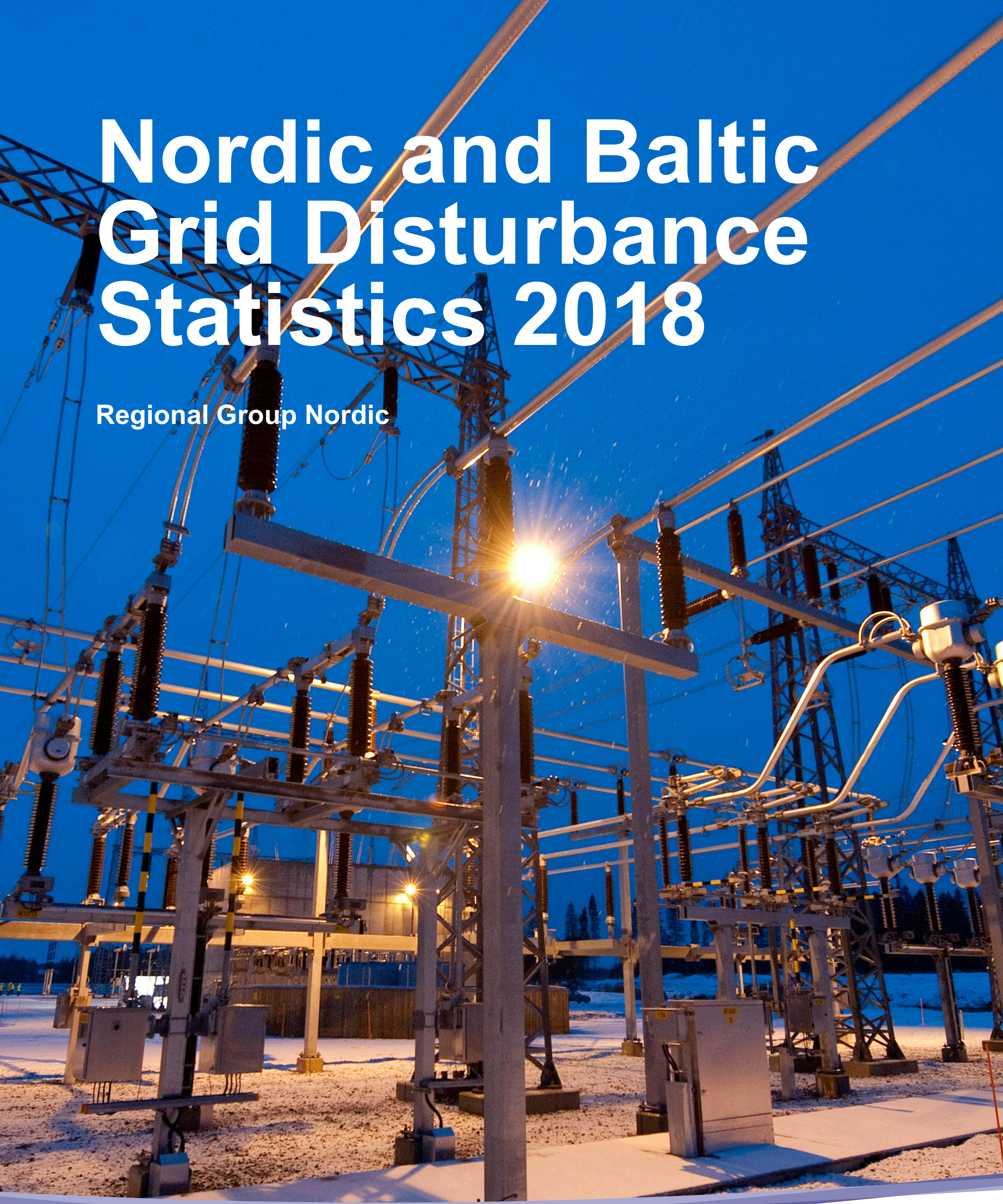
Nordic and Baltic Grid Disturbance Statistics 2018

Regional Group Nordic



European Network of
Transmission System Operators
for Electricity

entsoe

Nordic and Baltic Grid Disturbance Statistics 2018

Report rendered September 13, 2019

Executive Summary

The Nordic and Baltic Grid Disturbance Statistics 2018 gives both an overview of the disturbances, faults and energy not supplied (ENS) in the Nordic and Baltic transmission systems, as well as a deeper dive into the statistics of individual HVAC components used in the power system. To explain the results of the statistics, it is important to understand the definitions and the scope of a fault within it.

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

Year 2018 compared to the 10-year average

The year 2018 was considerably warmer than previous years, which can be seen as an increased percentage of disturbances occurring during the summer period. However, the number of disturbances in 2018 is lower compared to the 10-year average (1377 vs 1816), as well as the number of disturbances causing energy not supplied (366 in 2018 vs the 10-year average of 406 disturbances causing ENS).

Energy not supplied (ENS) in 2018 is continuing its decreasing trend, and was only 2686 MWh in 2018 (10-year average 6947 MWh). However, ENS did not show correlation with warmer months in the way disturbances did in 2018. This is a result of the grid being most often constructed according to the N-1 principle and thus being well protected against loss of supply. ENS was caused most by other and unknown causes, 55 % of the total ENS and 24 % compared to the 10-year average, while other environmental causes have been the most usual cause during the last 10-years.

Secondary faults, which are closely connected to disturbances with multiple faults, caused approximately 9 % of the total Nordic and Baltic ENS in 2018. Over half of the secondary faults were due to operation and maintenance and technical equipment causes in 2018. However, the ENS caused by secondary faults due to operation and maintenance and technical equipment only stand for approximately 25 % of the ENS caused by secondary faults. The dominating cause of ENS due to secondary faults is other causes.

The most vulnerable HVAC component type, as seen from the statistics, is overhead line causing 58 % of all faults (10-year average 63 %) and 29 % of the ENS (10-year average 52 %). However, this is explained by overhead lines being the most exposed HVAC component used in the transmission grid. Still, the number of overhead line faults per 100 km of line are decreasing. Faults in 100–150 kV and 220–330 kV control equipment are increasing slightly.

Finally, it should be noted that the response rate for Finland and Sweden was lower than usual. The statistics cover only about 82 % (normally 94 %) of the 110 kV transmission lines and 73 % (normally 93 %) of the 110 kV main transformers in Finland, and in Sweden, two regional grids that normally participate in the statistics did not take part in 2018.

Baltic summary

The number of grid disturbances in 2018 in the Baltic area decreased slightly compared to 2017 and was lower than the 10 year average. Furthermore, the amount of energy not supplied (ENS) is also decreasing.

Secondary faults, which are closely connected to disturbances with multiple faults, caused approximately 47 % of the total ENS in 2018 in the Baltic area. Over 68 % of the secondary faults were due to operation and maintenance and technical equipment causes in 2018, and they caused nearly all of the Baltic secondary faults ENS.

The power system component that were most prone to faults in 2018 in the Baltic area were overhead lines and substation components, causing 56 % and 28 % of the faults respectively. Compared to the 10-year average, overhead line faults decreased by 10 %. However, the percentage of control equipment faults was significantly higher while the other substation components showed an overall decrease. This evolution is not directly related to the energy not supplied (ENS) in 2018. Instead, the ENS caused by overhead line faults decreased by half while ENS caused by substation faults was more than double than the 10-year average (59 % vs the 10-year average of 24 %). Control equipment faults caused 30 % of all ENS during 2018.

Nordic summary

The number of grid disturbances in 2018 in the Nordic area increased slightly compared to 2017 but was still lower than the 10 year average. Furthermore, the amount of energy not supplied (ENS) is also decreasing.

Secondary faults, which are closely connected to disturbances with multiple faults, caused approximately 7 % of the total ENS in 2018 in the Nordic area. Over a third of the secondary faults were due to other causes in 2018, however, they caused nearly all of the Nordic secondary faults ENS.

The power system component that were most prone to faults in 2018 in the Nordic area were overhead lines and substation components, causing 58 % and 30 % of the faults respectively. Compared to the 10-year average, overhead line faults did not change significantly. However, the percentage of control equipment faults was significantly higher while the other substation components showed an overall decrease. This evolution is not directly visible in the energy not supplied (ENS) in 2018. Instead, the ENS caused by overhead line faults decreased while ENS caused by faults in the adjoining grid was 18 % higher than the 10-year average (3 % of all ENS).

Conclusion

In 2018, 75 % of the disturbances in the Nordic and Baltic area occurred in the Nordic area, which includes the Danish, Finnish, Icelandic, Norwegian and Swedish transmission grids. Furthermore, 95 % of the energy not supplied in the Nordic and Baltic area was caused in the Nordic transmission grid. However, this is understandable due to the Nordic grid being significantly larger than the Baltic grid. The Nordic and Baltic transmission grids are very comparable when the energy not supplied is scaled according to, for example, each country's consumption.

The year 2018 was an unusually warm year, which resulted in the number of disturbances concentrating to the summer period. Nevertheless, the total number of disturbances, as well as the amount of energy not supplied (ENS) caused by them, has decreased during the recent years.

Secondary faults, which are closely connected to disturbances with multiple faults, in the Nordic and Baltic areas have not shown to cause a significant portion of energy not supplied (ENS) in the whole area. However, they caused nearly half of all the Baltic ENS in 2018.

The most vulnerable HVAC component type in the Nordic and Baltic transmission grid is overhead line. Still, the number of overhead line faults per 100 km of line are decreasing while the number of control equipment faults showed an increase in 2018. Furthermore, ENS caused by faults in an adjoining grid was significantly higher in 2018 compared to the 10-year average.

Table of contents

List of Figures

List of Tables

1 Introduction

This report is an overview of the Nordic and Baltic HVAC transmission grid disturbance statistics for the year 2018. Transmission System Operators providing the statistical data are *Energinet* in Denmark, *Elering* in Estonia, *Fingrid Oyj* in Finland, *Landsnet* in Iceland, *Augstsprieguma tīkls* in Latvia, *Litgrid* in Lithuania, *Statnett SF* in Norway and *Svenska kraftnät* in Sweden. The statistics can be found at ENTSO-E website, www.entsoe.eu. The disturbance data of the whole Denmark is included in this report, although only the grid of eastern Denmark belongs to the Nordic synchronous grid. Figure 1.1.1 presents the grids of the statistics.

The report includes the faults causing disturbances in the 100–420 kV grids and is made according to the *Guidelines for Classification of Grid Disturbances above 100 kV* [1], which is published by ENTSO-E.

The report is organised as follows:

- Chapter 2 summarises the statistics, covering the consequences of disturbances in the form of energy not supplied (ENS) and covering the total number of disturbances in the Nordic and Baltic power system. In addition, each Transmission System Operator has presented the most important issues of the year 2018.
- Chapter 3 presents the disturbances and focuses on the analysis and allocation of the causes of disturbances. The distribution of disturbances during the year 2018 for each country is presented; for example, the consequences of the disturbances in the form of energy not supplied.
- Chapter 4 presents the tables and figures of energy not supplied for each country.
- Chapter 5 presents secondary faults and their impact on the Nordic and Baltic power systems.
- Chapter 6 presents the faults in different components. A summary of all the faults is followed by the presentation of more detailed statistics.

The Disturbance, Energy Not Supplied and Secondary Fault sections are to be considered on a general level. The faults in power system components section contains detailed information and is aimed towards experts working with primary equipment. The power system components included are: Overhead lines, cables, power transformers, breakers, instrument transformers, control equipment, disconnectors and compensation devices.

1.1 History

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

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

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

Figure 1.1.1: The Nordic and Baltic main grids [2]. The disturbance data of the whole Denmark is included in this report, although only the grid of eastern Denmark belongs to the Nordic synchronous grid.

1.2 The Scope and limitations of the statistics

The scope of the statistics, per the guidelines [1], is the following:

The statistics comprise:

- Grid disturbances
- Faults causing or aggravating a grid disturbance
- Disconnection of end users in connection with grid disturbances
- Outage in parts of the electricity system in conjunction with grid disturbance

The statistics do not comprise:

- Faults in production units
- Faults detected during maintenance
- Planned operational interruptions in parts of the electricity system
- Behaviour of circuit breakers and relay protection if they do not result in or extend a grid disturbance
- HVDC units. However, DISTAC produces a separate report with HVDC statistics called *Nordic and Baltic HVDC Utilisation and Unavailability Statistics* [3].

The statistics cover the main systems and associated network devices with a voltage level of more than 100 kV. Control equipment and installations for reactive compensation are also included in the statistics. Figure 1.2.1 presents a graphical interpretation of the components included in the statistics.

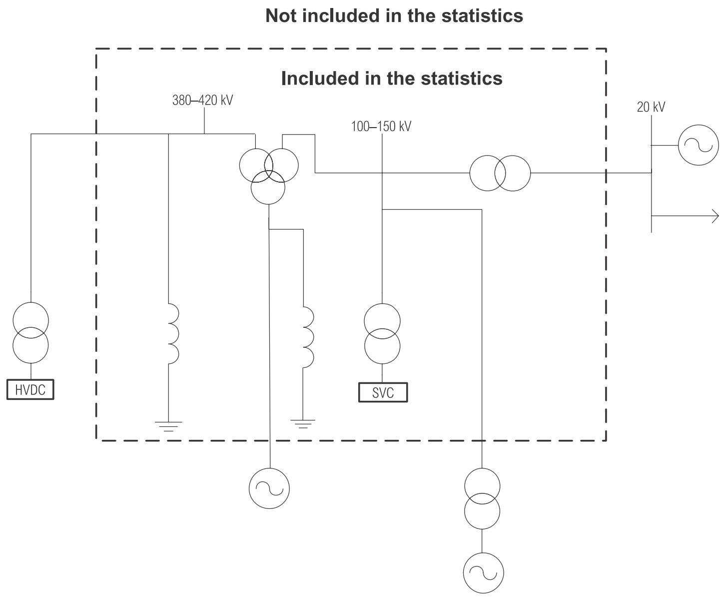


Figure 1.2.1: A graphical representation of the included power system components in the statistics.

Although the statistics are built upon common guidelines [1], there are slight differences in the interpretations between different countries and companies. However, these differences are considered to have a minor impact on the statistical material. Nevertheless, readers should – partly because of these differences, but also because of the different maintenance and general policies in each company – use the appropriate published average values. Values concerning control equipment and unspecified faults or causes should be used with wider margins than other values.

1.3 Available data in the report

Most charts and tables include data for the period 2009–2018. In some cases, where older data has been available, even longer periods have been used. However, not all of the participating TSO's have data for the whole period 2009–2018. In these cases, the tables and figures show all the available data. In this report, Latvia and Lithuania have reported for the period 2012–2018.

1.4 Definitions

This chapter defines terms and key concepts that are essential when examining this report. Each concept has its own section.

1.4.1 Fault categories

Each disturbance and fault must have a cause reported to it. For faults, the cause is the cause that has the most significant impact on the fault, while for disturbances, the reported cause is the same as the cause of its primary fault. The used causes are lightning, other environmental causes, external influences, operation and maintenance, technical equipment, other and unknown, as presented and detailed in Table 1.4.1. The exact definitions are listed in Section 4.2.9 in the HVAC Guidelines [1].

It should be noted, that there are some minor differences in the definitions of fault causes and disturbances between countries. Some countries use up to 40 different options, and others differentiate between primary and underlying causes. The guidelines [1] describe the relations between the detailed fault causes and the common Nordic cause allocation. Furthermore, that each country in these statistics has its own detailed way of determining the cause of each fault. Appendix B describes how each TSO in the Nordic and Baltic power systems examines the cause of line faults.

Table 1.4.1: The fault cause categories used in the Nordic and Baltic Grid Disturbance Statistics as defined in the HVAC Guidelines for classification of disturbances above 100 kV [1].

Fault cause	Explanation
Lightning	The category Lightning is separated from the environmental causes because its impact is insignificant from a maintenance perspective. This is mainly because the Nordic grid is well protected against lightning.
Other environmental causes	Moisture, ice, low temperatures, earthquakes, pollution, rain, salt, snow, vegetation, wind, heat, forest fires etc.
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, fault in documentation, human fault.
Technical equipment	Dimensioning, fault in technical documentation (e.g., guidelines, manuals), design, corrosion, materials, installation, production, vibration, ageing.
Other	Operating problems, faults at customers', faults in other networks, problems in conjunction with faults in other components, system causes, other
Unknown	Unknown causes

1.5 Voltage levels in the Nordic and Baltic networks

Table 1.5.1 presents the transmission system voltage levels of the networks in the Nordic and Baltic countries. In the statistics, voltage levels are grouped as statistical voltages per the table. Table 1.5.2 presents the coverage of the statistics in each country. The network statistics of each country cover data from several grid owners, and the representation of their statistics is not fully consistent.

Table 1.5.1: Nominal voltage levels (U_N) in the respective statistical voltages and the percentage of the grid at the respective nominal voltage level (P).

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

Table 1.5.2: Percentage of national networks included in the statistics. The percentage of the grid is estimated per the length of lines included in the statistics material divided by the actual length of lines in the grid. The network statistics of each country cover data from several grid owners, and the representation of their statistics is not fully consistent.

	Voltage level		
Country	380–420 kV	220–330 kV	100–150 kV
Denmark	100 %	100 %	100 %
Estonia	-	100 %	100 %
Finland[1,2]	100 %	100 %	94 %
Iceland[3]	-	100 %	100 %
Latvia	-	100 %	100 %
Lithuania	100 %	100 %	100 %
Norway[4]	100 %	100 %	100 %
Sweden	100 %	100 %	100 %

1 Finland's 110 kV network is not fully covered because some regional grid owners did not deliver data.
2 Finland's data from 2018 covers approximately 82 % of the Finnish 110 kV lines and approximately 73 % of the 110/20 kV transformers.
3 Iceland's network statistics cover the whole 220 kV and 132 kV voltage levels.
4 A large part of Norway's 110 and 132 kV network is resonant earthed. This category is combined with the 100–150 kV solid earthed network in these statistics.

1.6 Contact persons

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

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

2 Summary

In 2018, the number of disturbances in the Nordic and Baltic 100–420 kV grids amounted to 1377, which is below the 10-year average of 1815.5 disturbances. The energy not supplied (ENS) due to faults in the Nordic main grid reached 2.6 GWh and 127 MWh in the Baltic main grids. Totally, there was 2.7 GWh of ENS in the Nordic and Baltic main grid, which is below the ten-year average 6.9 GWh. Out of these disturbances, 371 caused ENS, which is also below the 10-year average of 388.8 disturbances causing ENS.

The following sections present the summaries for each Nordic and Baltic country. This includes an overview of the number and causes of disturbances and the resulting energy not supplied. Furthermore, secondary faults, which are closely related to disturbances with multiple faults, are shortly included. Lastly, the summaries present the most important issues in 2018 referred by the country's Transmission System Operator.

2.1 Summary of Denmark

In Denmark, the energy not supplied (ENS) caused by disturbances was 11.7 MWh in 2018 (10-year average 26.9 MWh). There were 43 grid disturbances (10-year average 55.7) and 3 of them caused ENS. On average, 7.0 disturbances per year caused ENS in 2009–2018.

In 2018, 100.0 % of the total ENS was caused by substation faults. The most significant reason of ENS caused by disturbances was operation and maintenance (100.0 %). Disturbances were caused most by operation and maintenance (41.9 %) and external influences (30.2 %).

Secondary faults in Denmark only accounted for 7 % of all faults in 2018 and caused 3 % of the total ENS. They were all caused by operation and maintenance.

The three most influential disturbances in 2018 were the following:

- During testing of a new component at a 150 kV station in West-Jutland 17 December, the whole station got disconnected due to wrong settings in the said electrical component. The outage lasted 15 minutes and caused 11 MWh of ENS.
- A reactor caught fire at a critical 400 kV station west of Copenhagen 23 July. The fire was caused by a failed bushing to the reactor. The disturbance did not cause any ENS, but raised the system to an alert state with a risk of severe consequences. All 400 kV lines from the station had to be disconnected due to fire extinction.
- Three failed circuit breakers connected to reactors during 21 October, 11 November and 2 December. Two disturbances at 400 kV and one at 150 kV. All due to reignition in the breakers after disconnection of the reactors. No ENS, but high focus due to risk of personal injury.

2.2 Summary of Estonia

In Estonia, the energy not supplied (ENS) caused by disturbances was 29.5 MWh in 2018 (10-year average 173.4 MWh). There were 111 grid disturbances (10-year average 204.8) and 43 of them caused ENS. On average, 30.9 disturbances per year caused ENS in 2009–2018.

In 2018, 27.5 % of the total ENS was caused by substation faults and 9.9 % was caused by overhead line faults. The most significant reasons of ENS caused by disturbances were other causes (62.6 %) and technical equipment (23.9 %). Disturbances were caused most by technical equipment (22.5 %) and operation and maintenance (18.0 %).

Secondary faults in Estonia only accounted for 7 % of all faults in 2018 and caused 1 % of the total ENS. They were all caused by operation and maintenance (75 %) and technical equipment (25 %), and the ENS was solely due to operation and maintenance.

The three most influential disturbances in 2018 were the following:

- Two 110 kV transformers at substation Järve switched out from relay protection 10 March 2018. The secondary circuit had a connector failure on the client side.

- A 330 kV joint fastener on the 330 kV cross-border transmission line L358 was damaged and required emergency maintenance 30 March 2018.
- A 110 kV separator (primary equipment) fault at single-ended substation occurred 30 October 2018. Emergency maintenance had to be conducted and this event was the incident that caused the highest amount of energy not supplied (ENS) in 2018.

2.3 Summary of Finland

In Finland, the energy not supplied (ENS) caused by disturbances was 99.0 MWh in 2018 (10-year average 357.2 MWh). There were 308 grid disturbances (10-year average 439.2) and 55 of them caused ENS. On average, 78.0 disturbances per year caused ENS in 2009–2018.

In 2018, 60.7 % of the total ENS was caused by substation faults and 34.9 % was caused by overhead line faults. The most significant reasons of ENS caused by disturbances were other causes (53.4 %) and technical equipment (21.5 %). Disturbances were caused most by other causes (34.4 %) and other environmental causes (26.0 %).

Secondary faults in Finland only accounted for 3 % of all faults in 2018 and caused approximately 33 % of the total ENS. They were mainly caused by operation and maintenance (33 %) and other causes (33 %), and the ENS was solely due to other causes.

The three most influential disturbances of 110–400 kV grids in 2018 were:

- 110 kV transmission line and 110 kV substation main power transformer tripped due to lightning and caused secondary faults. The incident caused 26.5 MWh of ENS.
- Current transformer fault in a 110 kV main transformer caused 19.2 MWh of ENS.
- A fault in a 110 kV main transformer caused 17.5 MWh of ENS.

