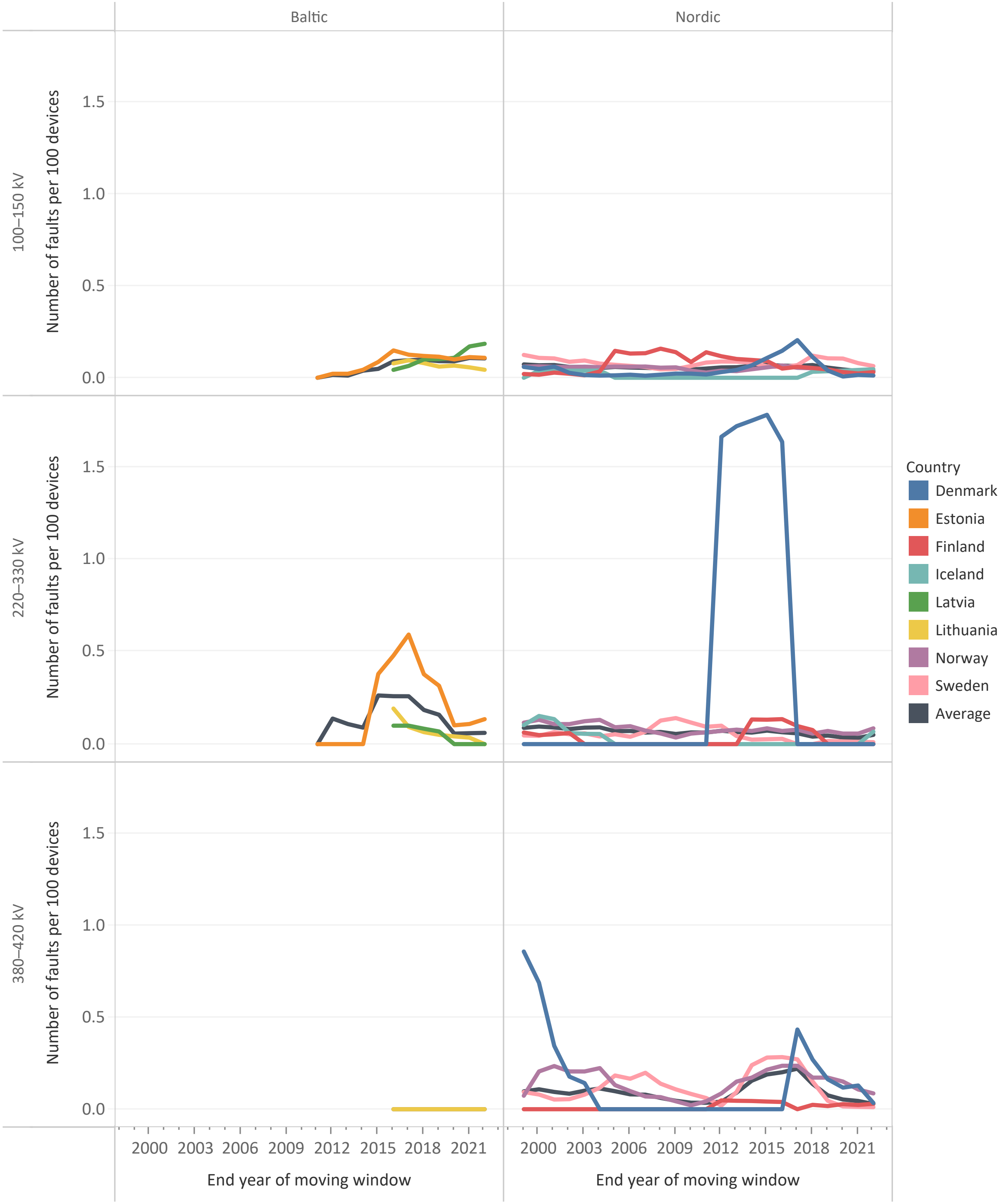

Figure 6.5: 5-year moving average of instrument transformer faults per 100 devices. Estonia has data since 2007, and Latvia and Lithuania have data since 2012. Estonia, Iceland and Latvia do not own 380–420 kV transmission grids. Denmark's high values during 2012–2016 are caused by one fault in 2012.

6.8 Faults in power transformers

This section presents power transformer faults in 2022 and for 2013–2022. The rated voltage of a power transformer is defined in these statistics as the winding with the highest voltage, as stated in the guidelines [1, p. 26].

Table 6.30 presents the number of power transformers and the number of faults in 2022, and the 10-year annual average of the number of faults for 2013–2022. Table 6.31 presents the number of faults per 100 devices in 2022 and the annual averages for 2013–2022.

Table 6.32 shows the percentage allocation of power transformer faults by cause in 2022. Table 6.33 presents the respective percentages over 2013–2022.

Figure 6.6 presents the 5-year moving average of power transformer faults per 100 devices.

Table 6.30: Number of power transformers and their faults in 2022, and the annual average number of faults for 2013–2022, grouped by voltage level.