The response rate in 2018 was lower than usual. The statistics cover only about 82 % (normally 94 %) of the 110 kV transmission lines and 73 % (normally 93 %) of the 110 kV main transformers in Finland.

2.4 Summary of Iceland

In Iceland, the energy not supplied (ENS) caused by disturbances was 475.6 MWh in 2018 (10-year average 877.2 MWh). There were 46 grid disturbances (10-year average 33.7) and 10 of them caused ENS. On average, 17.4 disturbances per year caused ENS in 2009–2018.

Registered grid disturbances were 46 compared to last year's 31, but ENS was dramatically lower. One disturbance caused the majority of ENS this year (425 MWh).

In 2018, 9.5 % of the total ENS was caused by substation faults and 1.2 % was caused by overhead line faults. The most significant reasons of ENS caused by disturbances were other causes (94.7 %) and operation and maintenance (5.2 %). Disturbances were caused most by other causes (78.3 %) and operation and maintenance (10.9 %).

Secondary faults in Iceland accounted for 28 % of all faults in 2018, and none of them caused any ENS. They were mostly caused by other causes (83 %).

The three most influential disturbances in the 220 and 132 kV network in 2018 were the following:

- A potline at an aluminium smelter tripped during maintenance work on a 220 kV transmission line 17 February. Unfortunately, the protection scheme did not work properly in these circumstances and caused a second potline to trip at the aluminium plant. This resulted in a trip of around 25 % of the system load and a widespread trip of other loads and all units of one geothermal station. The total amount of ENS of the incident was 425 MWh.
- A faulty surge arrestor tripped the 132 kV transmission line FI1 20 February. This caused widespread disturbances to distribution consumers and 19.7 MWh of ENS.
- Wrong relay settings in a substation caused a power transformer to trip 9 July. The incident resulted in 17 MWh of ENS.

2.5 Summary of Latvia

In Latvia, the energy not supplied (ENS) caused by disturbances was 63.0 MWh in 2018 (7-year average 86.9 MWh). There were 110 grid disturbances (7-year average 140.0) and 15 of them caused ENS. On average, 17.6 disturbances per year caused ENS in 2012–2018.

In 2018, 67.5 % of the total ENS was caused by substation faults and 32.3 % was caused by overhead line faults. The most significant reasons of ENS caused by disturbances were external influences (38.5 %) and other environmental causes (35.3 %). Disturbances were caused most by external influences (26.4 %) and other environmental causes (22.7 %).

Secondary faults in Latvia accounted for 16 % of all faults in 2018 and caused approximately 54 % of the total ENS. They were mainly caused by technical equipment (40 %) operation and maintenance (35 %), and the ENS was predominantly due to operation and maintenance (98 %).

The three most influential disturbances in 2018 were the following:

- A fault on a 110 kV overhead line close to 330 kV substation and due to other environmental causes caused two multiple faults on a 330 kV power transformer control equipment (commissioned short time before). The faults caused outages for one busbar and 14 units. Due to reconstruction works, supply reservation was not possible and resulted in 15.1 MWh of ENS.
- Other environmental cause fault on 110 kV overhead line that, due to reconstruction works, was only supplying point cause blackout of substation for 3 hours and ENS 18.9 MWh.
- Technical equipment fault on 110 kV power transformer that, due to planed maintenance, was only feeding point on substation caused interruption of supply for 2 hours and ENS 7.5 MWh.

2.6 Summary of Lithuania

In Lithuania, the energy not supplied (ENS) caused by disturbances was 34.1 MWh in 2018 (7-year average 40.0 MWh). There were 123 grid disturbances (7-year average 158.3) and 17 of them caused ENS. On average, 19.1 disturbances per year caused ENS in 2012–2018.

In 2018, 69.2 % of the total ENS was caused by substation faults and 11.3 % was caused by overhead line faults. The most significant reasons of ENS caused by disturbances were other causes (52.8 %) and external influences (35.2 %). Disturbances were caused most by unknown causes (30.1 %) and other causes (24.4 %).

Secondary faults in Lithuania accounted for 13 % of all faults in 2018 and caused approximately 74 % of the total ENS. They were mainly caused by unknown causes (37 %), technical equipment (26 %) and operation and maintenance (21 %), and the ENS was predominantly due to technical equipment (83 %).

The two most influential disturbances in 2018 were the following:

- A multiple fault situation occurred on 27 July 2018. Because of a fault in the distribution network, a transformer's 110 kV circuit breaker failed to trip in Saugos substation. As a result of circuit breaker failure, energy supply to Saugos and Silute substations were interrupted. The incident caused 54.4 % of total ENS in 2018 and was most influential.
- A multiple fault situation occurred on 21 April 2018. 110 kV transmission line supplying energy to Paberze substation tripped because a rotten tree fell on it. One of two transformers in the substation was switched off normally and second one lost energy supply because of the trip on the line. As a result, energy supply for energy consumers was interrupted. During energization of transformers from other 110 kV transmission line, surge arrester in Paberze substation exploded. The incident caused 26.4 % of total ENS.

2.7 Summary of Norway

In Norway, the energy not supplied (ENS) caused by disturbances was 588.6 MWh in 2018 (10-year average 3493.6 MWh). There were 267 grid disturbances (10-year average 293.7) and 66 of them caused ENS. On average, 86.8 disturbances per year caused ENS in 2009–2018.

In 2018, 76.3 % of the total ENS was caused by substation faults and 10.0 % was caused by overhead line faults. The most significant reasons of ENS caused by disturbances were operation and maintenance (36.3 %) and unknown causes (30.6 %). Disturbances were caused most by other environmental causes (30.7 %) and lightning (20.6 %).

Secondary faults in Norway accounted for 11 % of all faults in 2018 and caused approximately 22 % of the total ENS. They were mostly caused by operation and maintenance (29 %) and technical equipment (24 %), and the ENS was mainly due to other causes (97 %).

Norway had no major disturbances in 2018, only medium disturbances and many with insignificant consequences. On 28 of February a fire in a small station auxiliary transformer in Blinheimsbreivika resulted in 172 MWh of ENS due to long repair time. On 4 February a breaker explosion on Dolvik Transformer 2 tripped the full busbar and the surrounding stations correctly and resulted in 171 MWh of ENS in total.

2.8 Summary of Sweden

In Sweden, the energy not supplied (ENS) caused by disturbances was 1384.5 MWh in 2018 (10-year average 1891.8 MWh). There were 369 grid disturbances (10-year average 490.1) and 157 of them caused ENS. On average, 148.9 disturbances per year caused ENS in 2009–2018.

In 2018, 49.0 % of the total ENS was caused by overhead line faults and 46.7 % was caused by substation faults. The most significant reasons of ENS caused by disturbances were unknown causes (47.5 %) and technical equipment (23.6 %). Disturbances were caused most by lightning (40.1 %) and unknown causes (28.7 %). The reason of Sweden having more disturbances and ENS due to unknown causes is that if the cause of a disturbance is not 100 % certain, which might be case with lightning, it will be assigned as an unknown cause as explained in Appendix B. Additionally, the disturbance that caused the largest amount of ENS in 2018 was categorized with unknown as the cause.

Secondary faults in Sweden only accounted for 2 % of all faults in 2018, and none of them caused any ENS. They were mostly caused by technical equipment (43 %).

Sweden had one significant disturbance in 2018. It was caused by a trip on a 220 kV transmission line, which in turn caused an outage in a transformer substation that was being fed radially due to temporary switching configuration. The incident caused 277.2 MWh of ENS.

The response rate for the 2018 statistics was lower than usual with two regional grids not participating.

3 Disturbances

This chapter presents an overview of disturbances in the European countries included in this report. It also presents the connection between disturbances, energy not supplied, causes of faults, and distribution during the year 2018, together with the development of the number of disturbances over the 10-year period 2009–2018.

Grid disturbances are defined as:

> Outages, forced or unintended disconnection or failed manual reconnection as a result of faults in the power grid [1] [4].

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

3.1 Annual number of disturbances during the period 2009–2018

Table 3.1.1 presents the sum of disturbances during the year 2018 and the annual average for the period 2009–2018. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

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

Table 3.1.1: The number of disturbances and disturbances causing ENS in 2018.

	Disturbances		Disturbances causing ENS	
Country	Count 2018	Average 2009–2018	Count 2018	Average 2009–2018
Estonia	111	204.8	43	30.9
Latvia[1]	110	140.0	15	17.6
Lithuania[1]	123	158.3	17	19.1
Baltic total	344	503.1	75	67.6
Denmark	43	55.7	3	7.0
Finland	308	439.2	55	78.0
Iceland	46	33.7	10	17.4
Norway	267	293.7	66	86.8
Sweden	369	490.1	157	148.9
Nordic total	1033	1312.4	291	338.1
Nordic & Baltic	1377	1815.5	366	405.7

[1] The average values of Latvia and Lithuania use the period 2012–2018.

Figure 3.1.1 show the annual number of disturbances during the period 2009–2018 in the Nordic and Baltic countries.

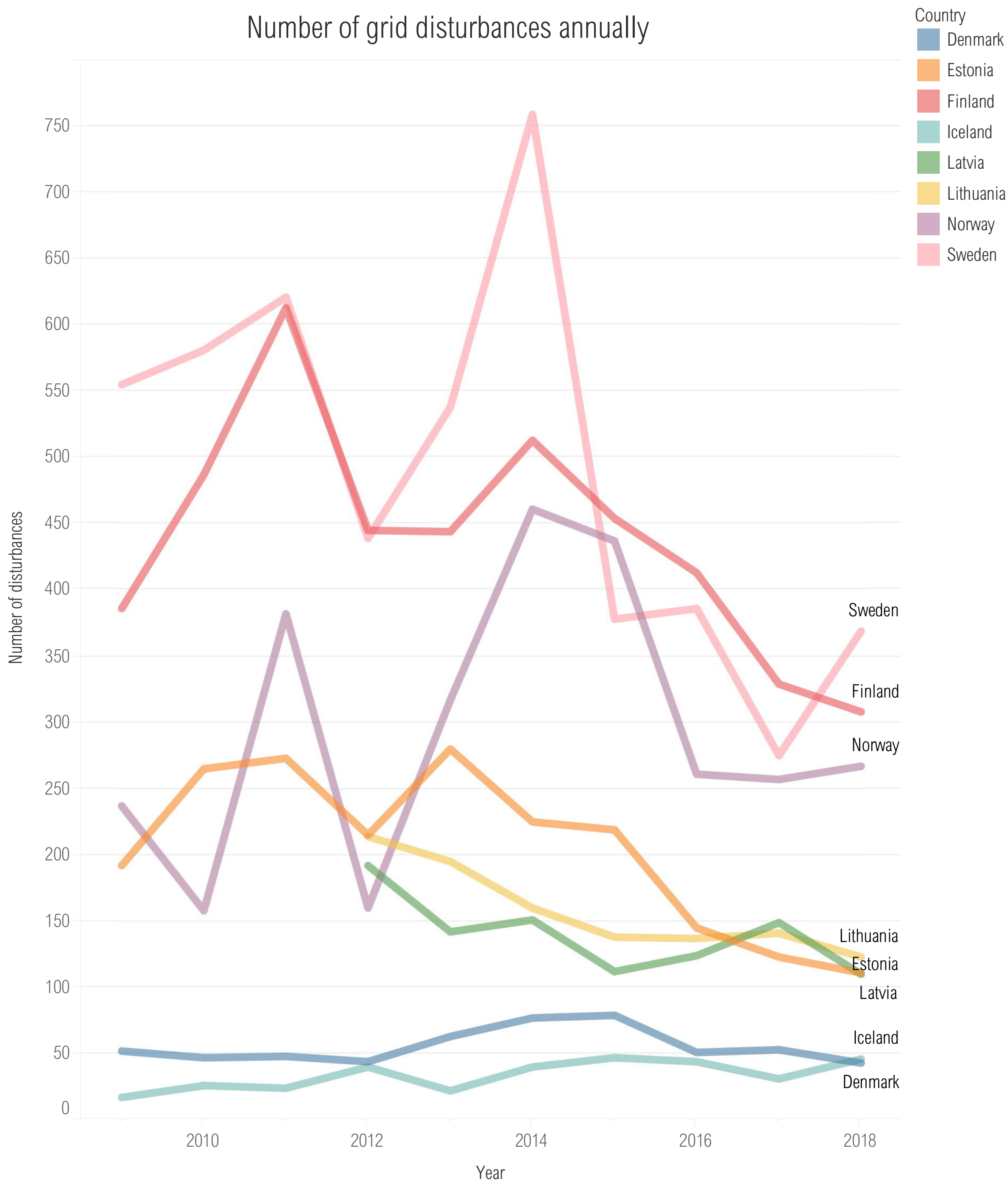


Figure 3.1.1: The annual number of grid disturbances in each Nordic country and Estonia during 2009–2018 and during 2012–2018 in Latvia and Lithuania. Finnish data covers 83 % of 110 kV grid in 2018 while it has normally covered 94 %.

3.2 Disturbances distributed per month

Table 3.2.1 presents the percentage distribution of grid disturbances per month for each Nordic country and Estonia during 2009–2018 and during 2012–2018 for Latvia and Lithuania. Table 3.2.2 presents the 10-year percentage distribution of grid disturbances per month for each Nordic country and Estonia during 2009–2018 and during 2012–2018 for Latvia and Lithuania. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

Table 3.2.1: Percentage distribution of grid disturbances per month in 2018 in each Nordic and Baltic country. The number of disturbances is usually largest during the summer period for all countries except Iceland. This is often caused by the amount of lightning strokes during summer.

Monthly distribution of grid disturbances in 2018

Regions	Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Baltic	Estonia	4%	3%	7%	7%	10%	12%	17%	15%	9%	9%	4%	4%
	Latvia	4%	4%	5%	10%	7%	16%	12%	21%	12%	4%	4%	3%
	Lithuania	2%	2%	6%	5%	12%	7%	28%	20%	5%	6%	6%	2%
	Total	3%	3%	6%	7%	10%	12%	19%	19%	8%	6%	4%	3%
Nordic	Denmark	16%	7%	9%	2%	7%	5%	14%	12%	5%	7%	7%	9%
	Finland	5%	3%	4%	7%	10%	8%	18%	21%	9%	4%	4%	6%
	Iceland	7%	17%	7%	13%	7%	2%	13%	4%	7%	13%	2%	9%
	Norway	17%	4%	4%	3%	7%	10%	18%	10%	9%	6%	6%	6%
	Sweden	8%	4%	5%	2%	7%	11%	27%	20%	6%	4%	5%	4%
	Total	10%	4%	5%	4%	8%	9%	21%	17%	7%	5%	5%	5%
Grand Total		8%	4%	5%	5%	8%	10%	20%	17%	8%	5%	5%	5%

Table 3.2.2: Average 10-year percentage distribution of grid disturbances per month during 2009–2018 in each Nordic country and Estonia and during 2012–2018 in Latvia and Lithuania. The number of disturbances is usually largest during the summer period for all countries except Iceland. This is often caused by the amount of lightning strokes during summer.

10-year average monthly distribution of grid disturbances

Regions	Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Baltic	Estonia	3%	2%	4%	4%	8%	12%	23%	23%	6%	6%	3%	5%
	Latvia	4%	3%	5%	5%	10%	11%	15%	22%	7%	7%	6%	7%
	Lithuania	2%	2%	5%	6%	9%	10%	19%	29%	5%	6%	3%	4%
	Total	3%	2%	4%	5%	9%	11%	20%	24%	6%	6%	4%	5%
Nordic	Denmark	6%	6%	6%	6%	10%	10%	8%	9%	10%	10%	9%	11%
	Finland	6%	4%	3%	6%	10%	13%	24%	14%	7%	4%	4%	5%
	Iceland	11%	12%	13%	6%	6%	4%	6%	4%	6%	8%	9%	15%
	Norway	13%	7%	8%	3%	5%	8%	13%	9%	6%	6%	7%	15%
	Sweden	5%	4%	4%	5%	8%	12%	25%	16%	6%	5%	5%	6%
	Total	7%	5%	5%	5%	8%	11%	21%	13%	7%	5%	5%	8%
Grand Total		6%	4%	5%	5%	8%	11%	21%	16%	6%	5%	5%	7%

3.3 Disturbances distributed per cause

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

Table 3.3.1 presents disturbances per cause in terms of the primary fault distributed for the year 2018 for each Nordic and Baltic country. Table 3.3.2 presents the respective average values for the period 2009–2018 in the Nordic countries and Estonia and during 2012–2018 in Latvia and Lithuania. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

Table 3.3.1: Percentage distribution of grid disturbances per cause in 2018 in each Nordic and Baltic country.

Grid disturbances according to cause in 2018

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	11%	13%	12%	18%	23%	12%	13%
	Latvia	6%	23%	26%	6%	6%	12%	20%
	Lithuania	7%	2%	23%	8%	6%	24%	30%
	Total	8%	12%	20%	11%	11%	16%	21%
Nordic	Denmark	0%	5%	30%	42%	7%	5%	12%
	Finland	15%	26%	3%	7%	6%	34%	9%
	Iceland	0%	7%	0%	11%	0%	78%	4%
	Norway	21%	31%	3%	19%	15%	7%	5%
	Sweden	40%	2%	3%	7%	14%	6%	29%
	Total	24%	17%	4%	12%	11%	18%	15%
Grand Total		20%	16%	8%	11%	11%	17%	16%

Table 3.3.2: Average distribution of grid disturbances per cause during 2009–2018 in each Nordic country and Estonia and during 2012–2018 in Latvia and Lithuania.

10-year average distribution of grid disturbances according to cause

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	10%	22%	5%	16%	18%	10%	18%
	Latvia	10%	21%	24%	7%	9%	10%	18%
	Lithuania	9%	4%	23%	7%	7%	13%	37%
	Total	10%	17%	14%	12%	13%	11%	23%
Nordic	Denmark	11%	10%	21%	18%	17%	10%	14%
	Finland	23%	26%	1%	6%	5%	16%	23%
	Iceland	3%	40%	2%	12%	18%	24%	1%
	Norway	21%	33%	2%	12%	18%	10%	5%
	Sweden	36%	4%	2%	8%	14%	11%	26%
	Total	26%	19%	2%	9%	12%	13%	19%
Grand Total		22%	19%	5%	9%	12%	12%	20%

Table 3.3.3 presents disturbances that caused ENS distributed by its cause for the year 2018. Table 3.3.4 presents the respective average values during 2009–2018 in the Nordic countries and Estonia and during 2012–2018 in Latvia and Lithuania. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

Table 3.3.3: Percentage distribution of grid disturbances causing ENS per cause in 2018 in each Nordic and Baltic country.

Grid disturbances causing ENS according to cause in 2018

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	9%	16%	7%	19%	19%	21%	9%
	Latvia	0%	40%	27%	13%	7%	13%	0%
	Lithuania	6%	0%	35%	24%	12%	24%	0%
	Total	7%	17%	17%	19%	15%	20%	5%
Nordic	Denmark	0%	0%	0%	100%	0%	0%	0%
	Finland	15%	9%	4%	4%	15%	31%	24%
	Iceland	0%	10%	0%	30%	0%	60%	0%
	Norway	26%	29%	3%	26%	8%	5%	5%
	Sweden	39%	1%	2%	9%	14%	2%	33%
	Total	30%	9%	2%	13%	12%	10%	23%
Grand Total		25%	11%	5%	14%	13%	12%	20%

Table 3.3.4: Average distribution of grid disturbances causing ENS per cause during 2009–2018 in each Nordic country and Estonia and during 2012–2018 in Latvia and Lithuania.

10-year average distribution of grid disturbances causing ENS according to cause

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	4%	8%	11%	28%	21%	19%	8%
	Latvia	1%	30%	25%	20%	16%	5%	3%
	Lithuania	5%	10%	36%	22%	13%	4%	10%
	Total	3%	14%	20%	25%	18%	13%	8%
Nordic	Denmark	4%	7%	1%	44%	23%	13%	7%
	Finland	19%	16%	3%	9%	8%	12%	33%
	Iceland	4%	45%	2%	13%	16%	18%	1%
	Norway	23%	28%	2%	16%	13%	12%	6%
	Sweden	38%	3%	2%	10%	12%	7%	28%
	Total	27%	15%	2%	12%	12%	10%	21%
Grand Total		24%	14%	5%	14%	13%	11%	19%

4 Energy not supplied (ENS)

This chapter presents energy not supplied (ENS) caused by faults and disturbances in the Nordic and Baltic power systems. This includes the amount of ENS in 2018 and the average during 2009–2018. Furthermore, ENS has been compared with consumption and line length in Section 4.2, distributed per month in Section 4.3, distributed per cause in Section 4.4, divided according to voltage level in Section 4.5 and finally examined at component level in Section 4.6.

Energy not supplied is defined as:

> The estimated energy, which would have been supplied to end users if no interruption and no transmission restrictions had occurred [1].

One should remember that the amount of ENS is always an estimation. The accuracy of the estimation varies between companies in different countries and so does the calculation method for energy not supplied, as can be seen in Appendix A.

4.1 Overview of energy not supplied (ENS)

Table 4.1.1 shows the amount of energy not supplied in 2018 and the annual average for the period 2009–2018. It should be noted that this table includes ENS caused by faults outside the statistical area of each country. Therefore, the amount of ENS in Table 4.1.1 may be higher than in the rest of the tables in this report.

Table 4.1.1: Energy not supplied (ENS) due to faults in each Nordic and Baltic country in 2018 and the annual average for the period 2009–2018. The ENS also includes ENS caused by faults outside the TSO's statistical area.

	ENS (MWh)	
Country	2018	2009–2018
Estonia	29.5	173.4
Latvia[1]	63.0	86.9
Lithuania[1]	34.1	40.0
Baltic total	126.6	300.3
Denmark	11.7	27.0
Finland	147.2	374.1
Iceland	475.6	925.4
Norway	588.6	3493.6
Sweden[2]	1384.6	1884.8
Nordic total	2607.6	6704.8
Nordic & Baltic	2734.1	7005.1

[1] The average values of Latvia and Lithuania use the period 2012–2018.
[2] One Swedish regional grid delivered incomplete data in 2012. The details of the origin of the fault were not reported and therefore 750 MWh of ENS is not included from that year.

4.2 Energy not supplied and total consumption

Table 4.2.1 shows the energy not supplied in relation to the total consumption of energy in each Nordic and Baltic country. Ppm (parts per million) represents ENS as a proportional value of the consumed energy, which is calculated: ENS × 10^6 / consumption. The value of ENS is the total amount of ENS caused by all faults, that is, faults inside the statistical area and faults from outside the own grid that effect other statistical area.