Country	100–150 kV			220–330 kV			380–420 kV		
	Number of devices in 2022	Number of faults in 2022	10-year ann. avg of faults	Number of devices in 2022	Number of faults in 2022	10-year ann. avg of faults	Number of devices in 2022	Number of faults in 2022	10-year ann. avg of faults
Estonia	195	5	7.9	20	13	4.1	0	0	0.0
Latvia	245	0	3.5	26	1	1.5	0	0	0.0
Lithuania	372	0	0.3	23	0	0.8	3	0	0.0
Denmark	244	4	3.5	12	0	0.2	51	3	1.4
Finland	1 141	5	6.8	14	0	1.0	71	0	0.7
Iceland	11	3	2.0	15	2	0.9	0	0	0.0
Norway	757	6	4.3	164	1	1.2	141	0	1.3
Sweden	659	6	16.7	66	0	3.0	82	2	1.3
Baltic & Nordic	3 624	29	45.0	340	17	12.7	348	5	4.7

Table 6.31: Number of power transformer faults per 100 devices in 2022 and the annual average for 2013–2022, grouped by voltage level.

Country	100–150 kV		220–330 kV		380–420 kV	
	Number of faults / 100 devices in 2022	10-year ann. avg no. of faults / 100 devices	Number of faults / 100 devices in 2022	10-year ann. avg no. of faults / 100 devices	Number of faults / 100 devices in 2022	10-year ann. avg no. of faults / 100 devices
Estonia	2.56	3.77	65.00	17.01	0.00	0.00
Latvia	0.00	1.42	3.85	5.84	0.00	0.00
Lithuania	0.00	0.08	0.00	3.38	0.00	0.00
Denmark	1.64	1.46	0.00	2.20	5.88	3.56
Finland	0.44	0.60	0.00	4.24	0.00	1.04
Iceland	27.27	6.64	13.33	6.38	0.00	0.00
Norway	0.79	0.52	0.61	0.49	0.00	1.38
Sweden	0.91	2.08	0.00	2.85	2.44	1.74
Baltic & Nordic	0.80	1.16	5.00	2.71	1.44	1.70

Table 6.32: Percentage allocation of power transformer faults by cause in 2022. Proportionately higher percentage values are highlighted in yellow and red.

Country	Environmental causes	External influences	Operation and maintenance	Technical equipment	Unknown
Estonia	6%	6%	33%	33%	22%
Latvia	0%	0%	0%	100%	0%
Lithuania	0%	0%	0%	0%	0%
Denmark	14%	0%	29%	57%	0%
Finland	0%	0%	0%	0%	100%
Iceland	20%	0%	0%	80%	0%
Norway	14%	29%	14%	0%	43%
Sweden	13%	0%	13%	63%	13%

Table 6.33: Percentage allocation of power transformer faults by cause over 2013–2022. Proportionately higher percentage values are highlighted in yellow and red.

Country	Environmental causes	External influences	Operation and maintenance	Technical equipment	Unknown
Estonia	3%	3%	21%	66%	8%
Latvia	0%	28%	36%	32%	4%
Lithuania	0%	18%	18%	45%	18%
Denmark	22%	0%	33%	43%	2%
Finland	19%	1%	16%	45%	19%
Iceland	10%	0%	10%	79%	0%
Norway	29%	6%	19%	35%	10%
Sweden	24%	4%	18%	29%	26%