Table 4.2.1: Consumption and energy not supplied (ENS) due to faults in each Nordic and Baltic country in 2018 and the average for the period 2009–2018. The ENS value is the total amount of ENS caused by all faults, that is, faults inside the statistical area and faults from outside the own grid that impact the other statistical area.

	Consumption (TWh)	ENS (MWh)	ENS / consumption (ppm)	
Country	2018	2018	2018	2009–2018
Estonia	8.7	29.5	3.4	22.3
Latvia[1]	7.4	63.0	8.5	12.4
Lithuania[1]	12.1	34.1	2.8	3.8
Baltic total	28.2	126.6	4.5	11.9
Denmark	33.6	11.7	0.3	0.8
Finland	85.8	147.2	1.7	4.4
Iceland	18.7	475.6	25.5	52.2
Norway	135.4	588.6	4.3	26.2
Sweden	141.1	1384.6	9.8	13.5
Nordic total	414.5	2607.6	6.3	16.4
Nordic & Baltic	442.7	2734.1	6.2	16.2

[1] The average values of Latvia and Lithuania use the period 2012–2018.

Table 4.2.2: Energy not supplied (ENS) in each Nordic and Baltic country in 2018 and the annual average for the period 2009–2018

	Consumption (TWh)	ENS (MWh)	ENS / consumption (ppm)	
Country	2018	2018	2018	2009–2018
Estonia	8.7	29.5	3.4	22.3
Latvia[1]	7.4	63.0	8.5	12.4
Lithuania[1]	12.1	34.1	2.8	3.8
Baltic total	28.2	126.6	4.5	11.9
Denmark	33.6	11.7	0.3	0.8
Finland	85.8	147.2	1.7	4.4
Iceland	18.7	475.6	25.5	52.2
Norway	135.4	588.6	4.3	26.2
Sweden	141.1	1384.6	9.8	13.5
Nordic total	414.5	2607.6	6.3	16.4
Nordic & Baltic	442.7	2734.1	6.2	16.2

[1] The average values Latvia and Lithuania use the period 2012–2018.

Figure 4.2.1 presents the 5-year moving average of ENS scaled by consumption since 1995 in the Nordic countries, since 2007 in Estonia and since 2012 in Latvia and Lithuania. The total line length is the sum of the lengths of overhead lines and cables. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

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

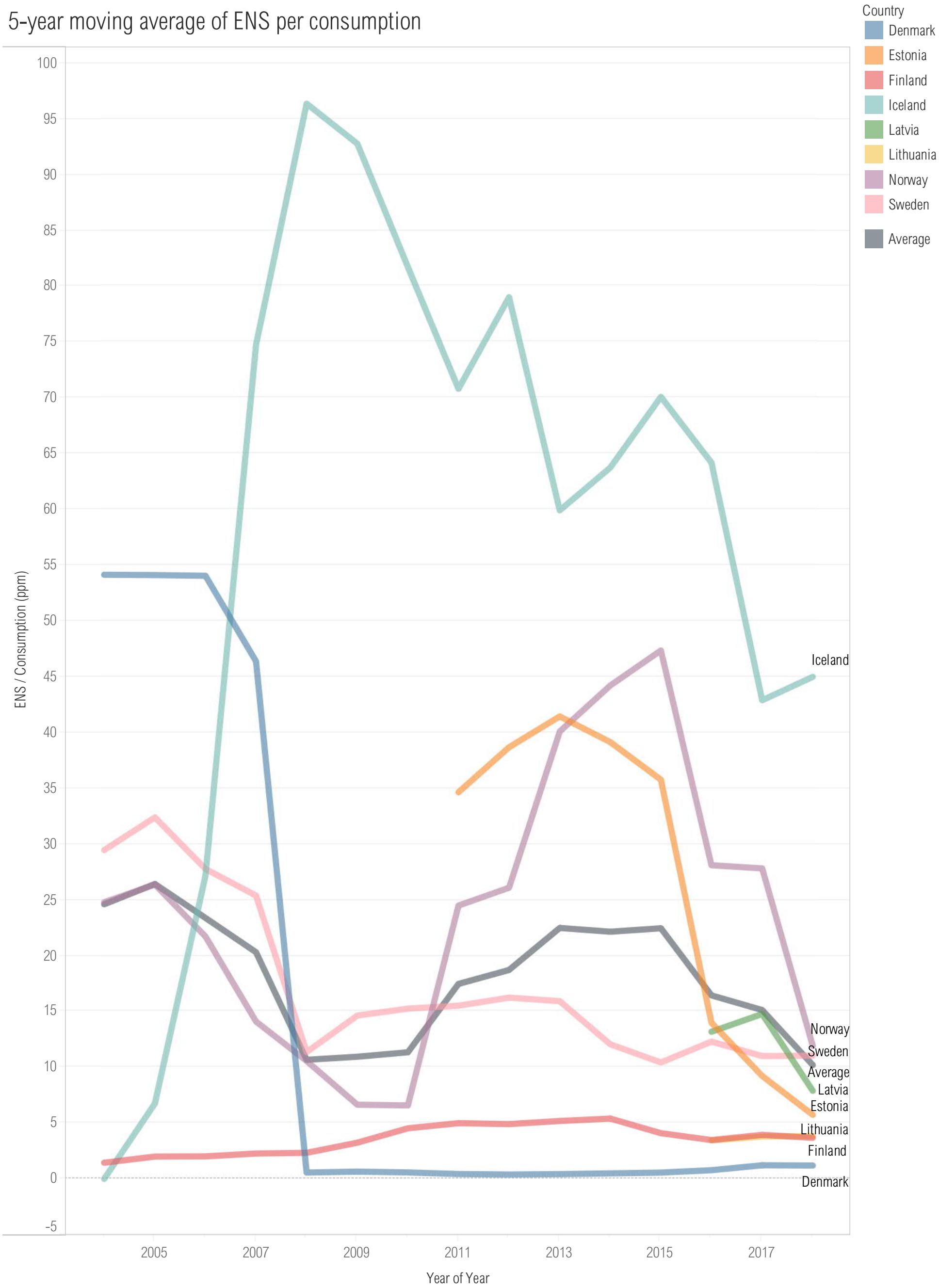


Figure 4.2.1: 5-year moving average amount of ENS divided per consumption (ppm) since 1995 in the Nordic countries, since 2007 in Estonia and since 2012 in Latvia and Lithuania. Denmark's low values are a result of various elements such as having a meshed grid and compared to the other Nordic countries, a mild climate. Iceland's high values are a result of power intensive industries that cause substantial amounts of ENS even during short interruptions. The unusually high ENS divided by consumption during 2011–2015 in Norway was caused by extreme weather conditions in December 2011 (aka the storm named Dagmar).

4.3 Energy not supplied distributed per month

This section presents energy not supplied (ENS) distributed per month. Table 4.3.1 presents the distribution of energy not supplied per month for the year 2018 in each Nordic and Baltic country. Table 4.3.2 presents the respective average values during 2009–2018 in the Nordic countries and Estonia during 2012–2018 in Latvia and Lithuania. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

Monthly distribution of ENS in 2018

Regions	Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Baltic	Estonia	2%	9%	43%	0%	15%	3%	0%	19%	6%	2%	0%	0%
	Latvia	14%	0%	0%	0%	24%	2%	1%	28%	30%	0%	1%	0%
	Lithuania	0%	0%	2%	23%	16%	4%	50%	1%	1%	1%	3%	0%
	Total	8%	2%	10%	6%	20%	3%	14%	18%	17%	1%	1%	0%
Nordic	Denmark	0%	0%	0%	0%	0%	0%	0%	0%	1%	2%	0%	96%
	Finland	1%	1%	3%	0%	18%	2%	45%	2%	7%	4%	1%	15%
	Iceland	0%	95%	0%	0%	1%	0%	4%	0%	0%	1%	0%	0%
	Norway	12%	58%	1%	2%	2%	3%	7%	1%	11%	0%	1%	2%
	Sweden	7%	8%	2%	7%	12%	5%	6%	12%	3%	25%	2%	10%
	Total	7%	35%	2%	4%	8%	4%	8%	7%	4%	14%	1%	7%
Grand Total		7%	34%	2%	4%	9%	3%	8%	7%	5%	13%	1%	7%

Table 4.3.1: Percentage distribution of ENS per month in 2018 in each Nordic and Baltic country.

10-year average monthly distribution of ENS

Regions	Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Baltic	Estonia	2%	4%	2%	2%	4%	4%	8%	7%	2%	11%	12%	42%
	Latvia	2%	0%	2%	1%	4%	5%	10%	11%	9%	45%	5%	6%
	Lithuania	3%	10%	2%	5%	7%	30%	15%	9%	2%	13%	1%	3%
	Total	2%	3%	2%	2%	4%	7%	9%	8%	3%	19%	9%	30%
Nordic	Denmark	6%	16%	7%	1%	13%	4%	0%	4%	0%	34%	4%	10%
	Finland	6%	4%	9%	6%	3%	6%	16%	10%	16%	3%	8%	13%
	Iceland	46%	10%	5%	2%	4%	6%	3%	1%	5%	5%	4%	8%
	Norway	8%	8%	30%	3%	1%	5%	2%	2%	2%	1%	4%	36%
	Sweden	3%	6%	2%	5%	9%	11%	22%	10%	5%	8%	14%	6%
	Total	11%	8%	17%	4%	4%	7%	8%	5%	4%	4%	7%	22%
Grand Total		11%	7%	17%	4%	4%	7%	8%	5%	4%	4%	7%	23%

Table 4.3.2: Average percentage distribution of ENS per month during 2009–2018 in each Nordic country and Estonia and during 2012–2018 in Latvia and Lithuania.

4.4 Energy not supplied distributed per cause

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

Table 4.4.1 presents the distribution of energy not supplied per cause in 2018 in each Nordic and Baltic country. Table 4.4.2 presents the respective average values during 2009–2018 in the Nordic countries and Estonia and during 2012–2018 in Latvia and Lithuania. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

Distribution of ENS according to cause in 2018

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	0%	0%	2%	10%	24%	63%	0%
	Latvia	0%	30%	2%	54%	13%	0%	0%
	Lithuania	0%	0%	11%	7%	68%	14%	0%
	Total	0%	15%	4%	31%	30%	18%	0%
Nordic	Denmark	0%	0%	0%	100%	0%	0%	0%
	Finland	3%	9%	2%	0%	14%	69%	3%
	Iceland	0%	0%	0%	5%	0%	95%	0%
	Norway	2%	14%	0%	35%	9%	25%	16%
	Sweden	17%	0%	3%	7%	23%	6%	44%
	Total	10%	4%	2%	13%	15%	30%	27%
Grand Total		9%	4%	2%	14%	16%	29%	26%

Table 4.4.1: Percentage distribution of ENS per cause in 2018 in each Nordic and Baltic country. The unusually high amount of ENS due to unknown causes in Sweden was caused by a single incident with 277 MWh of ENS, which in turn stands for almost half of the total ENS due to unknown causes.

10-year average distribution of ENS according to cause

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	3%	5%	25%	10%	30%	25%	2%
	Latvia	0%	50%	15%	24%	10%	0%	1%
	Lithuania	2%	16%	35%	7%	34%	4%	2%
	Total	2%	16%	24%	13%	26%	17%	2%
Nordic	Denmark	1%	7%	0%	53%	29%	7%	4%
	Finland	9%	25%	8%	11%	21%	19%	7%
	Iceland	3%	46%	1%	16%	14%	20%	0%
	Norway	4%	64%	0%	6%	12%	11%	2%
	Sweden	24%	2%	6%	8%	24%	15%	22%
	Total	9%	42%	3%	8%	16%	14%	8%
Grand Total		9%	41%	3%	8%	17%	14%	7%

Table 4.4.2: Average percentage distribution of ENS per cause during 2009–2018 in each Nordic country and Estonia and during 2012–2018 in Latvia and Lithuania. The reason of Sweden having more disturbances and ENS due to unknown causes is that if the cause of a disturbance is not 100 % certain, which might be the case with lightning, it will be reported as an unknown cause as explained in Appendix B. Additionally, the disturbance that caused the largest amount of ENS in 2018 was categorized with unknown as the cause.

4.5 Energy not supplied per voltage level

This section presents energy not supplied (ENS) per voltage level. The used voltage levels are 100–150 kV, 220–330 kV and 380–420 kV. Table 4.5.1 shows the amount of energy not supplied and its distribution per voltage level. The voltage level of a disturbance is determined by the voltage level of its primary fault.

Table 4.5.1: Energy not supplied (ENS) in each Nordic and Baltic country in 2018 and the annual average during 2009–2018. Furthermore, the average percentage distribution of ENS per voltage level during 2009–2018 is shown. The voltage level is determined by the voltage level of each individual fault. It should be noted, that the ENS in this table includes ENS caused by faults outside the TSO's statistical area. This table is therefore not directly comparable to Figure 4.5.2. The percentages may slightly deviate from 100 % due to rounding.

	ENS (MWh)		Average ENS (%) per voltage levels during 2009–2018			
Country	2018	2009–2018	100–150 kV	220–330 kV	380–420 kV	Other[1]
Estonia	29.5	173.4	78 %	1 %	0 %	21 %
Latvia[2]	63.0	86.9	97 %	3 %	0 %	0 %
Lithuania[2]	34.1	40.0	96 %	3 %	0 %	2 %
Baltic total	126.6	300.3	85 %	2 %	0 %	13 %
Denmark	11.7	27.0	94 %	0 %	0 %	6 %
Finland	147.2	374.1	85 %	2 %	3 %	9 %
Iceland	475.6	925.4	28 %	55 %	0 %	18 %
Norway	588.6	3493.6	35 %	7 %	58 %	0 %
Sweden	1384.6	1884.8	80 %	12 %	3 %	4 %
Nordic total	2607.6	6704.8	49 %	15 %	31 %	5 %
Nordic & Baltic	2734.1	7005.1	51 %	15 %	29 %	5 %

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

2 The average values of Latvia and Lithuania use the period 2012–2018.

Figure 4.5.1 presents the energy not supplied per the different voltage levels in 2018 and Figure 4.5.2 summarises the energy not supplied per the different voltage levels during 2009–2018. The values only account for faults and the caused ENS inside each country's own statistical area. Therefore, the presented values may differ to the values in Table 4.5.1.

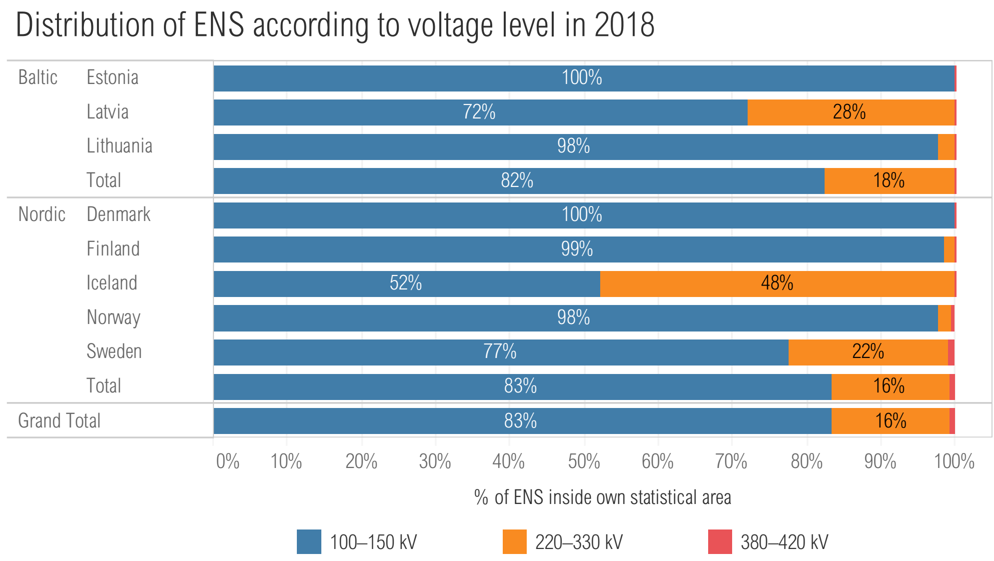


Figure 4.5.1: Percentage distribution of energy not supplied (ENS) per voltage level in 2018 in each Nordic and Baltic country. It should be noted, that the ENS in this figure only includes ENS caused by faults inside the TSO's statistical area.

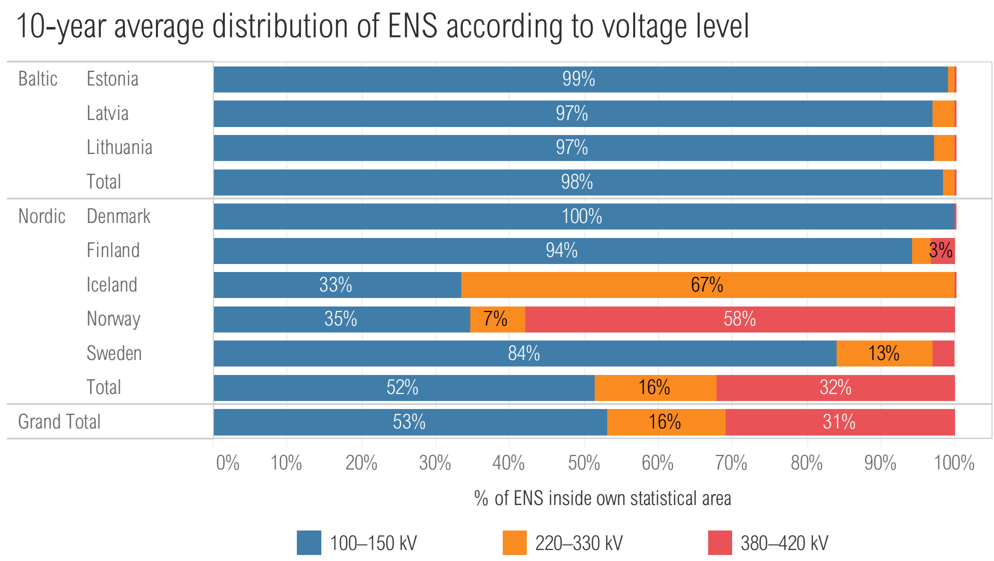


Figure 4.5.2: Average percentage distribution of Energy not supplied per voltage level during 2009–2018 in the Nordic countries and Estonia and during 2012–2018 in Latvia and Lithuania. It should be noted, that the ENS in this figure only includes ENS caused by faults inside the TSO's statistical area.

4.6 Energy not supplied distributed per component

Table 4.6.1 presents the distribution of energy not supplied per installation. The sum of the ENS divided per installation may not be exactly 100 % because all the ENS is not always connected with a cause. Table 4.6.2 shows the distribution of energy not supplied per component in each Nordic and Baltic country in 2018, and Table 4.6.3 show the respective average values for the period 2009–2018 for the Nordic countries and Estonia and for the period 2012–2018 for Latvia and Lithuania.

Table 4.6.1: Energy not supplied (ENS) due to faults in each Nordic and Baltic country in 2018 and the average during 2009–2018 in the Nordic countries and Estonia and during 2012–2018 in Latvia and Lithuania. Additionally, ENS divided by installation type is presented for the Nordic countries and Estonia for the period 2009–2018 and for the period 2012–2018 for Latvia and Lithuania. It should be noted, that the sum of the ENS divided per installation may not be exactly 100 % because all the ENS is not always connected with a cause. Furthermore, some countries register the total amount of energy not supplied in a disturbance in terms of the primary fault. Therefore, the data is not necessarily comparable. The ENS in this table includes ENS caused by faults outside the TSOs statistical area.

	ENS (MWh)		Average ENS (%) per installation during 2009–2018			
Country	2018	2009–2018	Lines	Substation components	Compensation devices	Other
Estonia	29.5	173.4	59 %	17 %	2 %	23 %
Latvia[1]	63.0	86.9	65 %	35 %	0 %	0 %
Lithuania[1]	34.1	40.0	51 %	47 %	0 %	2 %
Baltic total	126.6	300.3	60 %	26 %	1 %	13 %
Denmark	11.7	27.0	3 %	91 %	1 %	6 %
Finland	147.2	374.1	61 %	28 %	1 %	10 %
Iceland	475.6	925.4	21 %	60 %	0 %	19 %
Norway	588.6	3493.6	70 %	29 %	0 %	0 %
Sweden	1384.6	1884.8	39 %	56 %	0 %	5 %
Nordic total	2607.6	6704.8	54 %	41 %	0 %	5 %
Nordic & Baltic	2734.1	7005.1	54 %	40 %	0 %	5 %

[1] The average values of Latvia and Lithuania use the period 2012–2018.

Percentage distribution of ENS per HVAC component in 2018

		Baltic				Nordic						
		Estonia	Latvia	Lithuania	Region total	Denmark	Finland	Iceland	Norway	Sweden	Region total	Nordic & Baltic
Lines	Cables	0%	0%	6%	2%	0%	0%	0%	4%	0%	1%	1%
	Overhead lines	10%	32%	11%	21%	0%	23%	1%	10%	49%	30%	29%
	Total	10%	32%	17%	23%	0%	23%	1%	14%	49%	31%	30%
Substation components	Busbars	0%	1%	0%	1%	96%	9%	0%	4%	0%	2%	2%
	Circuit breakers	1%	1%	48%	14%	0%	0%	0%	15%	3%	5%	6%
	Common ancillary equipment	0%	0%	0%	0%	0%	0%	0%	29%	0%	7%	6%
	Control equipment	11%	53%	4%	30%	0%	3%	5%	22%	18%	15%	16%
	Disconnectors and earth connectors	0%	0%	0%	0%	0%	0%	0%	0%	1%	1%	1%
	Instrumental transformers	1%	0%	2%	1%	0%	15%	0%	1%	10%	7%	6%
	Other high voltage appliances	0%	0%	0%	0%	0%	0%	0%	3%	2%	2%	2%
	Power transformers	15%	12%	0%	9%	4%	14%	0%	1%	3%	2%	3%
	Surge arresters and spark gaps	0%	0%	14%	4%	0%	0%	4%	1%	10%	6%	6%
	Total	28%	67%	69%	59%	100%	41%	10%	76%	47%	46%	47%
Compensation devices	Reactors	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Series capacitors	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Shunt capacitors	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	SVC and statcom	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Synchronous compensators	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Total	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Other	Adjoining grid	63%	0%	14%	18%	0%	36%	89%	0%	4%	21%	21%
	System faults	0%	0%	0%	0%	0%	0%	0%	10%	0%	2%	2%
	Total	63%	0%	14%	18%	0%	36%	89%	10%	4%	23%	23%

Table 4.6.2: Percentage distribution of energy not supplied per HVAC component in 2018 each Nordic and Baltic country. It should be noted that some countries register the total amount of energy not supplied in a disturbance in terms of the primary fault. Therefore, the data is not necessarily comparable.