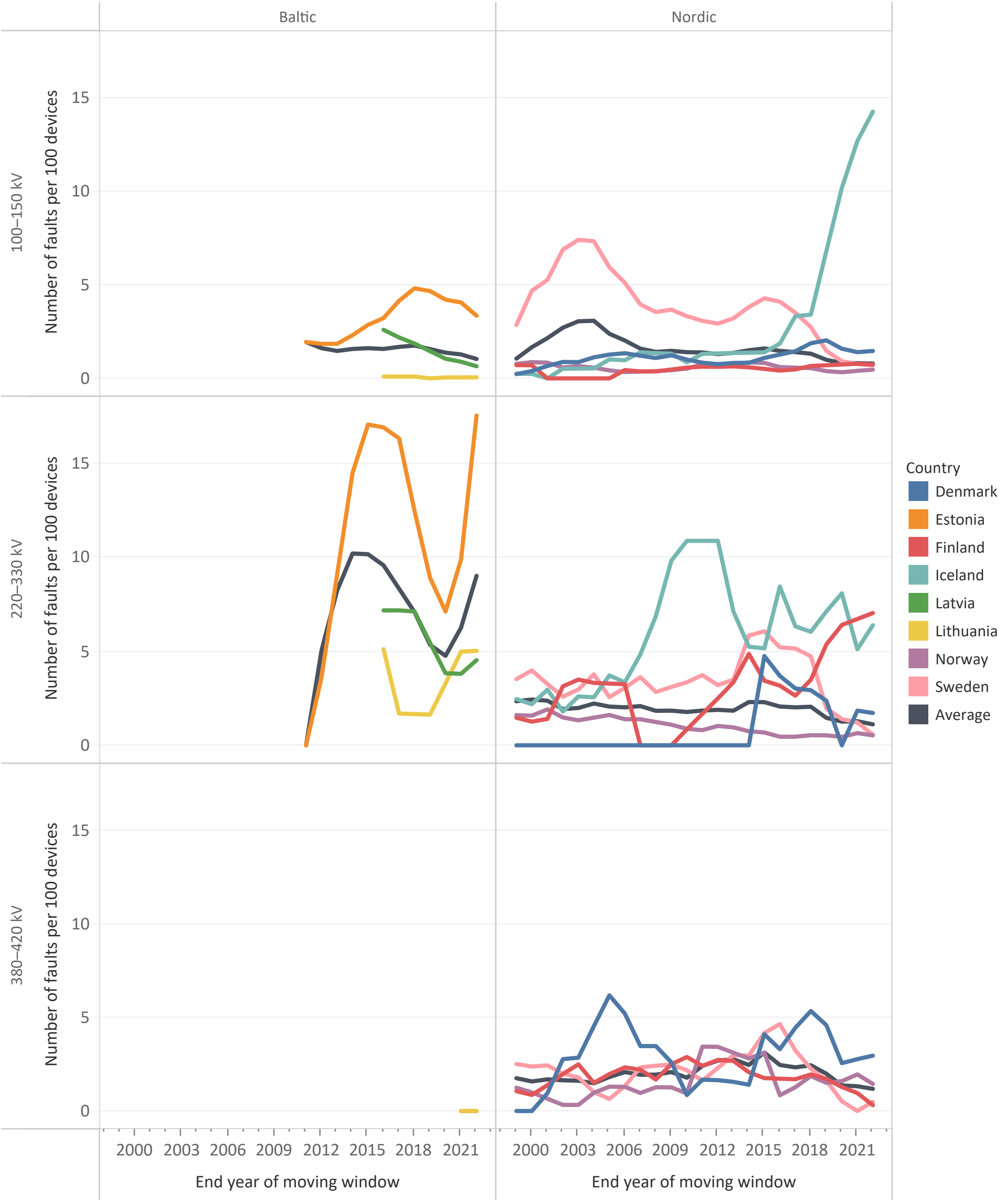

Figure 6.6: 5-year moving average of power transformer faults per 100 devices. Estonia has data since 2007, and Latvia and Lithuania have data since 2012. Estonia, Iceland, Latvia and Lithuania do not own 380–420 kV power transformers in their transmission grids.

6.9 Faults in compensation devices

The following sections present fault statistics for compensation devices. The following compensation devices are presented in this section: reactors, series capacitors, shunt capacitors and Static var compensators (SVCs). The statistics include the number of devices and their faults, number of faults per 100 devices and ENS in 2022 and their annual averages for 2013–2022.

The voltage level of compensation devices is not registered in the collected data for this report.

6.9.1 Faults in reactors

Table 6.34 presents the number of reactors and their faults, the number of faults per 100 devices, and the amount of ENS.

Table 6.34: The number of reactors and their faults in 2022, the number of faults per 100 devices, the amount of ENS due to reactor faults in 2022 and their annual averages for 2013–2022.

	Devices	Faults	Faults per 100 devices		ENS (MWh)	
Country	2022	2022	2022	Annual avg. 2013–2022	2022	Annual avg. 2013–2022
Estonia	30	2	6.7	7.7	0.0	0.0
Latvia	18	0	0.0	4.1	0.0	0.0
Lithuania	2	0	0.0	0.0	0.0	0.0
Baltic total	50	2	4.0	5.8	0.0	0.0
Denmark	133	3	2.3	1.5	0.0	0.0
Finland	208	0	0.0	0.2	0.0	1.1
Iceland	–	–	–	–	–	–
Norway	167	3	1.8	2.7	0.0	0.0
Sweden	105	1	1.0	1.8	0.0	12.9
Nordic total	613	7	1.1	1.5	0.0	14.0
Baltic & Nordic total	663	9	1.4	1.8	0.0	14.0

[1] In Finland, reactors compensating the reactive power of 400 kV lines are connected to the 20 kV tertiary winding of the 400/110/20 kV power transformers.
[2] The number of reactors in Sweden in 2019 was reported erroneously as 91 devices. The correct value was 803 devices, and the annual average value over 2012–2021 above is calculated with this corrected value.

6.9.2 Faults in series capacitors

Table 6.35 presents the number of series capacitors and their faults, the number of faults per 100 devices and the amount of ENS.

Table 6.35: The number of series capacitors and their faults in 2022, the number of faults per 100 devices, the amount of ENS due to series capacitor faults in 2022 and their annual averages for 2013–2022.

	Devices	Faults	Faults per 100 devices		ENS (MWh)	
Country	2022	2022	2022	Annual avg. 2013–2022	2022	Annual avg. 2013–2022
Estonia	–	–	–	–	–	–
Latvia	–	–	–	–	–	–
Lithuania	–	–	–	–	–	–
Baltic total	–	–	–	–	–	–
Denmark	–	–	–	–	–	–
Finland	13	9	69.2	48.6	0.0	1.9
Iceland	1	0	0.0	12.5	0.0	0.0
Norway	3	0	0.0	3.3	0.0	0.0
Sweden	9	13	144.4	45.3	0.0	0.0
Nordic total	26	22	84.6	40.6	0.0	1.9
Baltic & Nordic total	26	22	84.6	38.8	0.0	1.9

6.9.3 Faults in shunt capacitors

Table 6.36 presents the number of shunt capacitors (including filters) and their faults, the number of faults per 100 devices and the amount of ENS.

Table 6.36: The number of shunt capacitors and their faults in 2022, the number of faults per 100 devices, the amount of ENS due to shunt capacitor faults in 2022 and their annual average for 2013–2022.