10-year average distribution of ENS per HVAC component

		Baltic				Nordic						
		Estonia	Latvia	Lithuania	Region total	Denmark	Finland	Iceland	Norway	Sweden	Region total	Nordic & Baltic
Lines	Cables	1%	0%	1%	1%	0%	0%	0%	2%	4%	2%	2%
	Overhead lines	58%	65%	50%	59%	2%	61%	21%	68%	35%	52%	52%
	Total	59%	65%	51%	59%	3%	61%	21%	70%	39%	54%	54%
Substation components	Busbars	1%	3%	1%	1%	50%	1%	0%	3%	2%	3%	3%
	Circuit breakers	2%	0%	8%	2%	6%	3%	33%	1%	3%	6%	6%
	Common ancillary equipment	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%
	Control equipment	1%	23%	32%	10%	6%	10%	18%	8%	5%	9%	9%
	Disconnectors and earth connectors	0%	4%	1%	1%	8%	2%	0%	3%	1%	2%	2%
	Instrumental transformers	1%	0%	1%	1%	7%	4%	0%	2%	6%	3%	3%
	Other high voltage appliances	8%	0%	0%	5%	0%	2%	5%	6%	31%	12%	12%
	Power transformers	4%	5%	2%	4%	14%	3%	3%	3%	7%	4%	4%
	Surge arresters and spark gaps	0%	0%	2%	0%	0%	2%	0%	3%	1%	2%	2%
	Total	17%	35%	47%	24%	91%	28%	60%	29%	56%	41%	40%
Compensation devices	Reactors	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%
	Series capacitors	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%
	Shunt capacitors	2%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%
	SVC and statcom	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Synchronous compensators	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Total	2%	0%	0%	1%	1%	1%	0%	0%	0%	0%	0%
Other	Adjoining grid	23%	0%	2%	15%	6%	9%	9%	0%	4%	3%	3%
	System faults	0%	0%	0%	0%	0%	0%	10%	0%	0%	2%	2%
	Total	23%	0%	2%	15%	6%	10%	19%	0%	5%	5%	5%

Table 4.6.3: Average percentage distribution of energy not supplied per HVAC component in during 2009–2018 in the Nordic countries and Estonia and during 2012–2018 in Latvia and Lithuania. It should be noted that some countries register the total amount of energy not supplied in a disturbance in terms of the primary fault. Therefore, the data is not necessarily comparable.

5 Secondary faults and disturbances with multiple faults

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

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

It should be noted, that this chapter is still new to this report and therefore under development. Therefore, only data for 2018 is presented as there is not enough historical data available. Average values and trend curves will be presented when a sufficient amount of data about secondary faults has been collected.

5.1 Overview of secondary faults

Table 5.1.1 presents the number of faults, faults causing energy not supplied (ENS), total ENS (MWh) and the number of secondary faults and amount of ENS (MWh) caused by them in 2018 in each Nordic and Baltic country. As can be seen, the number of secondary faults and faults with ENS is significantly smaller than the total number of faults. Secondary faults caused approximately 9 % of the total Nordic and Baltic ENS in 2018.

Table 5.1.1: The number of faults, faults causing ENS, total ENS (MWh) and the number of secondary faults and amount of ENS (MWh) caused by them in 2018 in each Nordic and Baltic country.

	Faults in 2018			Secondary faults in 2018	
Country	Count	causing ENS	ENS (MWh)	Count	ENS (MWh)
Estonia	119	45	29.5	8	0.3
Latvia	125	17	63.0	20	34.1
Lithuania	142	18	34.1	19	25.2
Baltic total	386	80	126.6	47	59.6
Denmark	46	3	11.7	3	0.3
Finland	315	55	147.2	9	48.2
Iceland	64	10	475.6	18	0.0
Norway	301	69	588.6	34	131.3
Sweden	376	157	1384.6	7	0.0
Nordic total	1102	294	2607.6	71	179.7
Nordic & Baltic	1488	374	2734.1	118	239.3

5.2 Secondary faults and their ENS distributed per cause

Table 5.2.1 presents the percentage distribution of secondary faults faults per cause in 2018. Table 5.2.2 presents the percentage distribution of energy not supplied (ENS), caused by secondary faults, per cause in 2018. As can be seen, over half of the secondary faults were caused by operation and maintenance and technical equipment in 2018. However, the ENS caused by secondary faults due to operation and maintenance and technical equipment only stand for approximately 25 % of the ENS caused by secondary faults. The dominating cause of ENS due to secondary faults were other causes.

Table 5.2.1: Percentage distribution of secondary faults per cause in the Nordic and Baltic countries in 2018.

% distribution of secondary faults per cause in 2018

		Number of secondary faults per cause						
		Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	0%	0%	0%	75%	25%	0%	0%
	Latvia	0%	0%	0%	35%	40%	15%	10%
	Lithuania	0%	0%	0%	21%	26%	16%	37%
	Total	0%	0%	0%	36%	32%	13%	19%
Nordic	Denmark	0%	0%	0%	100%	0%	0%	0%
	Finland	11%	11%	0%	33%	0%	33%	11%
	Iceland	0%	0%	0%	17%	0%	83%	0%
	Norway	21%	3%	0%	29%	24%	15%	9%
	Sweden	14%	0%	0%	14%	43%	14%	14%
	Total	13%	3%	0%	28%	15%	34%	7%
Grand Total		8%	2%	0%	31%	22%	25%	12%

Table 5.2.2: Percentage distribution of ENS caused by secondary faults per cause in the Nordic and Baltic countries in 2018. Iceland and Sweden had no ENS caused by secondary faults in 2018.

% distribution of ENS caused by secondary faults per cause in 2018

		ENS, secondary faults						
		Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	0%	0%	0%	100%	0%	0%	0%
	Latvia	0%	0%	0%	98%	2%	0%	0%
	Lithuania	0%	0%	0%	4%	83%	13%	0%
	Total	0%	0%	0%	58%	36%	6%	0%
Nordic	Denmark	0%	0%	0%	100%	0%	0%	0%
	Finland	0%	0%	0%	0%	0%	100%	0%
	Iceland	0%	0%	0%	0%	0%	0%	0%
	Norway	0%	0%	0%	3%	0%	97%	0%
	Sweden	0%	0%	0%	0%	0%	0%	0%
	Total	0%	0%	0%	2%	0%	98%	0%
Grand Total		0%	0%	0%	16%	9%	75%	0%

6 Faults in power system components

This chapter presents an overview of all faults in the Nordic and Baltic transmission grid. Furthermore, faults for each type of power system component are presented. It should be noted, that the grid in each country contains a different set of components. To keep the data comparable, the values have been scaled according to the length of the component type or the amount of installed components in each country. Readers who need more detailed data should use the national statistics published by the national regulators.

A component fault is defined as:

> The inability of a component to perform its required function [4].

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

Section 6.1 gives an overview of all faults registered in the component groups used in these statistics, followed by more detailed statistics relating to each specific component group. Furthermore, the chapters present fault trends for each component.

It should be noted, that some countries are not able to provide fault statistics on a component level because they do not own those components. Therefore, some figures may be missing values. This is informed in the figure captions if relevant.

6.1 Overview of faults

This chapter presents an overview of fault in the Nordic and Baltic countries. This includes a a brief presentation of faults and the ENS caused by them, a comparison of faults and disturbances and a summary of faults distributed according to the type of the component.

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

Table 6.1.1 presents the number of faults and the ENS caused by them in 2018 for each Nordic and Baltic country and the average during 2009–2018 in each Nordic country and Estonia and during 2012–2018 in Latvia and Lithuania. Table 6.1.2 presents the number of faults and disturbances and their average ratio.

Table 6.1.1: Number of faults and amount of energy not supplied (ENS) in 2018 and their averages 2009–2018 in each Nordic country and Estonia and during 2012–2018 in Latvia and Lithuania.

	Number of faults		ENS (MWh)	
Country	2018	2009–2018	2018	2009–2018
Estonia	119	209.1	29.5	173.4
Latvia[1]	125	152.9	63.0	86.9
Lithuania[1]	142	169.9	34.1	40.0
Baltic total	386	531.8	126.6	300.3
Denmark	46	62.5	11.7	27.0
Finland	315	461.0	147.2	374.1
Iceland	64	48.2	475.6	925.4
Norway	301	339.1	588.6	3493.6
Sweden	376	503.8	1384.6	1884.8
Nordic total	1102	1414.6	2607.6	6704.8
Nordic & Baltic	1488	1946.4	2734.1	7005.1

[1] The average values of Latvia and Lithuania use the period 2012–2018.

Table 6.1.2: Number of faults and grid disturbances in 2018 in each Nordic and Baltic country and the average during 2009–2018 in the Nordic countries and Estonia and during 2012–2018 in Latvia and Lithuania. Furthermore, the average ratio between faults and disturbances is shown.

	Number of faults		Disturbances		Ratio
Country	2018	2009–2018	2018	2009–2018	2009–2018
Estonia	119	209.1	111	204.8	1.0
Latvia[1]	125	152.9	110	140.0	1.1
Lithuania[1]	142	169.9	123	158.3	1.1
Baltic total	386	531.8	344	503.1	1.1
Denmark	46	62.5	43	55.7	1.1
Finland	315	461.0	308	439.2	1.0
Iceland	64	48.2	46	33.7	1.4
Norway	301	339.1	267	293.7	1.2
Sweden	376	503.8	369	490.1	1.0
Nordic total	1102	1414.6	1033	1312.4	1.1
Nordic & Baltic	1488	1946.4	1377	1815.5	1.1

[1] The average values of Latvia and Lithuania use the period 2012–2018.

Table 6.1.3 shows the distribution of faults per component in each Nordic and Baltic country in 2018, and Table 6.1.4 show the respective average values for the period 2009–2018 for the Nordic countries and Estonia and for the period 2012–2018 for Latvia and Lithuania. The component groups used in these statistics are further described in the guidelines [1].

Percentage distribution of faults per HVAC component in 2018

		Baltic				Nordic						
		Estonia	Latvia	Lithuania	Region total	Denmark	Finland	Iceland	Norway	Sweden	Region total	Nordic & Baltic
Lines	Cables	0%	0%	1%	0%	7%	0%	0%	1%	1%	1%	1%
	Overhead lines	46%	65%	55%	56%	37%	79%	14%	46%	60%	58%	58%
	Total	46%	65%	56%	56%	43%	80%	14%	47%	61%	59%	58%
Substation components	Busbars	3%	2%	1%	2%	9%	1%	0%	1%	0%	1%	1%
	Circuit breakers	6%	1%	4%	3%	7%	1%	6%	5%	2%	3%	3%
	Common ancillary equipment	0%	0%	0%	0%	0%	0%	0%	2%	0%	1%	0%
	Control equipment	14%	14%	15%	15%	7%	6%	19%	27%	19%	17%	16%
	Disconnectors and earth connectors	4%	0%	0%	1%	0%	0%	2%	1%	1%	1%	1%
	Instrumental transformers	2%	2%	1%	2%	2%	2%	2%	0%	3%	2%	2%
	Other high voltage appliances	2%	0%	1%	1%	0%	0%	2%	3%	2%	1%	1%
	Power transformers	11%	4%	1%	5%	17%	6%	0%	3%	2%	4%	4%
	Surge arresters and spark gaps	0%	2%	1%	1%	0%	0%	2%	1%	1%	1%	1%
	Total	41%	24%	23%	29%	41%	15%	31%	43%	30%	30%	30%
Compensation devices	Reactors	2%	0%	0%	1%	9%	0%	0%	0%	2%	1%	1%
	Series capacitors	0%	0%	0%	0%	0%	2%	2%	0%	0%	1%	0%
	Shunt capacitors	0%	0%	0%	0%	0%	1%	0%	2%	0%	1%	1%
	SVC and statcom	0%	0%	0%	0%	2%	0%	0%	5%	1%	2%	1%
	Synchronous compensators	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%
	Total	2%	0%	0%	1%	11%	3%	2%	8%	3%	4%	3%
Other	Adjoining grid	11%	10%	22%	15%	4%	2%	41%	0%	6%	5%	8%
	System faults	0%	0%	0%	0%	0%	0%	13%	3%	0%	2%	1%
	Total	11%	10%	22%	15%	4%	2%	53%	3%	6%	7%	9%

Table 6.1.3: Percentage distribution of faults per HVAC component in 2018 each Nordic and Baltic country.

10-year average distribution of faults per HVAC component

		Baltic				Nordic						
		Estonia	Latvia	Lithuania	Region total	Denmark	Finland	Iceland	Norway	Sweden	Region total	Nordic & Baltic
Lines	Cables	0%	0%	0%	0%	6%	0%	0%	1%	1%	1%	1%
	Overhead lines	64%	66%	68%	66%	46%	80%	38%	48%	60%	62%	63%
	Total	64%	66%	69%	66%	52%	80%	38%	50%	61%	63%	64%
Substation components	Busbars	2%	1%	1%	1%	4%	0%	0%	1%	1%	1%	1%
	Circuit breakers	3%	2%	5%	3%	5%	1%	5%	4%	2%	2%	3%
	Common ancillary equipment	0%	0%	1%	1%	0%	0%	0%	1%	0%	0%	0%
	Control equipment	3%	14%	10%	8%	13%	8%	16%	18%	8%	11%	10%
	Disconnectors and earth connectors	3%	1%	1%	2%	2%	0%	0%	2%	1%	1%	1%
	Instrumental transformers	1%	1%	1%	1%	3%	1%	0%	2%	1%	1%	1%
	Other high voltage appliances	8%	0%	0%	4%	3%	2%	2%	12%	7%	6%	6%
	Power transformers	5%	5%	1%	4%	7%	2%	4%	3%	6%	4%	4%
	Surge arresters and spark gaps	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%
	Total	25%	24%	20%	23%	37%	14%	29%	44%	26%	27%	26%
Compensation devices	Reactors	1%	1%	0%	0%	2%	0%	0%	0%	2%	1%	1%
	Series capacitors	0%	0%	0%	0%	0%	1%	0%	0%	3%	2%	1%
	Shunt capacitors	0%	0%	0%	0%	0%	0%	1%	1%	0%	1%	0%
	SVC and statcom	0%	0%	0%	0%	0%	0%	0%	5%	2%	2%	1%
	Synchronous compensators	0%	0%	0%	0%	1%	0%	0%	1%	0%	0%	0%
	Total	1%	1%	0%	1%	3%	2%	2%	6%	7%	5%	4%
Other	Adjoining grid	10%	10%	11%	10%	8%	4%	13%	0%	5%	4%	5%
	System faults	0%	0%	0%	0%	0%	0%	19%	0%	1%	1%	1%
	Total	10%	10%	11%	10%	8%	4%	31%	0%	6%	5%	6%

Table 6.1.4: Average percentage distribution of faults per HVAC component in during 2009–2018 in the Nordic countries and Estonia and during 2012–2018 in Latvia and Lithuania.

6.2 Faults distributed per cause

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

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

Table 6.2.1 presents faults per cause the year 2018 for each Nordic and Baltic country. Table 6.2.2 presents the respective average values for the period 2009–2018 in the Nordic countries and Estonia and during 2012–2018 in Latvia and Lithuania. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

Table 6.2.1: Percentage distribution of faults per cause in 2018 in each Nordic and Baltic country.

Faults according to cause in 2018

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	10%	12%	11%	22%	23%	11%	12%
	Latvia	6%	20%	23%	10%	10%	10%	20%
	Lithuania	6%	1%	20%	10%	8%	23%	31%
	Total	7%	11%	18%	14%	13%	15%	22%
Nordic	Denmark	0%	4%	28%	46%	7%	4%	11%
	Finland	15%	25%	3%	8%	6%	35%	9%
	Iceland	0%	5%	0%	13%	0%	83%	0%
	Norway	21%	28%	3%	19%	16%	9%	5%
	Sweden	39%	2%	3%	7%	14%	9%	27%
	Total	23%	16%	4%	13%	11%	20%	14%
Grand Total		19%	15%	7%	13%	12%	19%	16%

Table 6.2.2: Average distribution of faults per cause during 2009–2018 in each Nordic country and Estonia and during 2012–2018 in Latvia and Lithuania.

10-year average distribution of faults according to cause

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	10%	22%	5%	16%	19%	10%	18%
	Latvia	9%	19%	22%	10%	12%	10%	17%
	Lithuania	8%	4%	21%	8%	8%	13%	38%
	Total	10%	16%	14%	13%	14%	11%	23%
Nordic	Denmark	10%	10%	19%	20%	17%	11%	13%
	Finland	22%	25%	2%	7%	5%	16%	23%
	Iceland	2%	32%	2%	9%	18%	36%	0%
	Norway	20%	30%	2%	14%	18%	11%	6%
	Sweden	35%	4%	2%	8%	15%	12%	25%
	Total	25%	19%	2%	10%	13%	14%	18%
Grand Total		21%	18%	5%	10%	13%	13%	19%

Table 6.2.3 presents faults that caused ENS distributed by its cause for the year 2018. Table 6.2.4 presents the respective average values during 2009–2018 in the Nordic countries and Estonia and during 2012–2018 in Latvia and Lithuania. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

Table 6.2.3: Percentage distribution of faults causing ENS per cause in 2018 in each Nordic and Baltic country.

Faults causing ENS according to cause in 2018

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	9%	16%	7%	22%	18%	20%	9%
	Latvia	0%	24%	18%	41%	12%	6%	0%
	Lithuania	0%	0%	22%	39%	22%	17%	0%
	Total	5%	14%	13%	30%	18%	16%	5%
Nordic	Denmark	0%	0%	0%	100%	0%	0%	0%
	Finland	15%	9%	4%	4%	15%	31%	24%
	Iceland	0%	10%	0%	30%	0%	60%	0%
	Norway	22%	26%	3%	28%	7%	10%	4%
	Sweden	38%	1%	2%	9%	13%	8%	29%
	Total	28%	9%	2%	14%	11%	15%	21%
Grand Total		23%	10%	5%	17%	13%	15%	18%

Table 6.2.4: Average distribution of faults causing ENS per cause during 2009–2018 in each Nordic country and Estonia and during 2012–2018 in Latvia and Lithuania.

10-year average distribution of faults causing ENS according to cause

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	4%	8%	11%	29%	21%	19%	8%
	Latvia	1%	22%	15%	29%	26%	2%	4%
	Lithuania	4%	10%	34%	24%	15%	5%	8%
	Total	3%	12%	17%	28%	21%	12%	7%
Nordic	Denmark	4%	7%	1%	42%	24%	16%	7%
	Finland	17%	15%	3%	12%	8%	14%	32%
	Iceland	4%	43%	2%	12%	17%	23%	1%
	Norway	22%	26%	2%	18%	14%	12%	6%
	Sweden	35%	3%	2%	11%	14%	9%	27%
	Total	25%	14%	2%	13%	13%	12%	21%
Grand Total		22%	13%	4%	15%	14%	12%	19%

6.3 Faults in cables

This section presents cable faults in 2018 and during 2009–2018 at the voltage levels 100–150 kV, 220–330 kV and 380–420 kV. Underground cables and overhead lines are the parts that make country wide power transmission possible in the transmissions grids worldwide. Overhead lines are used more often than cables because they are easier and more economical to install and repair. However, they are more prone to faults than underground cables.

Table 6.3.1 presents the installed length of cables in kilometres, the number of faults, the 10-year average number of faults and the number of permanent faults in 2018. Table 6.3.2 presents the percentage distribution of faults faults per cause in 2018. Table 6.3.3 presents the respective average values for the period 2009–2018 in the Nordic countries and Estonia and during 2012–2018 in Latvia and Lithuania. The used causes are lightning, other environmental causes, external influences, operation and maintenance, technical equipment, other and unknown. The fault categories used are explained in more detail in Chapter 1.4.1. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

Figure 6.3.1, Figure 6.3.2 and Figure 6.3.3 present the 5-year moving average of 100–150 kV, 220–330 kV and 380–420 kV cable faults per 100 km in each Nordic and Baltic country. Trend curves are used filter out the annual deviation and make it easier to follow on trends and decide on whether actions have to be taken in the future.

Figure 6.3.4 presents the 5-year moving average of the permanent faults to number of faults ratio, for all voltage level ranges, in each Nordic and Baltic country. Permanent faults are only recorded for cables and overhead lines.

Table 6.3.1: Number of units, faults and permanent faults in cables per voltage level in each Nordic and Baltic country. The average number of faults is presented for the period 2009–2018 for the Nordic countries and Estonia and for the period 2012–2018 for Latvia and Lithuania. Estonia, Iceland and Latvia had no faults in their cables in 2018. One unit of cable is 1 km.