	Devices	Faults	Faults per 100 devices		ENS (MWh)	
Country	2022	2022	2022	Annual average 2013–2022	2022	Annual average 2013–2022
Estonia	10	0	0.0	11.7	0.0	3.3
Latvia	2	0	0.0	0.0	0.0	0.0
Lithuania	2	0	0.0	0.0	0.0	0.0
Baltic total	14	0	0.0	8.8	0.0	3.3
Denmark	43	3	7.0	1.3	0.0	0.0
Finland	37	0	0.0	4.5	0.0	0.0
Iceland	13	1	7.7	4.3	0.0	0.0
Norway	43	1	2.3	2.0	0.0	0.0
Sweden	161	2	1.2	0.8	0.0	15.2
Nordic total	297	7	2.4	1.9	0.0	15.2
Baltic & Nordic total	311	7	2.3	2.1	0.0	18.5

6.9.4 Faults in SVC devices

Table 6.37 presents the number of SVCs and their faults, the number of faults per 100 devices and the amount of ENS.

Table 6.37: The number of SVCs and their faults in 2022, the number of faults per 100 devices, the amount of ENS due to SVC faults in 2022 and their annual averages for 2013–2022.

	Devices	Faults	Faults per 100 devices		ENS (MWh)	
Country	2022	2022	2022	Annual avg. 2013–2022	2022	Annual avg. 2013–2022
Estonia	–	–	–	–	–	–
Latvia	1	0	0.0	0.0	0.0	0.0
Lithuania	11	0	0.0	2.7	0.0	0.0
Baltic total	12	0	0.0	2.6	0.0	0.0
Denmark	1	0	0.0	50.0	0.0	0.0
Finland	1	0	0.0	14.8	0.0	0.0
Iceland	2	0	0.0	12.5	0.0	0.0
Norway	17	11	64.7	81.1	0.0	0.0
Sweden	2	0	0.0	181.1	0.0	0.0
Nordic total	23	11	47.8	77.7	0.0	0.0
Baltic & Nordic total	35	11	31.4	56.9	0.0	0.0

References

[1] Nordel, "Nordel's Guidelines for the Classification of Grid Disturbances, Version 3.3." https://eepublicdownloads.entsoe.eu/clean-documents/pre2015/publications/nordic/operations/Nordel_guidelines_2008_07_02_ENG_G_V2.pdf, July 2008.

[2] IEC 60050-826:2004: Electrical installations, 2020.

[3] ENTSO-E, "The Interconnected network of Northern Europe 2019." https://eepublicdownloads.entsoe.eu/clean-documents/Publications/maps/2019/Map_Northern-Europe-3.000.000.pdf. [Online; accessed 2.11.2021].

[4] ENTSO-E, "ENTSO-E HVDC Utilisation and Unavailability Statistics." https://www.entsoe.eu/publications/system-operations-reports/#fault-statistics.

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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 in the transmission grid is calculated for those faults that have caused an outage at the point of supply. When the outage lasts less than two hours, ENS is calculated with 5 minute average load before the outage and multiplied by the interruption time at the consumption point. If the interruption last longer, ENS is calculated based on the average load from the same period of the previous or next day, depending on if the interruption occurred during the working days or not, and multiplied by the time of outage. The outage time ends when power has been restored to the point of consumption regardless of whether the supply is restored by TSO or by the customer.

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 if 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, ENS is calculated at the end-customer's point of supply, which is the low voltage side of the 110/35/10 kV or 110/10 kV transformer at the low voltage customer's connection point. ENS for outages in radial 110 kV connections is calculated by the Distribution System Operator (DSO), which during the outage, considers the possibility to supply the energy from the other 35 kV or 10 kV voltage substations. The DSO then uses the average load before the outage multiplied by its duration to calculate ENS. All events with the energy not supplied are investigated with the DSO or the Significant Grid Users (SGUs) directly connected to 110 kV network. All parties also agree and confirm the amounts of energy not supplied.

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 as of 2020, ENS is calculated by using the annual average output after directions from the Swedish regulator.

Prior to 2020, ENS was calculated by multiplying the outage duration with the detected pre-outage load. However, some companies used instead the rated power at the point of supply because the pre-outage load was rarely registered.

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 '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, 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, lightning is set as the fault cause if it can be concluded from the lightning detection system or other well known source. Without confirmation, Svenska kraftnät prefers to declare the cause as unknown even though lightning might 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). Contact persons for the distribution network statistics 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 collected data.

Section E.1 and Section E.2 show statistics about environmental causes and operation and maintenance, respectively.

E.1 Faults due to environmental causes

The following two figures show 5-year moving averages for fault causes due to environmental causes. Figure E.1 is for all component faults, and Figure E.2 is for overhead line faults only. The cause category 'Environmental causes' is explained in Section 1.6.