Number of units, faults and permanent faults in 2018, Cables

		100–150 kV				220–330 kV				380–420 kV			
Regions	Country	# units	# faults	10-year average # faults	Number of permanent faults	# units	# faults	10-year average # faults	Number of permanent faults	# units	# faults	10-year average # faults	Number of permanent faults
Baltic	Estonia	65	0	0.2	0	0	0	0.0	0	0	0	0.0	0
	Latvia	82	0	0.1	0	14	0	0.1	0	0	0	0.0	0
	Lithuania	94	1	0.1	1	0	0	0.0	0	0	0	0.0	0
	Total	241	1	0.1	1	14	0	0.0	0	0	0	0.0	0
Nordic	Denmark	1,492	3	1.6	3	164	0	0.2	0	153	0	0.1	0
	Finland	224	1	0.6	1	0	0	0.0	0	0	0	0.0	0
	Iceland	123	0	0.1	0	1	0	0.0	0	0	0	0.0	0
	Norway	422	2	1.7	2	98	0	0.1	0	25	0	0.5	0
	Sweden	524	1	1.3	1	180	0	1.4	0	15	3	0.4	3
	Total	2,785	7	1.0	7	443	0	0.3	0	193	3	0.2	3
Grand Total		3,026	8	0.7	8	457	0	0.2	0	193	3	0.1	3

Table 6.3.2: Percentage distribution of faults in cables per cause in the Nordic and Baltic countries in 2018. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

% distribution of faults per cause in 2018, Cables, all voltage levels

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	0%	0%	0%	0%	0%	0%	0%
	Latvia	0%	0%	0%	0%	0%	0%	0%
	Lithuania	0%	0%	0%	0%	100%	0%	0%
	Total	0%	0%	0%	0%	100%	0%	0%
Nordic	Denmark	0%	0%	67%	33%	0%	0%	0%
	Finland	0%	0%	0%	0%	0%	100%	0%
	Iceland	0%	0%	0%	0%	0%	0%	0%
	Norway	0%	50%	0%	0%	0%	50%	0%
	Sweden	0%	0%	0%	0%	75%	0%	25%
	Total	0%	10%	20%	10%	30%	20%	10%
Grand Total		0%	9%	18%	9%	36%	18%	9%

Table 6.3.3: Average distribution of faults in cables per cause during 2009–2018 in each Nordic country and Estonia and during 2012–2018 in Latvia and Lithuania. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

10-year average % distribution of faults per cause, Cables, all voltage levels

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	0%	0%	50%	0%	50%	0%	0%
	Latvia	0%	0%	0%	0%	100%	0%	0%
	Lithuania	0%	0%	50%	0%	50%	0%	0%
	Total	0%	0%	38%	0%	63%	0%	0%
Nordic	Denmark	0%	0%	11%	11%	71%	0%	6%
	Finland	0%	0%	0%	27%	27%	27%	18%
	Iceland	0%	0%	0%	100%	0%	0%	0%
	Norway	3%	18%	5%	8%	33%	21%	13%
	Sweden	4%	0%	4%	4%	67%	2%	19%
	Total	2%	5%	6%	10%	54%	9%	13%
Grand Total		2%	5%	8%	9%	55%	8%	13%

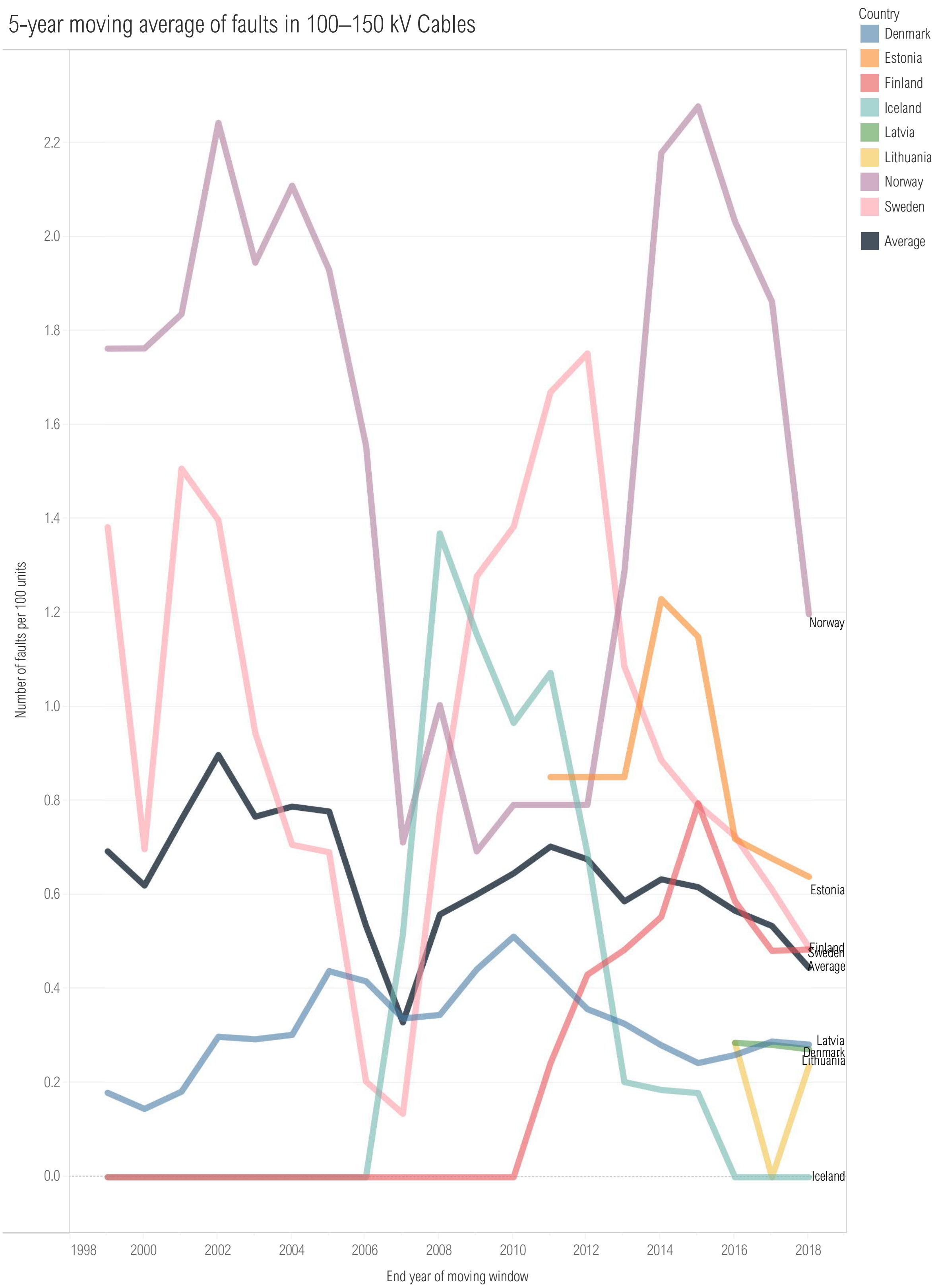


Figure 6.3.1: 5-year moving average of faults per 100 km 100–150 kV cable in each Nordic and Baltic country.

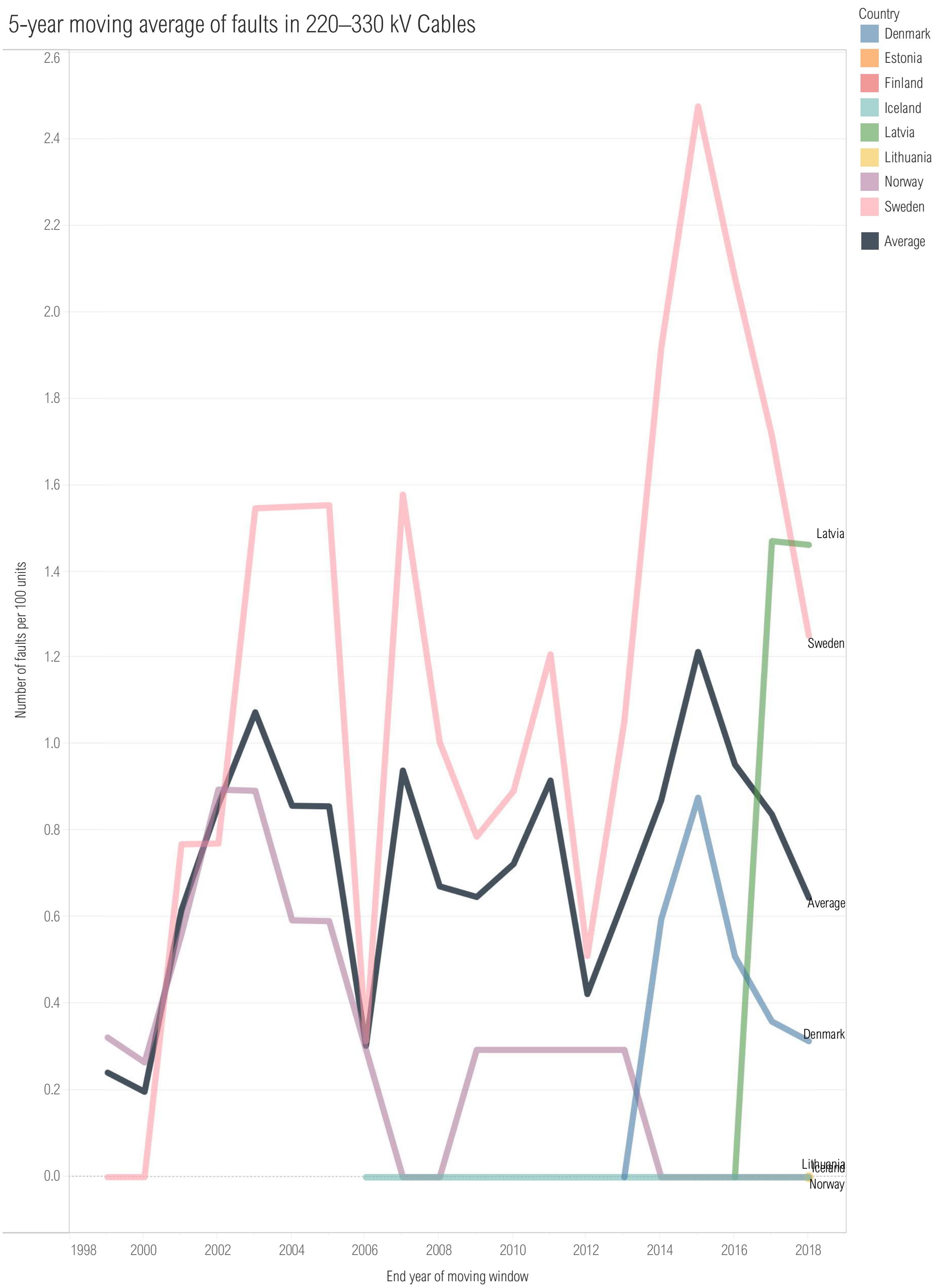


Figure 6.3.2: 5-year moving average of faults per 100 km 220–330 kV cable in each Nordic and Baltic country. Estonia has data since 2007 and Latvia and Lithuania have data since 2012. Furthermore, Estonia, Finland and Lithuania do not own 220–330 kV cables.

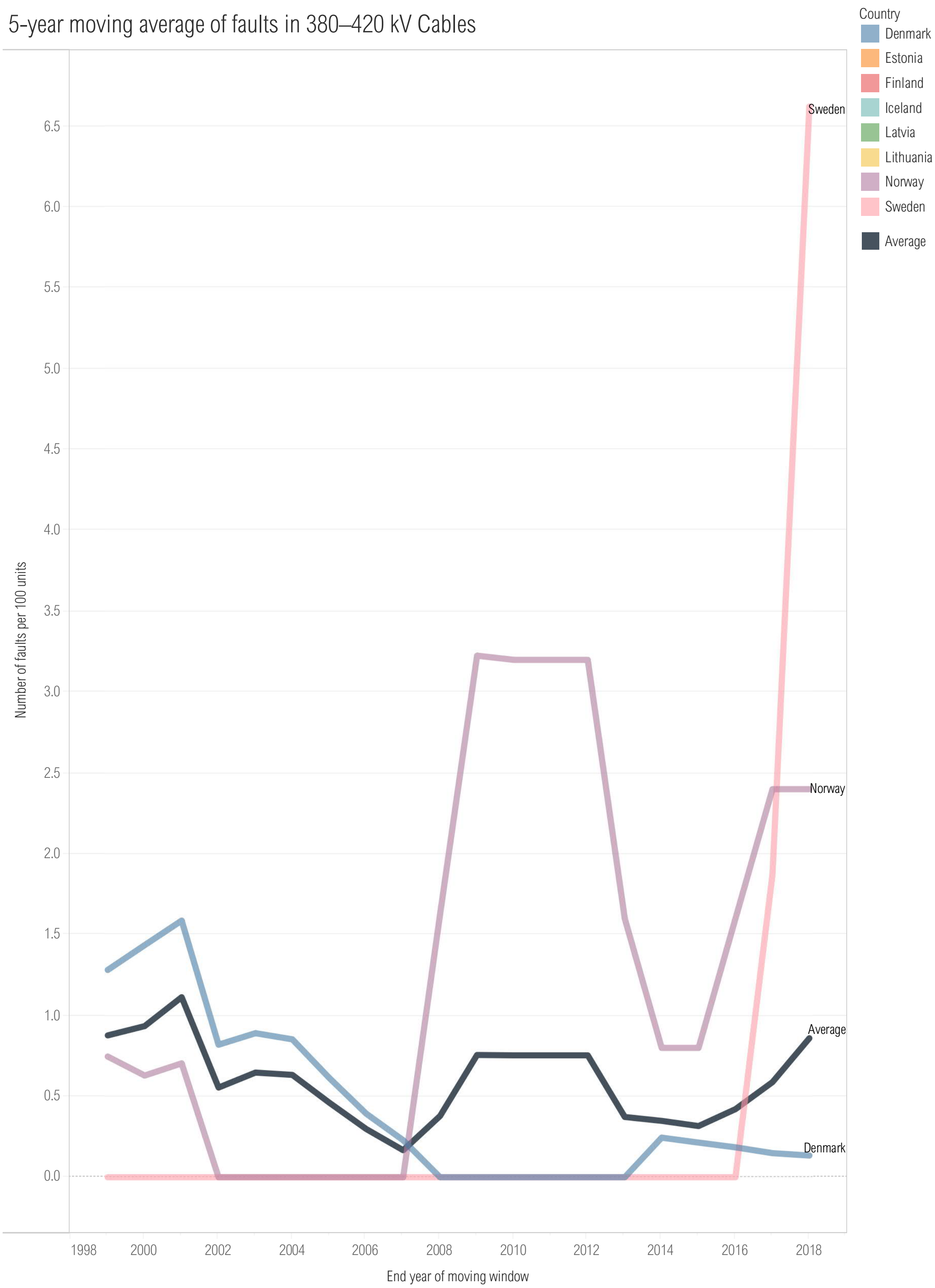


Figure 6.3.3: 5-year moving average of faults per 100 km 380–420 kV cable in each Nordic and Baltic country. Estonia has data since 2007 and Latvia and Lithuania have data since 2012. 380–420 kV trend lines are missing for Estonia, Finland, Iceland, Latvia and Lithuania because they do not own cables in the 380–420 kV voltage range, as can be seen from Table 6.3.1.

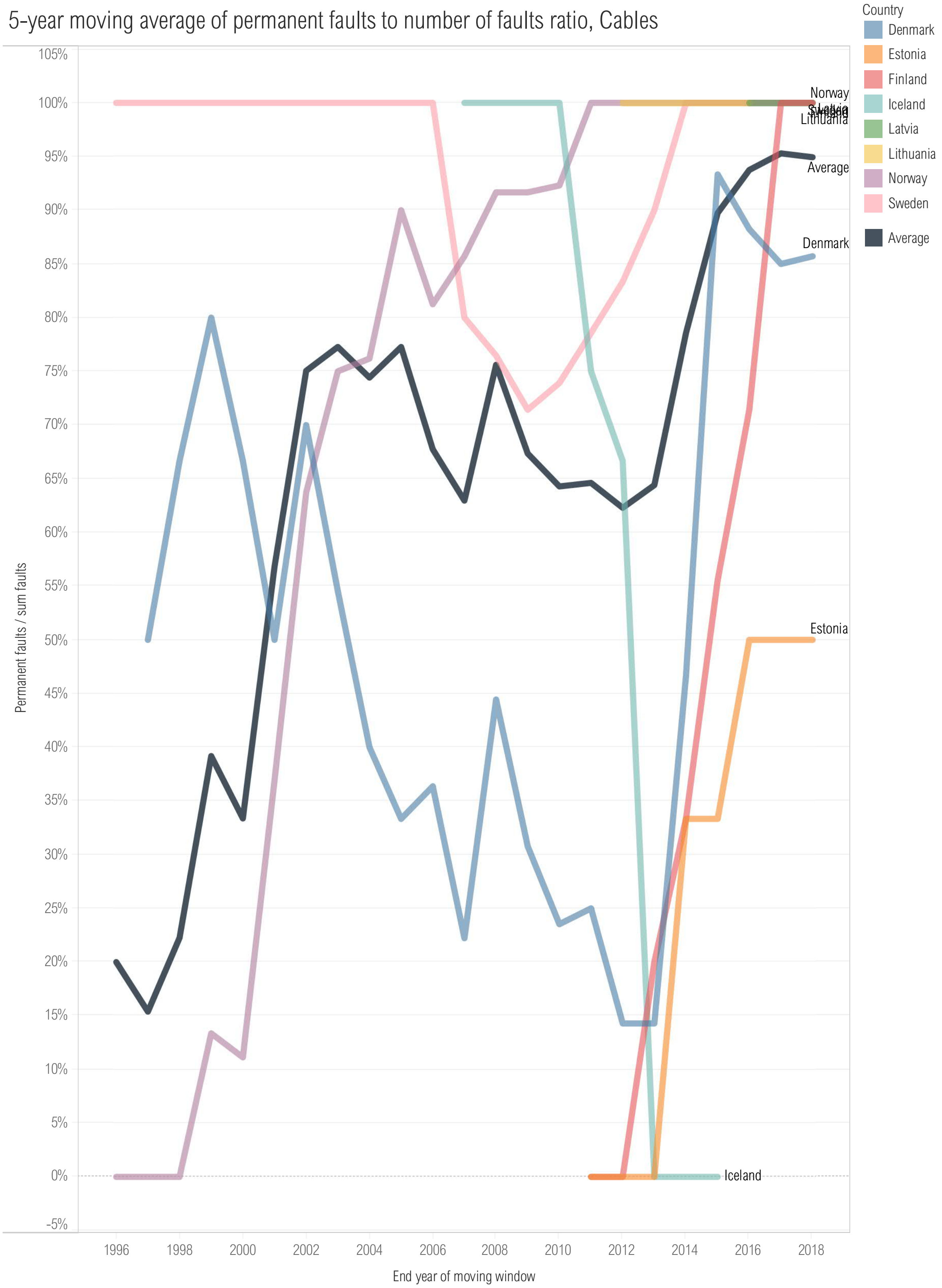


Figure 6.3.4: 5-year moving average of the permanent faults to number of faults ratio in each Nordic and Baltic country. Estonia has data since 2007 and Latvia and Lithuania have data since 2012.

6.4 Faults on overhead lines

This section presents overhead line faults in 2018 and during 2009–2018 at the voltage levels 100–150 kV, 220–330 kV and 380–420 kV. Overhead lines and underground cables are the backbone of the transmission grid, that make country wide power transmission possible in the transmissions grids worldwide. Overhead lines are used more often than cables because they are easier and more economical to install and repair. However, they are more prone to faults than underground cables.

Table 6.4.1 presents the installed length of overhead lines in kilometres, the number of faults, the 10-year average number of faults and the number of permanent faults in 2018. Table 6.4.2 presents the percentage distribution of faults faults per cause in 2018. Table 6.4.3 presents the respective average values for the period 2009–2018 in the Nordic countries and Estonia and during 2012–2018 in Latvia and Lithuania. The used causes are lightning, other environmental causes, external influences, operation and maintenance, technical equipment, other and unknown. The fault categories used are explained in more detail in Chapter 1.4.1. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

Figure 6.4.1, Figure 6.4.2 and Figure 6.4.3 present the 5-year moving average of 100–150 kV, 220–330 kV and 380–420 kV overhead line faults per 100 km in each Nordic and Baltic country. Trend curves are used filter out the annual deviation and make it easier to follow on trends and decide on whether actions have to be taken in the future.

Figure 6.4.4 presents the 5-year moving average of the permanent faults to number of faults ratio, for all voltage level ranges, in each Nordic and Baltic country. Permanent faults are only recorded for cables and overhead lines.

Table 6.4.1: Number of units, faults and permanent faults in overhead lines, separated by voltage level, in each Nordic and Baltic country. The average number of faults is presented for the period 2009–2018 for the Nordic countries and Estonia and for the period 2012–2018 for Latvia and Lithuania. One unit of overhead line is 1 km.

Number of units, faults and permanent faults in 2018, Overhead lines

		100–150 kV				220–330 kV				380–420 kV			
Regions	Country	# units	# faults	10-year average # faults	Number of permanent faults	# units	# faults	10-year average # faults	Number of permanent faults	# units	# faults	10-year average # faults	Number of permanent faults
Baltic	Estonia	3,424	51	59.9	8	1,859	4	14.3	0	0	0	0.0	0
	Latvia	3,818	72	45.5	32	1,333	11	10.0	0	0	0	0.0	0
	Lithuania	4,972	71	51.8	7	1,759	6	12.0	0	103	1	0.6	1
	Total	12,214	194	53.3	47	4,951	21	12.4	0	103	1	0.2	1
Nordic	Denmark	2,809	16	12.5	1	65	0	0.4	0	1,361	1	3.2	0
	Finland	13,920	232	171.5	24	1,605	13	15.0	7	5,927	6	9.8	1
	Iceland	1,248	4	7.6	2	857	5	3.0	4	0	0	0.0	0
	Norway	10,736	84	46.0	24	5,355	21	39.4	6	3,266	33	32.8	0
	Sweden	14,710	154	114.9	8	4,028	42	31.6	2	10,564	31	37.1	2
	Total	43,423	490	70.5	59	11,909	81	17.9	19	21,118	71	16.6	3
Grand Total		55,637	684	64.9	106	16,860	102	16.1	19	21,221	72	11.3	4

Table 6.4.2: Percentage distribution of faults in overhead lines per cause in the Nordic and Baltic countries in 2018. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

% distribution of faults per cause in 2018, Overhead lines, all voltage levels

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	22%	24%	18%	13%	5%	0%	18%
	Latvia	8%	30%	34%	0%	0%	0%	28%
	Lithuania	12%	3%	36%	1%	1%	1%	46%
	Total	13%	19%	31%	4%	2%	0%	32%
Nordic	Denmark	0%	0%	59%	12%	6%	0%	24%
	Finland	18%	31%	3%	1%	2%	34%	11%
	Iceland	0%	33%	0%	0%	0%	67%	0%
	Norway	43%	50%	1%	2%	0%	1%	2%
	Sweden	60%	0%	3%	2%	1%	0%	33%
	Total	38%	24%	4%	2%	1%	15%	17%
Grand Total		32%	22%	11%	2%	1%	11%	21%

Table 6.4.3: Average distribution of faults in overhead lines per cause during 2009–2018 in each Nordic country and Estonia and during 2012–2018 in Latvia and Lithuania. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

10-year average % distribution of faults per cause, Overhead lines, all voltage levels

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	16%	32%	7%	14%	6%	0%	25%
	Latvia	14%	29%	29%	1%	1%	0%	24%
	Lithuania	12%	6%	29%	2%	3%	1%	48%
	Total	14%	24%	19%	8%	4%	0%	31%
Nordic	Denmark	21%	16%	35%	4%	0%	1%	23%
	Finland	27%	32%	1%	2%	1%	13%	25%
	Iceland	6%	80%	3%	1%	6%	3%	1%
	Norway	37%	54%	1%	1%	2%	3%	2%
	Sweden	52%	5%	2%	4%	4%	2%	32%
	Total	36%	27%	2%	2%	2%	7%	22%
Grand Total		31%	26%	7%	4%	2%	5%	25%

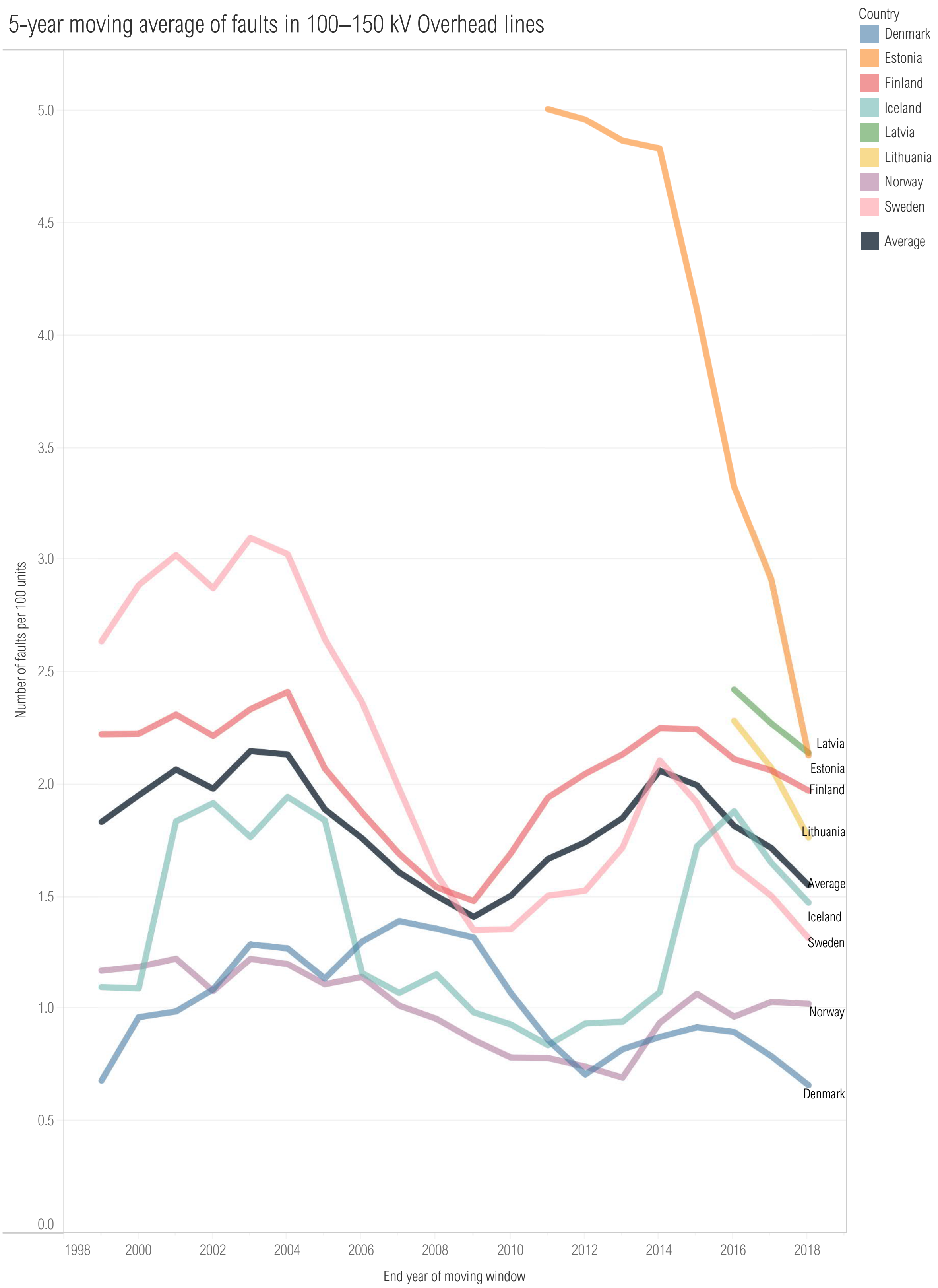


Figure 6.4.1: 5-year moving average of 100–150 kV overhead line faults per 100 km in each Nordic and Baltic country. Estonia has data since 2007 and Latvia and Lithuania have data since 2012.

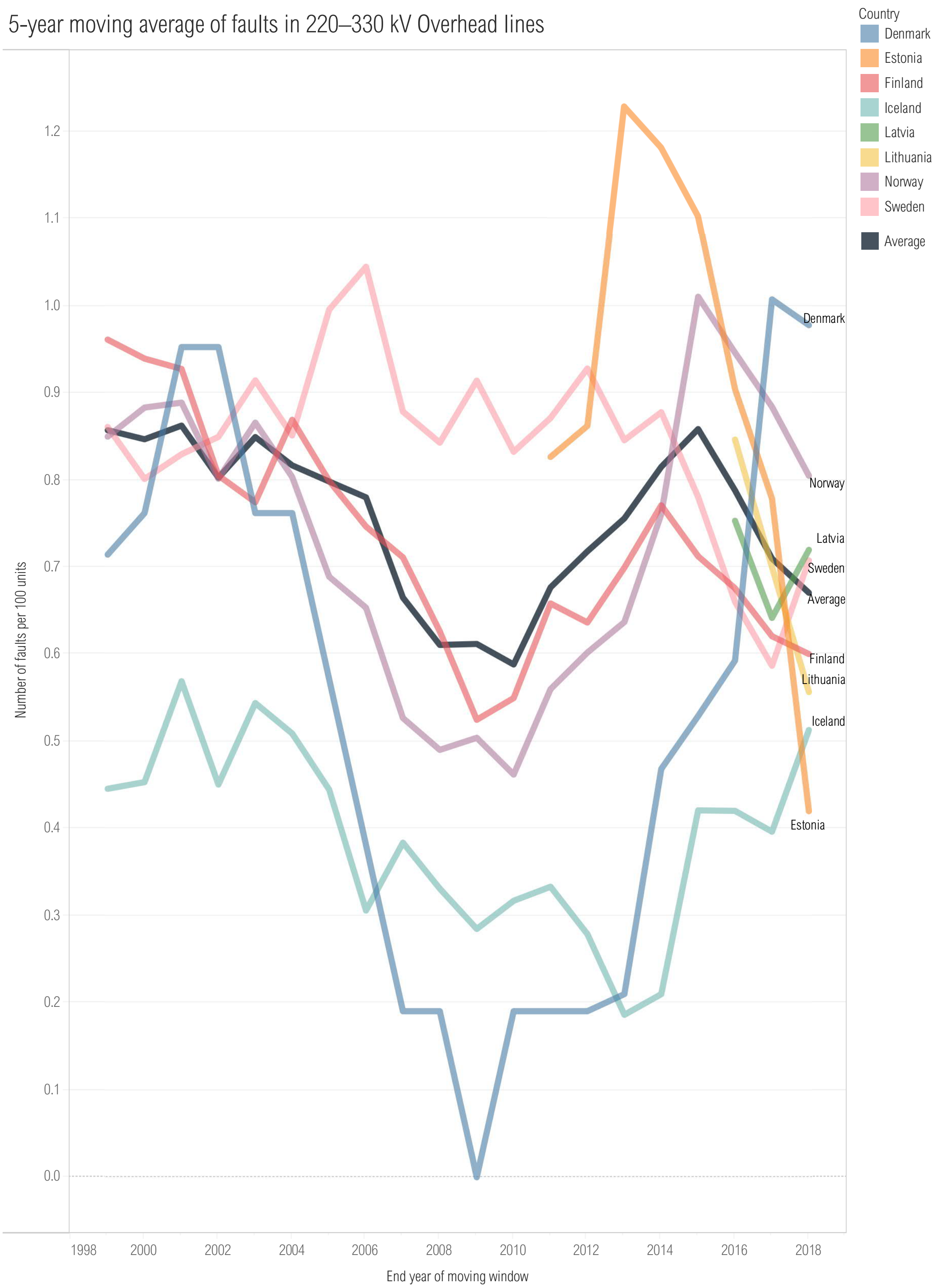


Figure 6.4.2: 5-year moving average of 220–330 kV overhead line faults per 100 km in each Nordic and Baltic country. Estonia has data since 2007 and Latvia and Lithuania have data since 2012.

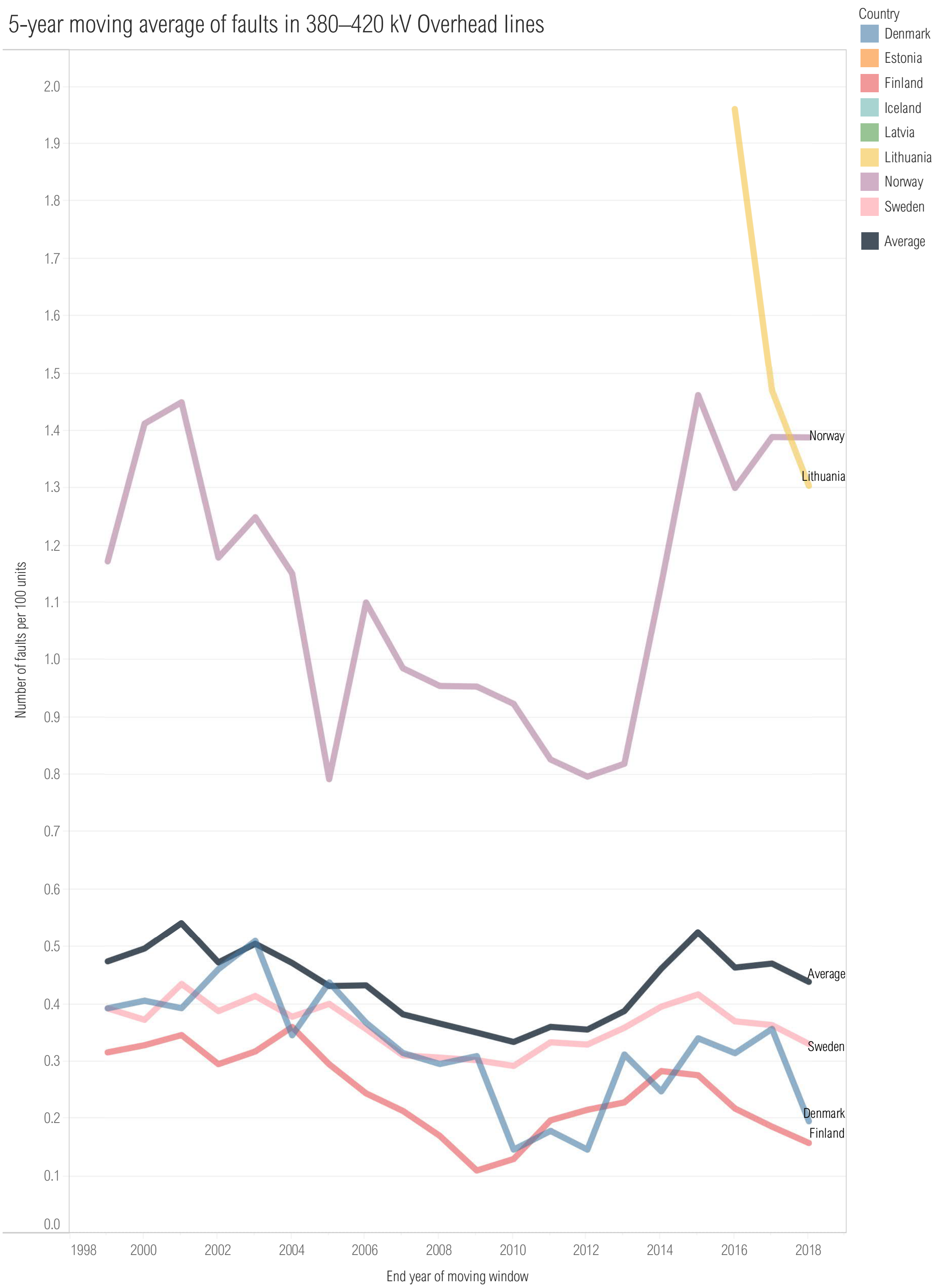


Figure 6.4.3: 5-year moving average of 380–420 kV overhead line faults per 100 km in each Nordic and Baltic country. Estonia has data since 2007 and Latvia and Lithuania have data since 2012. 380–420 kV trend lines are missing for Estonia, Iceland and Latvia because they do not own overhead lines in the 380–420 kV voltage range, as can be seen from Table 6.4.1.

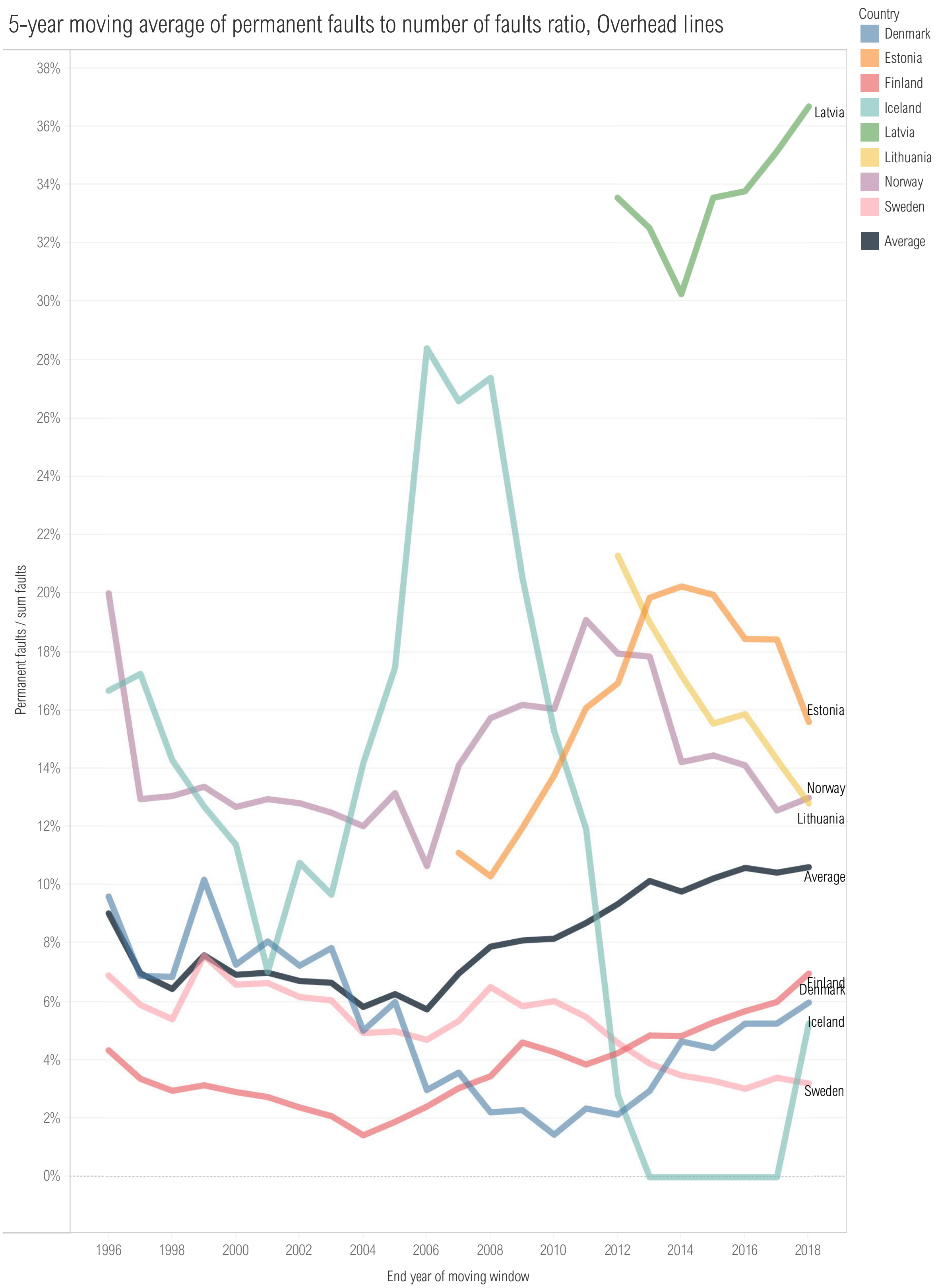


Figure 6.4.4: 5-year moving average of the permanent faults to number of faults ratio in each Nordic and Baltic country. Estonia has data since 2007 and Latvia and Lithuania have data since 2012.

6.5 Faults in circuit breakers

This section presents circuit breaker faults in 2018 and during 2009–2018 at the voltage levels 100–150 kV, 220–330 kV and 380–420 kV. Circuit breakers are used to protect the grid when it is experiencing faults. When functioning correctly, they break the power flow to the faulty part of the grid, thereby isolating the fault and preventing an outage from spreading further into the grid. Therefore, it is essential to keep the circuit breakers in good working condition.

Table 6.5.1 presents the number of installed circuit breakers, the number of faults, the 10-year average number of faults and the number of permanent faults in 2018. Table 6.5.2 presents the percentage distribution of faults faults per cause in 2018. Table 6.5.3 presents the respective average values for the period 2009–2018 in the Nordic countries and Estonia and during 2012–2018 in Latvia and Lithuania. The used causes are lightning, other environmental causes, external influences, operation and maintenance, technical equipment, other and unknown. The fault categories used are explained in more detail in Chapter 1.4.1. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

Figure 6.5.1, Figure 6.5.2 and Figure 6.5.3 present the 5-year moving average of 100–150 kV, 220–330 kV and 380–420 kV circuit breaker faults per 100 devices in each Nordic and Baltic country. Trend curves are used filter out the annual deviation and make it easier to follow on trends and decide on whether actions have to be taken in the future.

Table 6.5.1: Number of units and faults in circuit breakers, separated by voltage level, in each Nordic and Baltic country. The average number of faults is presented for the period 2009–2018 for the Nordic countries and Estonia and for the period 2012–2018 for Latvia and Lithuania. One unit of circuit breaker is 1 device.

Number of units and faults in 2018, Circuit breakers

		100–150 kV			220–330 kV			380–420 kV		
Regions	Country	# units	# faults	10-year average # faults	# units	# faults	10-year average # faults	# units	# faults	10-year average # faults
Baltic	Estonia	615	5	4.7	114	2	2.0	0	0	0.0
	Latvia	611	1	2.4	99	0	0.1	0	0	0.0
	Lithuania	876	4	7.4	113	1	0.7	5	0	0.0
	Total	2,102	10	4.8	326	3	1.1	5	0	0.0
Nordic	Denmark	974	1	2.5	16	0	0.0	225	2	0.5
	Finland	2,210	1	4.1	74	0	0.2	349	1	0.6
	Iceland	176	2	1.8	80	2	0.7	0	0	0.0
	Norway	2,491	5	8.6	730	6	4.3	453	5	2.3
	Sweden	2,576	4	3.6	337	2	1.3	649	3	3.7
	Total	8,427	13	4.1	1,237	10	1.3	1,676	11	1.4
Grand Total		10,529	23	4.4	1,563	13	1.2	1,681	11	1.0

Table 6.5.2: Percentage distribution of faults in circuit breakers per cause in the Nordic and Baltic countries in 2018. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

% distribution of faults per cause in 2018, Circuit breakers, all voltage levels

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	0%	0%	0%	14%	57%	0%	29%
	Latvia	0%	0%	0%	0%	100%	0%	0%
	Lithuania	0%	0%	0%	0%	100%	0%	0%
	Total	0%	0%	0%	8%	77%	0%	15%
Nordic	Denmark	0%	0%	0%	100%	0%	0%	0%
	Finland	0%	0%	0%	50%	50%	0%	0%
	Iceland	0%	0%	0%	0%	0%	100%	0%
	Norway	6%	6%	0%	31%	50%	0%	6%
	Sweden	22%	0%	0%	11%	56%	0%	11%
	Total	9%	3%	0%	29%	41%	12%	6%
Grand Total		6%	2%	0%	23%	51%	9%	9%

Table 6.5.3: Average distribution of faults in circuit breakers per cause during 2009–2018 in each Nordic country and Estonia and during 2012–2018 in Latvia and Lithuania.

10-year average % distribution of faults per cause, Circuit breakers, all voltage levels

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	1%	0%	0%	9%	81%	0%	9%
	Latvia	0%	0%	6%	6%	89%	0%	0%
	Lithuania	2%	0%	4%	30%	40%	5%	19%
	Total	1%	0%	2%	17%	65%	2%	12%
Nordic	Denmark	0%	0%	0%	70%	27%	0%	3%
	Finland	6%	2%	2%	20%	35%	10%	24%
	Iceland	0%	8%	4%	16%	56%	16%	0%
	Norway	3%	2%	2%	42%	30%	7%	15%
	Sweden	12%	1%	1%	13%	65%	0%	8%
	Total	5%	2%	2%	32%	41%	6%	13%
Grand Total		4%	1%	2%	28%	48%	5%	12%

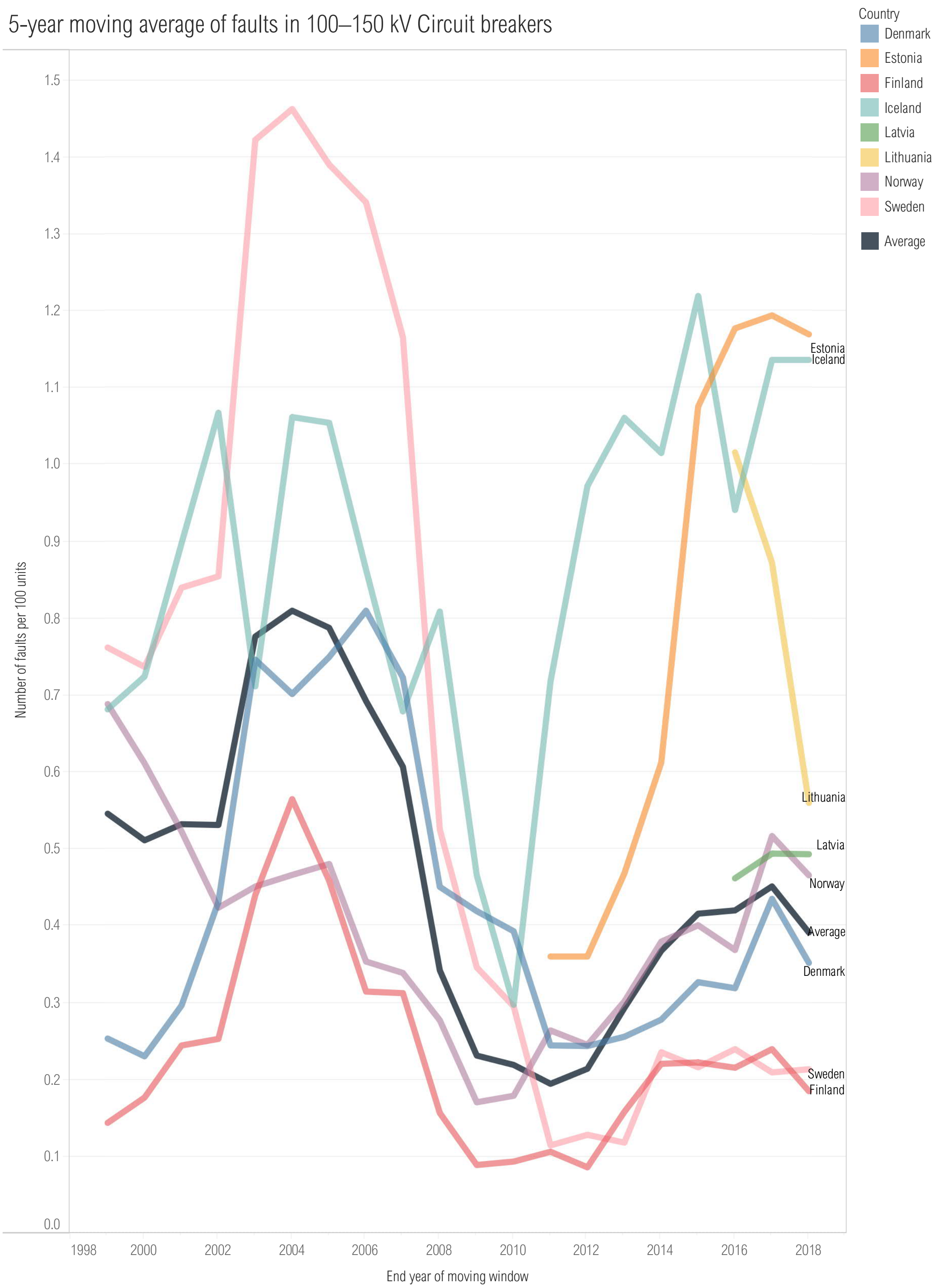


Figure 6.5.1: 5-year moving average of faults per 100 devices of 100–150 kV circuit breakers in each Nordic and Baltic country. Estonia has data since 2007 and Latvia and Lithuania have data since 2012.