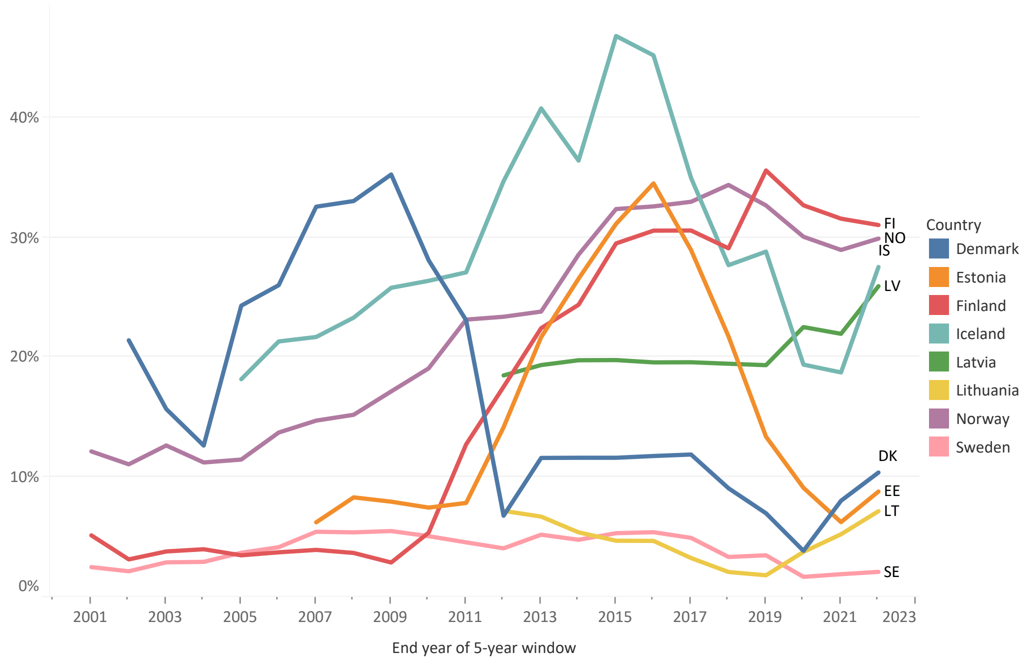

Figure E.1: 5-year moving average for fault causes due to environmental causes. All components are included.

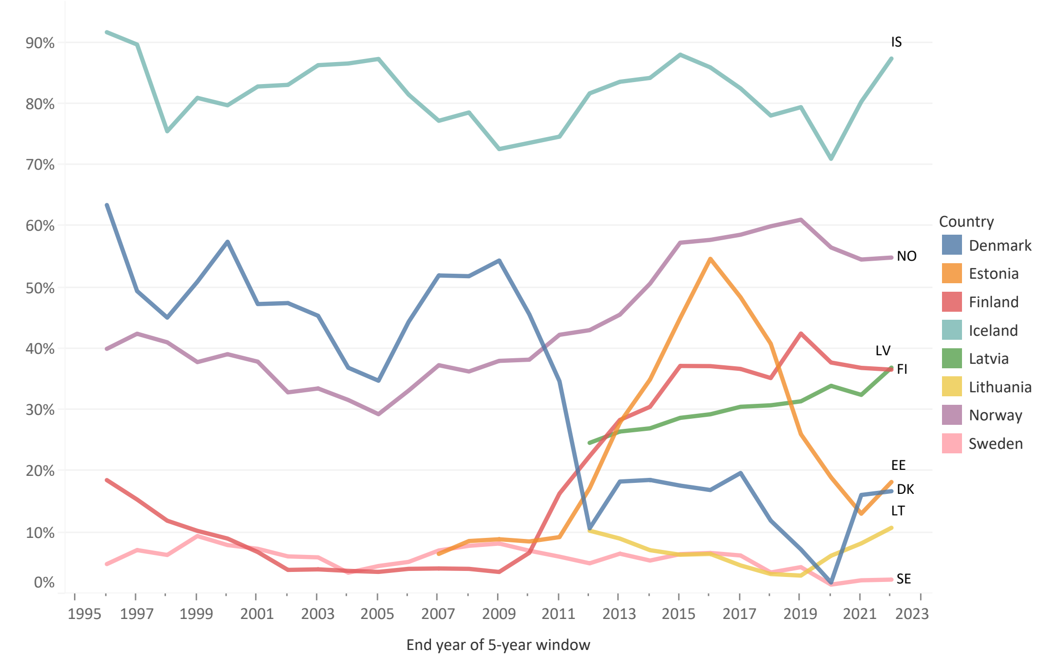

Figure E.2: 5-year moving average of overhead line fault causes due to environmental causes.

E.2 Faults due to operation and maintenance

The following two figures show 5-year moving averages for faults due to operation and maintenance. Figure E.3 is for all component faults, and Figure E.4 is for overhead line faults only. The cause category 'Operation and maintenance' is explained in Section 1.6.

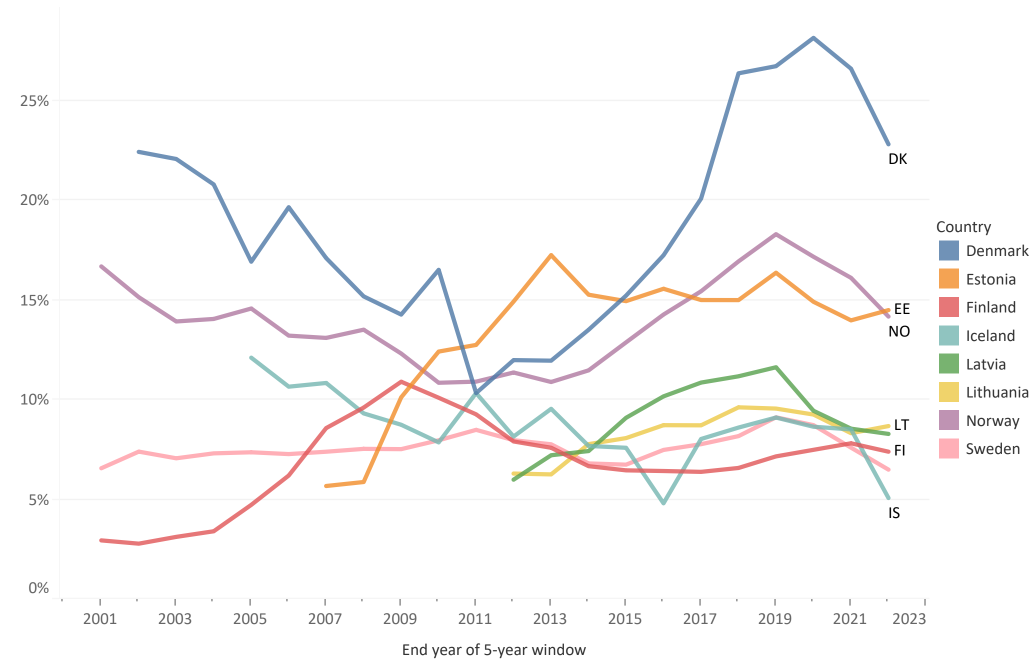

Figure E.3: 5-year moving average of fault causes due to operation and maintenance. All components are included.

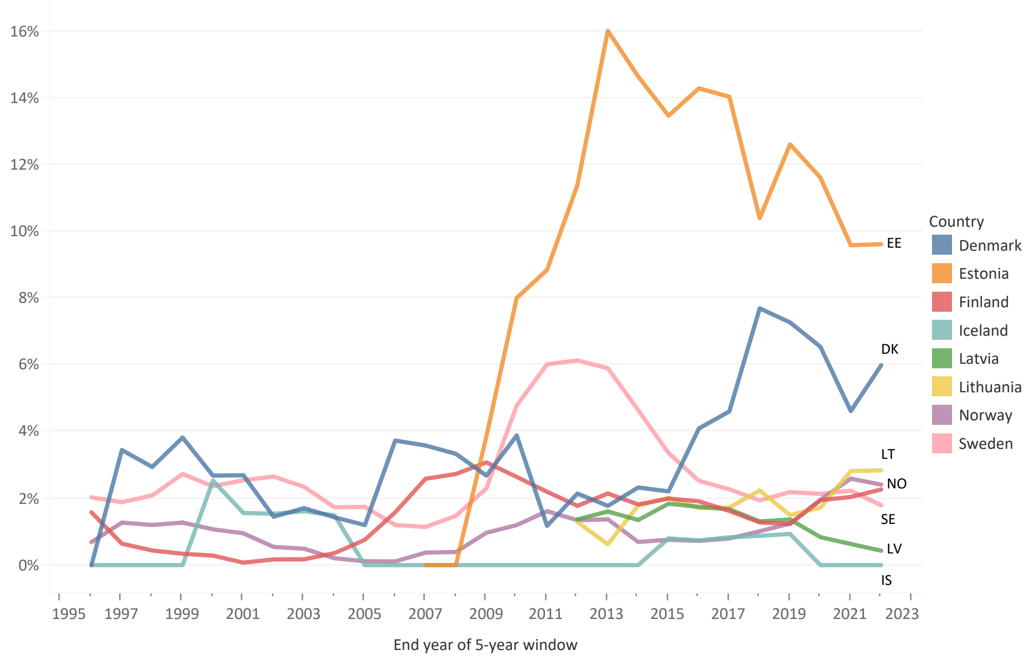

Figure E.4: 5-year moving average of overhead line fault causes due to operation and maintenance.

E.3 Installed components

This section presents the length of lines (km) and the number of components in the 100–420 kV grids at the end of each year.

Figure E.5 and Figure E.6 present the length of cables and overhead lines (km). Figure E.7–E.9 present the number of circuit breakers, control equipment, instrument transformers and power transformers.

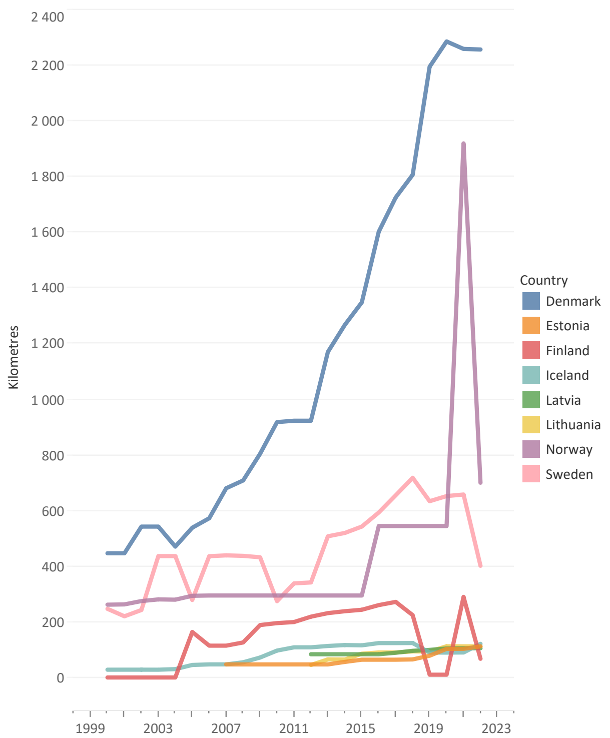

Figure E.5: Length of cables (km) in the 100–420 kV grids at the end of each year.