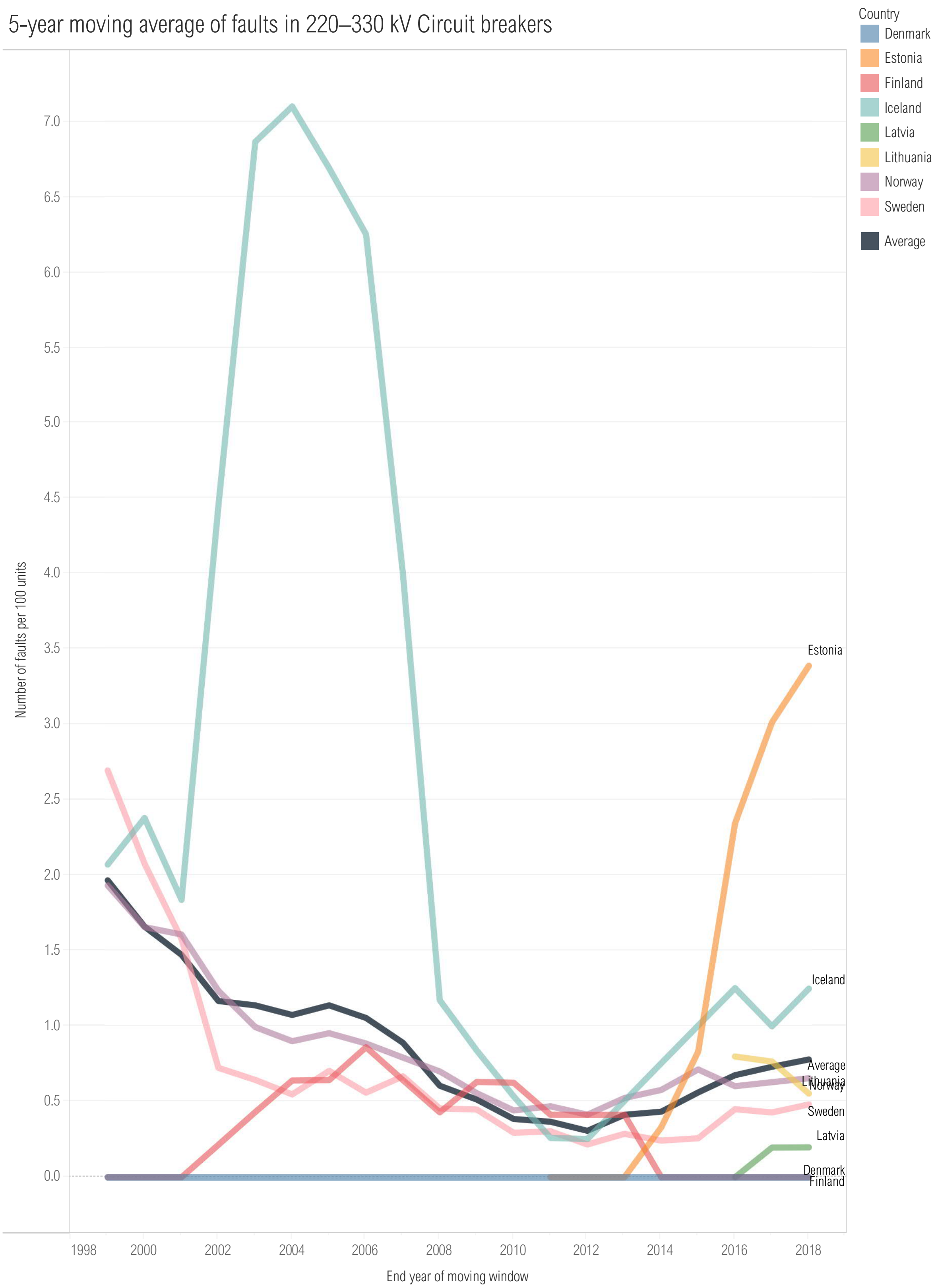


Figure 6.5.2: 5-year moving average of faults per 100 devices of 220–330 kV circuit breakers in each Nordic and Baltic country. Estonia has data since 2007 and Latvia and Lithuania have data since 2012.

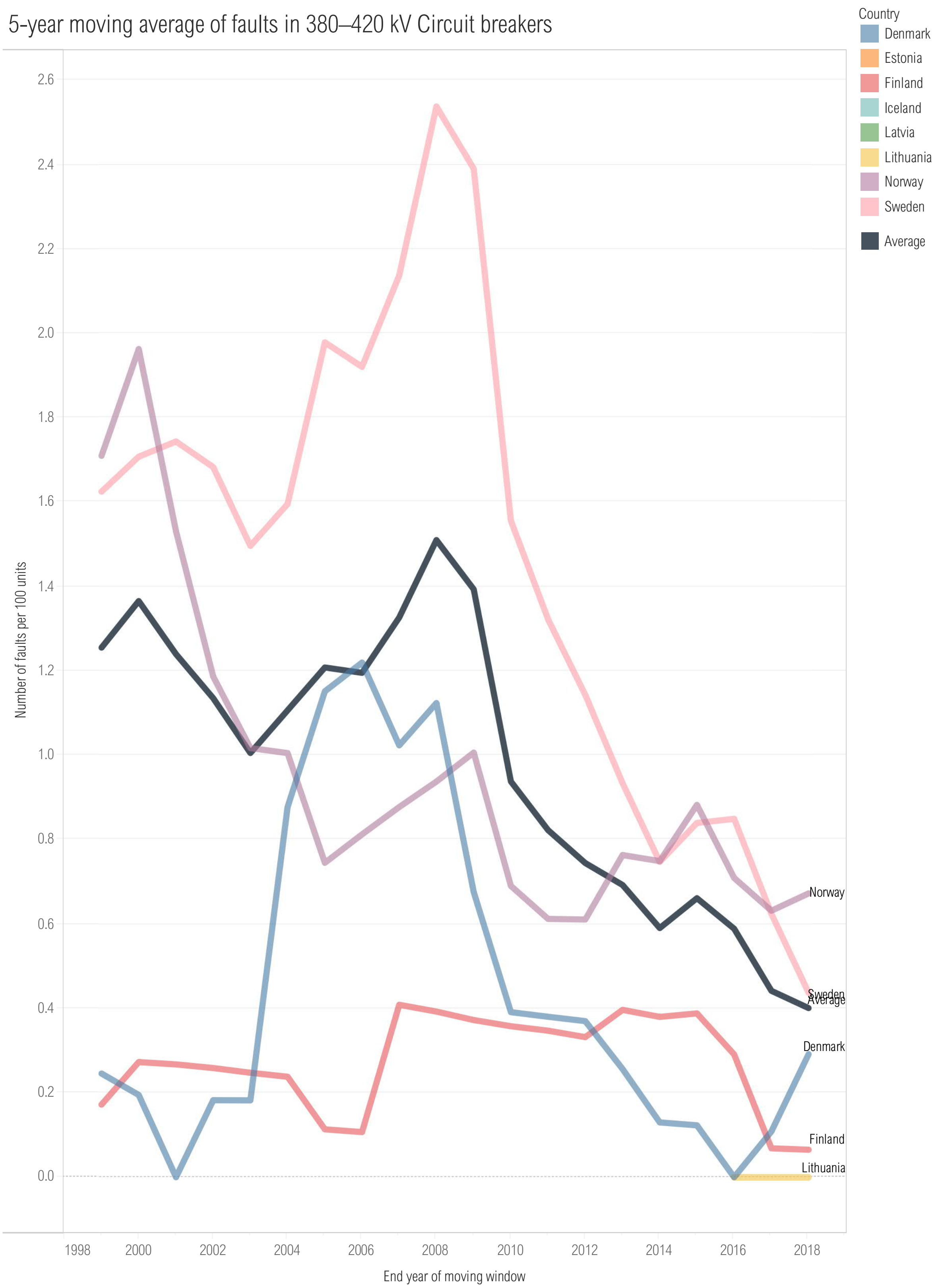


Figure 6.5.3: 5-year moving average of faults per 100 devices of 380–420 kV circuit breakers in each Nordic and Baltic country. Estonia has data since 2007 and Latvia and Lithuania have data since 2012. 380–420 kV trend lines are missing for Estonia, Iceland, Latvia and Lithuania because they do not own circuit breakers in the 380–420 kV voltage range, as can be seen from Table 6.5.1.

6.6 Faults in control equipment

This section presents control equipment faults in 2018 and during 2009–2018 at the voltage levels 100–150 kV, 220–330 kV and 380–420 kV. Control equipment are the components that help the grid owner to monitor their power grid. However, control equipment integrated in other components are not included in this category.

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

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

Table 6.6.1 presents the number of installed control equipment, the number of faults, the 10-year average number of faults and the number of permanent faults in 2018.

Table 6.6.2 presents the percentage distribution of faults faults per cause in 2018. Table 6.6.3 presents the respective average values for the period 2009–2018 in the Nordic countries and Estonia and during 2012–2018 in Latvia and Lithuania. The used causes are lightning, other environmental causes, external influences, operation and maintenance, technical equipment, other and unknown. The fault categories used are explained in more detail in Chapter 1.4.1. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

Figure 6.6.1, Figure 6.6.2 and Figure 6.6.3 present the 5-year moving average of 100–150 kV, 220–330 kV and 380–420 kV control equipment faults per 100 devices in each Nordic and Baltic country. Trend curves are used filter out the annual deviation and make it easier to follow on trends and decide on whether actions have to be taken in the future.

Table 6.6.1: Number of units and faults in control equipment per voltage level in each Nordic and Baltic country. The average number of faults is presented for the period 2009–2018 for the Nordic countries and Estonia and for the period 2012–2018 for Latvia and Lithuania. One unit of control equipment is 1 device.

Number of units and faults in 2018, Control equipment

		100–150 kV			220–330 kV			380–420 kV		
Regions	Country	# units	# faults	10-year average # faults	# units	# faults	10-year average # faults	# units	# faults	10-year average # faults
Baltic	Estonia	615	14	5.7	114	3	0.9	0	0	0.0
	Latvia	611	13	18.3	99	5	3.0	0	0	0.0
	Lithuania	876	12	13.4	113	10	3.0	5	0	0.0
	Total	2,102	39	11.6	326	18	2.1	5	0	0.0
Nordic	Denmark	974	3	6.2	16	0	0.1	225	0	1.7
	Finland	2,210	13	26.6	74	2	2.8	349	4	7.0
	Iceland	176	5	4.6	80	7	3.3	0	0	0.0
	Norway	2,491	43	28.8	730	21	19.0	453	17	12.1
	Sweden	2,576	34	11.5	337	23	9.8	649	15	20.1
	Total	8,427	98	15.5	1,237	53	7.0	1,676	36	8.2
Grand Total		10,529	137	14.3	1,563	71	5.4	1,681	36	5.5

Table 6.6.2: Percentage distribution of faults in control equipment per cause in the Nordic and Baltic countries in 2018. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

% distribution of faults per cause in 2018, Control equipment, all voltage levels

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	0%	0%	0%	71%	24%	0%	6%
	Latvia	0%	0%	0%	56%	31%	0%	13%
	Lithuania	0%	0%	0%	50%	14%	5%	32%
	Total	0%	0%	0%	58%	22%	2%	18%
Nordic	Denmark	0%	0%	0%	100%	0%	0%	0%
	Finland	0%	5%	0%	68%	16%	11%	0%
	Iceland	0%	0%	0%	58%	0%	42%	0%
	Norway	1%	5%	7%	48%	25%	7%	6%
	Sweden	6%	6%	0%	22%	43%	7%	17%
	Total	3%	5%	3%	42%	29%	10%	9%
Grand Total		2%	4%	2%	45%	27%	8%	11%

Table 6.6.3: Average distribution of faults in control equipment per cause during 2009–2018 in each Nordic country and Estonia and during 2012–2018 in Latvia and Lithuania.

10-year average % distribution of faults per cause, Control equipment, all voltage levels

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	0%	0%	0%	47%	47%	0%	6%
	Latvia	0%	1%	1%	49%	41%	1%	7%
	Lithuania	0%	0%	8%	40%	16%	5%	31%
	Total	0%	0%	3%	45%	33%	2%	16%
Nordic	Denmark	5%	4%	5%	49%	25%	8%	5%
	Finland	1%	1%	1%	54%	22%	7%	14%
	Iceland	0%	1%	0%	38%	51%	10%	0%
	Norway	2%	5%	3%	45%	30%	10%	5%
	Sweden	1%	4%	0%	28%	54%	5%	8%
	Total	1%	3%	2%	42%	35%	8%	8%
Grand Total		1%	3%	2%	43%	35%	7%	9%

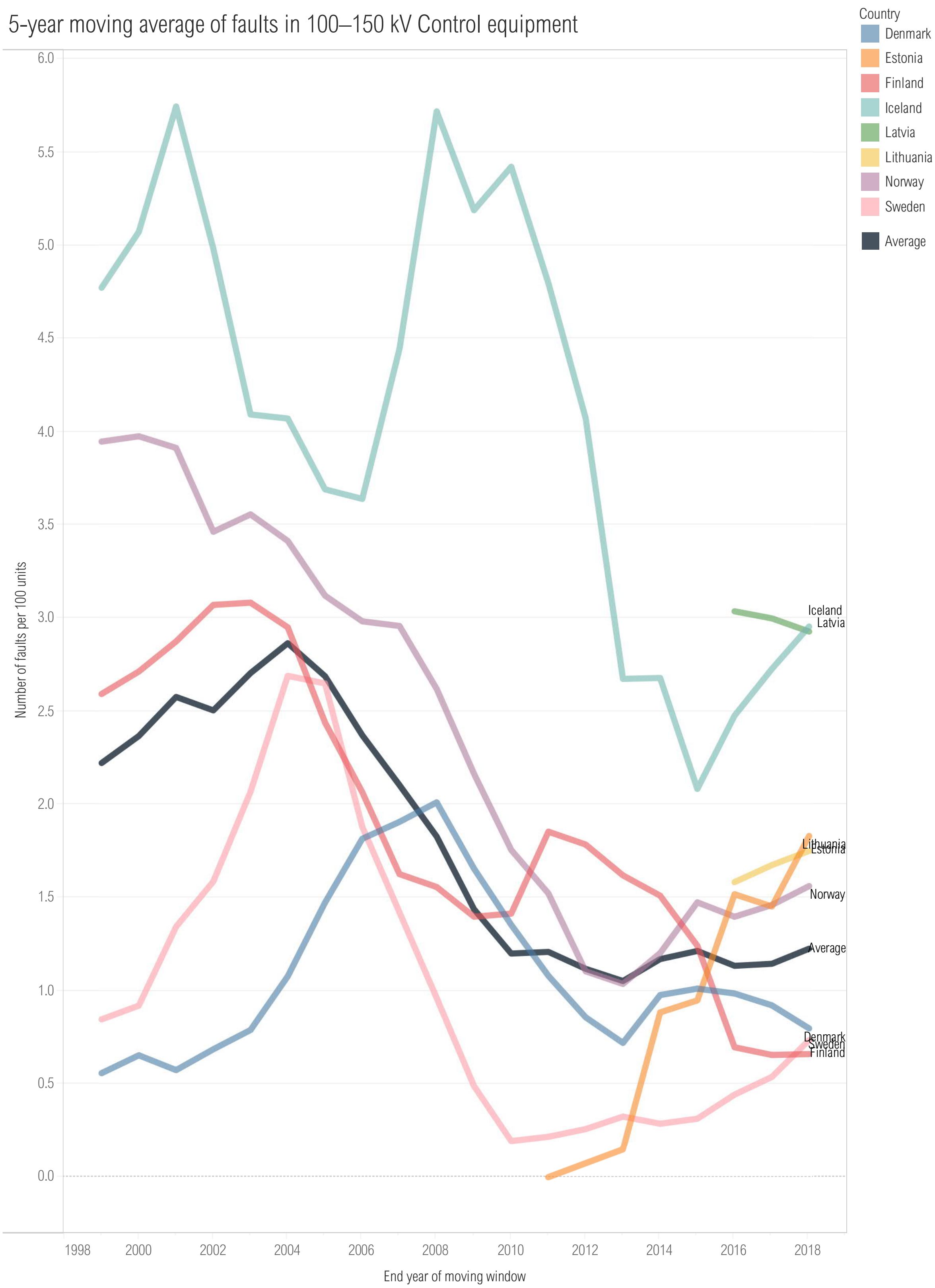


Figure 6.6.1: 5-year moving average of 100–150 kV control equipment faults per 100 devices in each Nordic and Baltic country. Estonia has data since 2007 and Latvia and Lithuania have data since 2012.

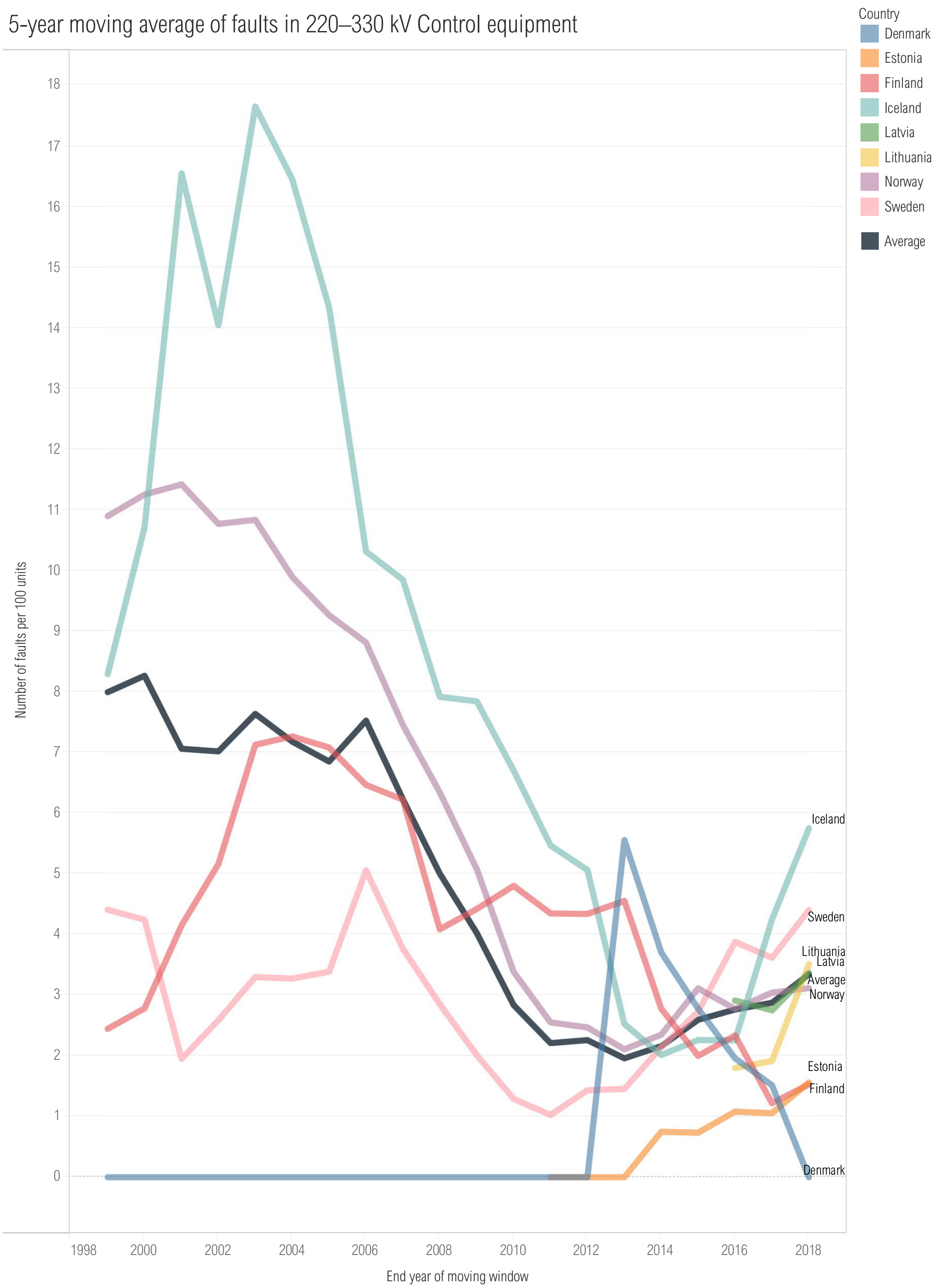


Figure 6.6.2: 5-year moving average of 220–330 kV control equipment faults per 100 devices in each Nordic and Baltic country. Estonia has data since 2007 and Latvia and Lithuania have data since 2012.