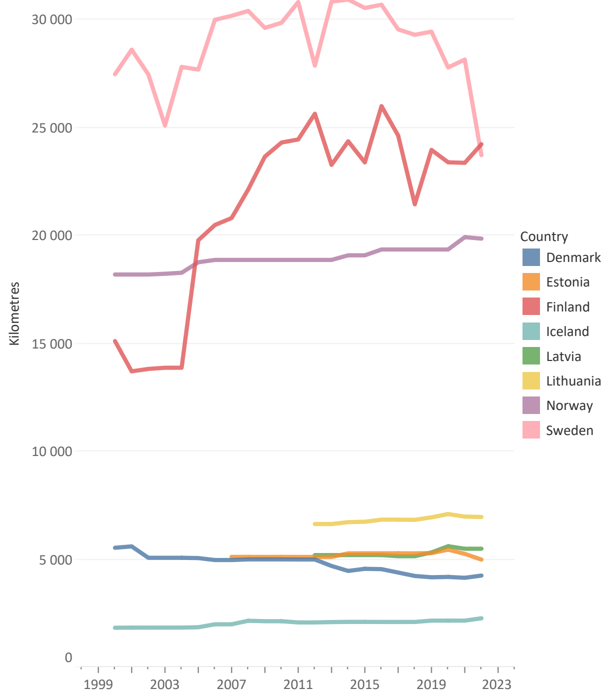

Figure E.6: Length of overhead lines (km) in the 100–420 kV grids at the end of each year.

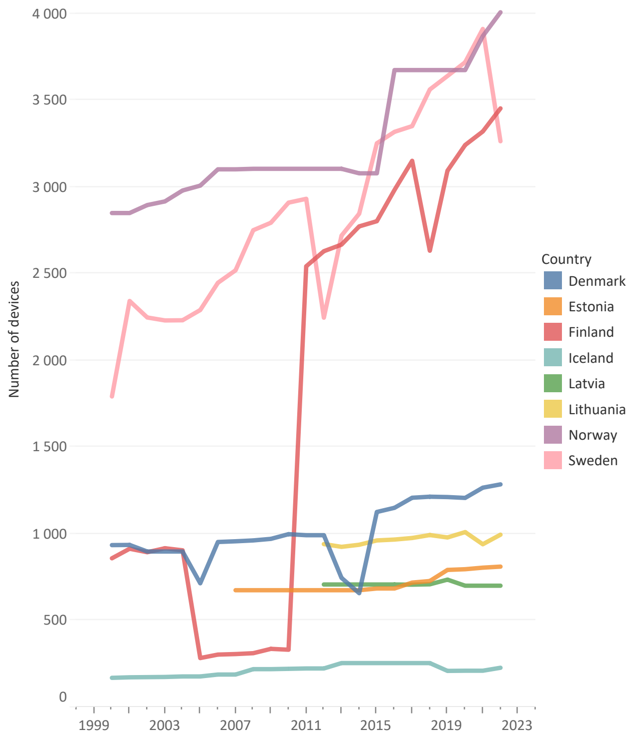

Figure E.7: Number of circuit breakers in the 100–420 kV grids at the end of each year. The number of circuit breakers is equal to the number of control equipment.

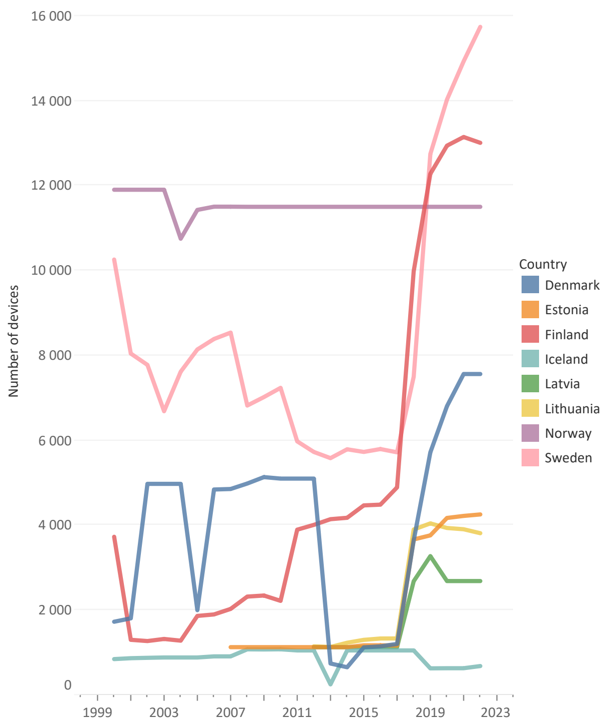

Figure E.8: Number of instrument transformers in the 100–420 kV grids at the end of each year.

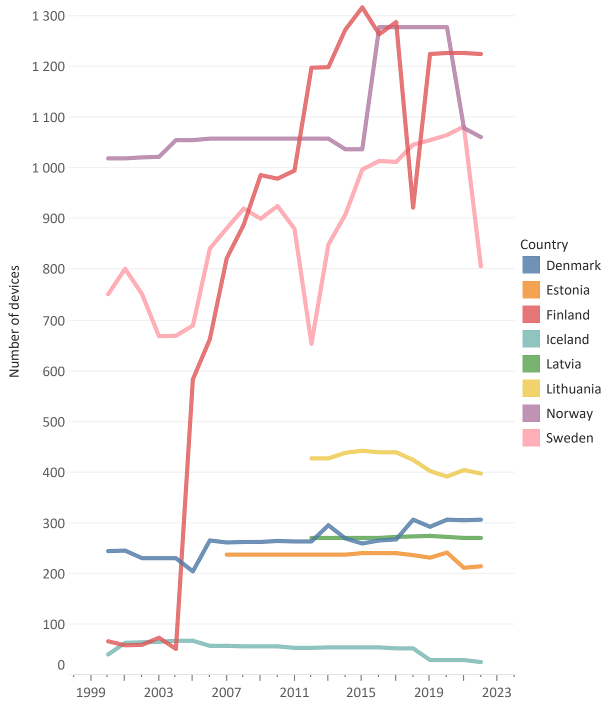

Figure E.9: Number of power transformers in the 100–420 kV grids at the end of each year.

E.4 ENS, consumption and line length

Figure E.10 presents the annual amount of ENS, consumption and total length of lines for 2013–2022. The total line length is the sum of the lengths of overhead lines and cables in the 100–420 kV grids.

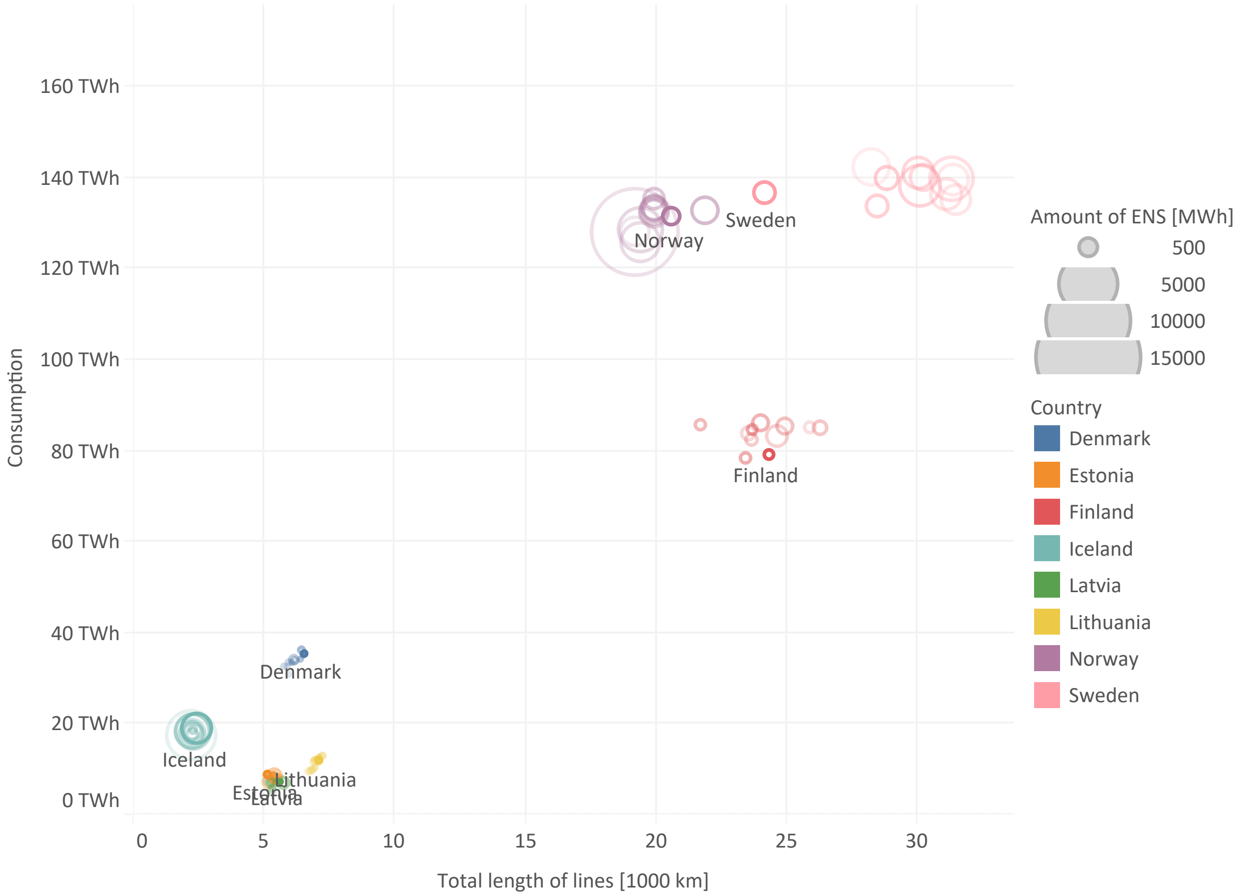

Figure E.10: The annual amount of ENS (circle size), length of lines (x-axis) and consumption (y-axis) for 2013–2022. The most recent statistical year 2022 is shown with the darkest colour. Each previous year is shown in a lighter colour.