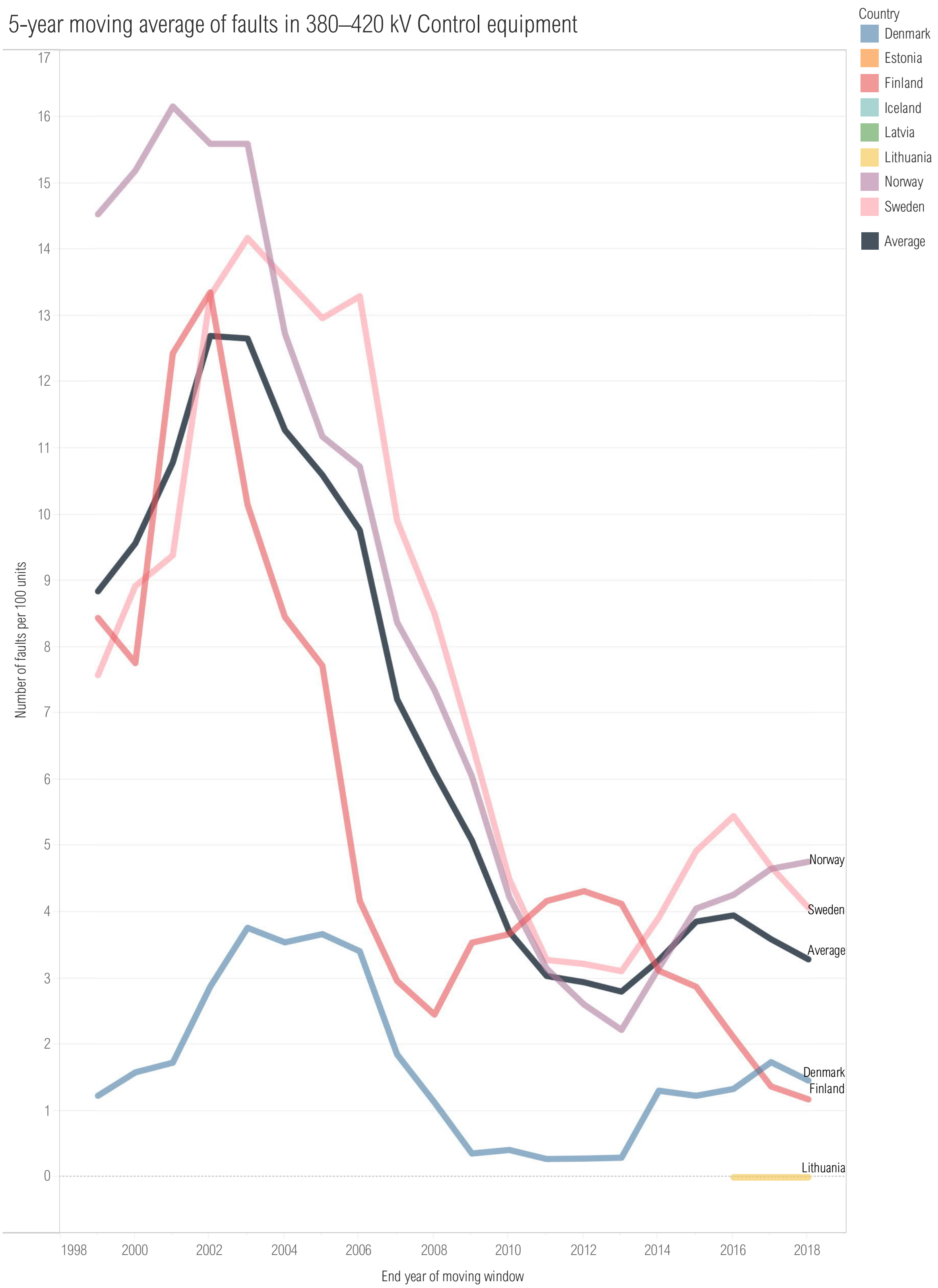


Figure 6.6.3: 5-year moving average of 380–420 kV control equipment faults per 100 devices in each Nordic and Baltic country. Estonia has data since 2007 and Latvia and Lithuania have data since 2012. 380–420 kV trend lines are missing for Estonia, Iceland and Latvia because they do not own control equipment in the 380–420 kV voltage range, as can be seen from Table 6.6.1.

6.7 Faults in instrumental transformers

This section presents instrumental transformer faults in 2018 and during 2009–2018 at the voltage levels 100–150 kV, 220–330 kV and 380–420 kV. Instrumental transformers provide the necessary power to metering and protection devices in the power grid. These, in turn, trigger the necessary protection relays when needed and allow the grid owner to monitor the state of the system. Both current and voltage transformers are included in instrumental transformers.

Table 6.7.1 presents the number of installed instrumental transformers, the number of faults, the 10-year average number of faults and the number of permanent faults in 2018. Table 6.7.2 presents the percentage distribution of faults faults per cause in 2018. Table 6.7.3 presents the respective average values for the period 2009–2018 in the Nordic countries and Estonia and during 2012–2018 in Latvia and Lithuania. The used causes are lightning, other environmental causes, external influences, operation and maintenance, technical equipment, other and unknown. The fault categories used are explained in more detail in Chapter 1.4.1. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

Figure 6.7.1, Figure 6.7.2 and Figure 6.7.3 present the 5-year moving average of 100–150 kV, 220–330 kV and 380–420 kV instrumental transformer faults per 100 devices in each Nordic and Baltic country. Trend curves are used filter out the annual deviation and make it easier to follow on trends and decide on whether actions have to be taken in the future.

Table 6.7.1: Number of units and faults in instrumental transformers per voltage level in each Nordic and Baltic country. The average number of faults is presented for the period 2009–2018 for the Nordic countries and Estonia and for the period 2012–2018 for Latvia and Lithuania. One unit of instrumental transformer is 1 device.

Number of units and faults in 2018, Instrumental transformers

		100–150 kV			220–330 kV			380–420 kV		
Regions	Country	# units	# faults	10-year average # faults	# units	# faults	10-year average # faults	# units	# faults	10-year average # faults
Baltic	Estonia	2,884	2	0.9	785	0	0.6	0	0	0.0
	Latvia	2,289	3	0.9	396	0	0.1	0	0	0.0
	Lithuania	3,219	1	0.9	657	0	0.4	27	0	0.0
	Total	8,392	6	0.9	1,838	0	0.4	27	0	0.0
Nordic	Denmark	2,922	1	1.5	48	0	0.1	675	0	0.4
	Finland	7,543	4	2.6	434	0	0.1	2,010	1	0.2
	Iceland	611	1	0.1	444	0	0.0	0	0	0.0
	Norway	7,768	1	3.4	2,805	0	1.9	930	0	1.5
	Sweden	2,447	10	4.0	1,616	0	0.2	3,438	0	1.8
	Total	21,291	17	2.3	5,347	0	0.5	7,053	1	0.8
Grand Total		29,683	23	1.9	7,185	0	0.4	7,080	1	0.5

Table 6.7.2: Percentage distribution of faults in instrumental transformers per cause in the Nordic and Baltic countries in 2018. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

% distribution of faults per cause in 2018, Instrumental transformers, all voltage levels

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	0%	0%	0%	50%	50%	0%	0%
	Latvia	0%	0%	0%	0%	100%	0%	0%
	Lithuania	0%	0%	0%	100%	0%	0%	0%
	Total	0%	0%	0%	33%	67%	0%	0%
Nordic	Denmark	0%	0%	0%	100%	0%	0%	0%
	Finland	0%	0%	0%	20%	60%	20%	0%
	Iceland	0%	0%	0%	0%	0%	100%	0%
	Norway	0%	0%	0%	0%	0%	0%	100%
	Sweden	20%	0%	0%	0%	80%	0%	0%
	Total	11%	0%	0%	11%	61%	11%	6%
Grand Total		8%	0%	0%	17%	63%	8%	4%

Table 6.7.3: Average distribution of faults in instrumental transformers per cause during 2009–2018 in each Nordic country and Estonia and during 2012–2018 in Latvia and Lithuania.

10-year average % distribution of faults per cause, Instrumental transformers, all voltage levels

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	0%	0%	0%	13%	87%	0%	0%
	Latvia	0%	0%	0%	0%	100%	0%	0%
	Lithuania	0%	0%	0%	11%	89%	0%	0%
	Total	0%	0%	0%	10%	90%	0%	0%
Nordic	Denmark	0%	0%	5%	10%	65%	5%	15%
	Finland	7%	0%	0%	3%	62%	10%	17%
	Iceland	0%	0%	0%	0%	0%	100%	0%
	Norway	13%	3%	1%	19%	37%	19%	7%
	Sweden	7%	0%	2%	7%	80%	0%	5%
	Total	8%	1%	2%	11%	58%	10%	9%
Grand Total		7%	1%	1%	11%	63%	9%	8%

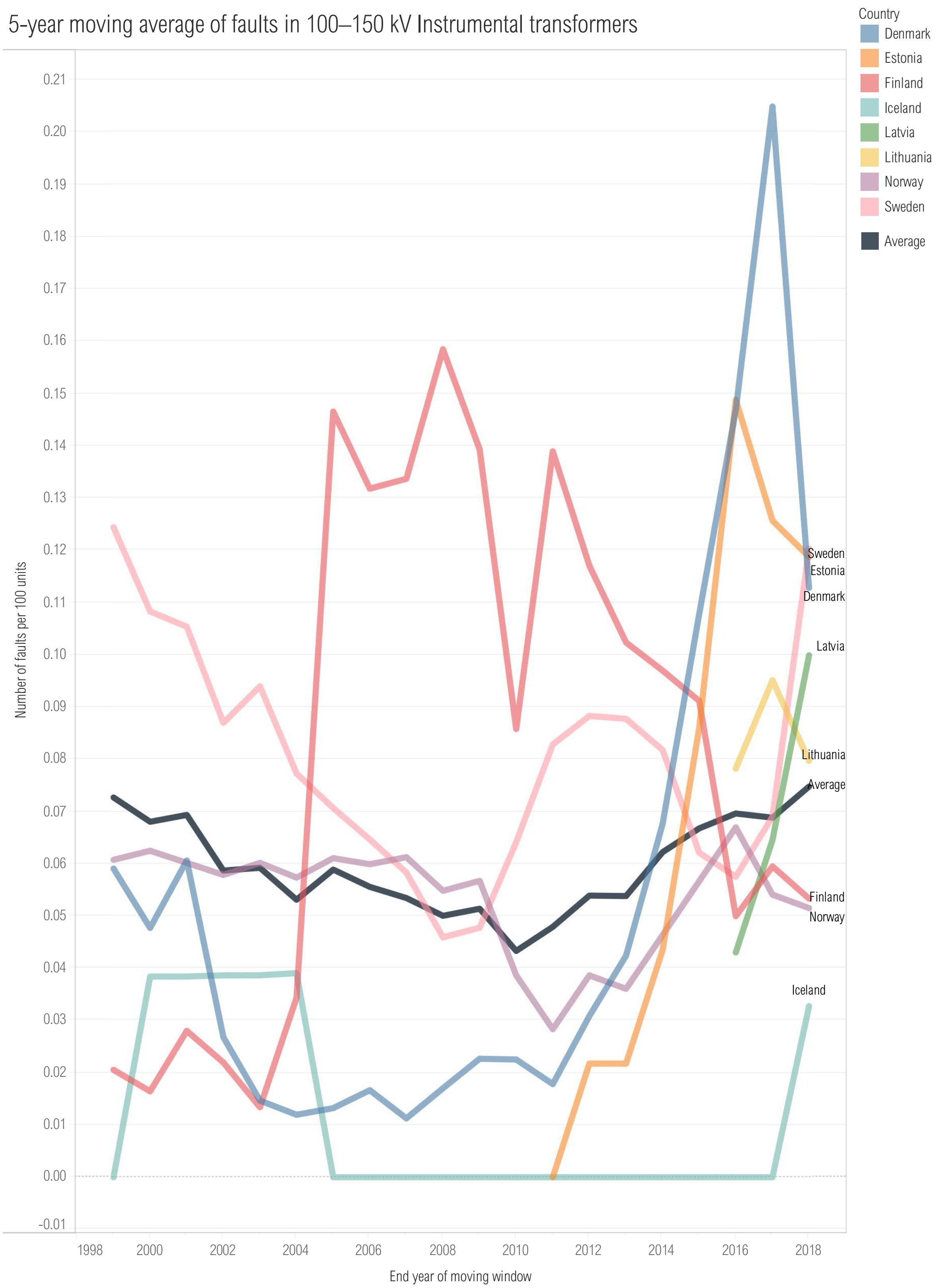


Figure 6.7.1: 5-year moving average of 100–150 kV instrumental transformer faults per 100 devices in each Nordic and Baltic country. Estonia has data since 2007 and Latvia and Lithuania have data since 2012.

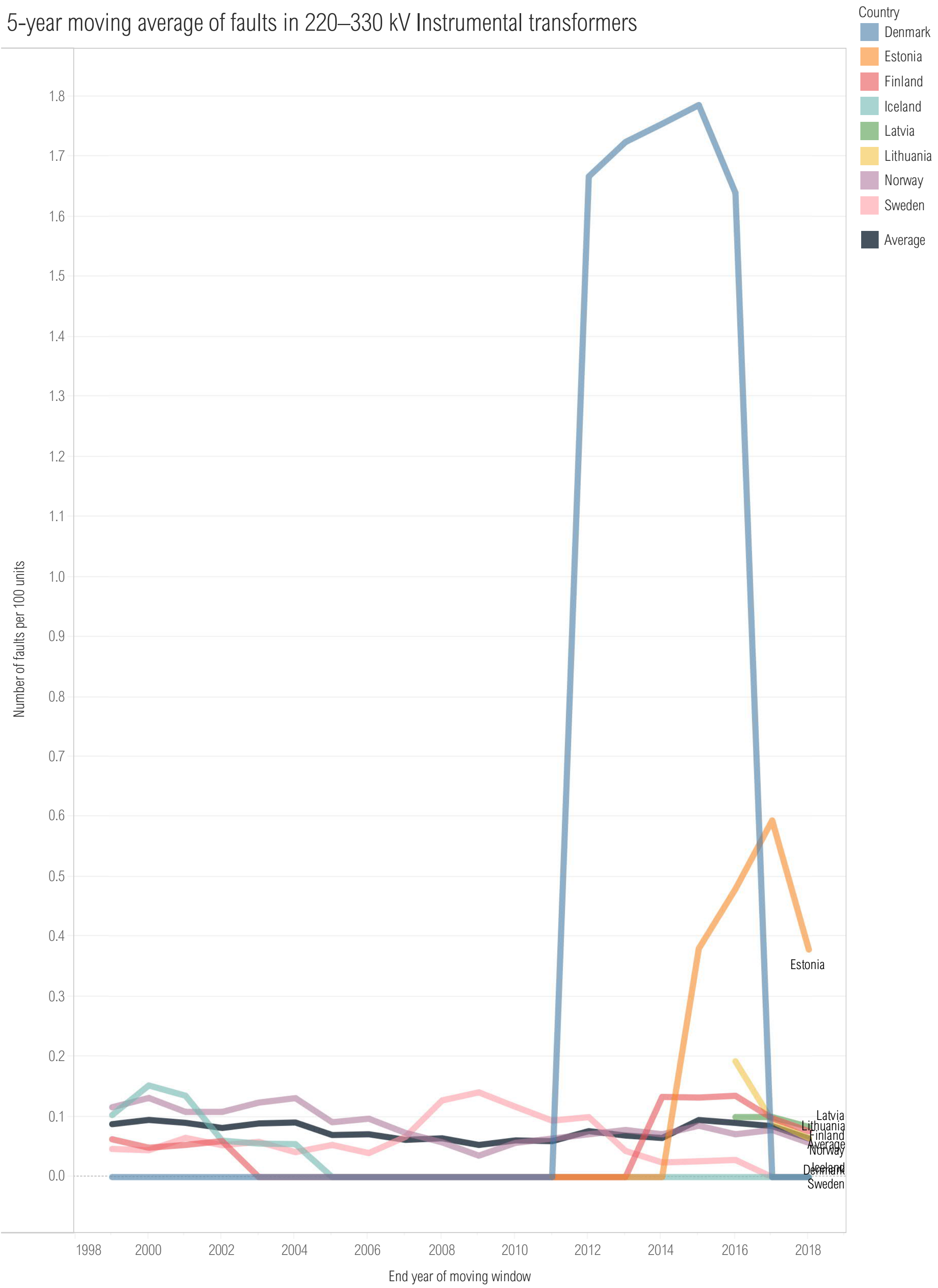


Figure 6.7.2: 5-year moving average of 220–330 kV instrumental transformer faults per 100 devices in each Nordic and Baltic country. Estonia has data since 2007 and Latvia and Lithuania have data since 2012. Denmark's high values during 2007–2016 are caused by 1 fault in 2012, as can be seen in Figure 6.5.4. The values seem to be extreme because Denmark owns significantly less instrumental transformers than the other countries.

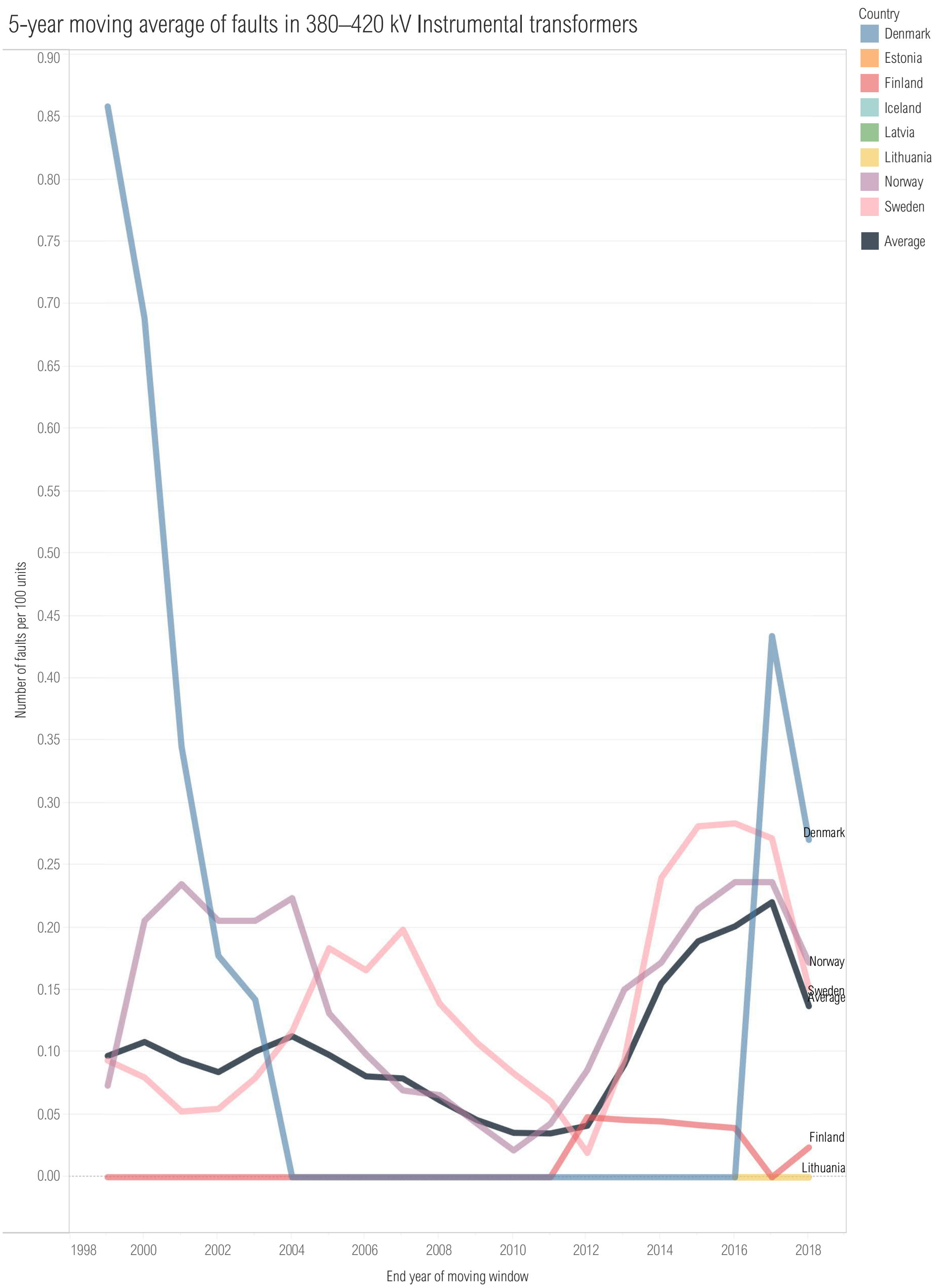


Figure 6.7.3: 5-year moving average of 380–420 kV instrumental transformer faults per 100 devices in each Nordic and Baltic country. Estonia has data since 2007 and Latvia and Lithuania have data since 2012. 380–420 kV trend lines are missing for Estonia, Iceland and Latvia because they do not own instrumental transformers in the 380–420 kV voltage range, as can be seen from Table 6.7.1.

6.8 Faults in power transformers

This section presents power transformer faults in 2018 and during 2009–2018 at the voltage levels 100–150 kV, 220–330 kV and 380–420 kV. Power transformers are essential when power needs to be transferred from where power is generated or imported to where power is consumed or exported. They allow the grid owner to optimize the voltage level in order to minimize transmission losses. The rated voltage of a power transformer is defined in these statistics as the winding with the highest voltage, as stated in the guidelines in Section 6.2 [1].

Table 6.8.1 presents the number of installed of power transformers, the number of faults, the 10-year average number of faults and the number of permanent faults in 2018. Table 6.8.2 presents the percentage distribution of faults faults per cause in 2018. Table 6.8.3 presents the respective average values for the period 2009–2018 in the Nordic countries and Estonia and during 2012–2018 in Latvia and Lithuania. The used causes are lightning, other environmental causes, external influences, operation and maintenance, technical equipment, other and unknown. The fault categories used are explained in more detail in Chapter 1.4.1. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

Figure 6.8.1, Figure 6.8.2 and Figure 6.8.3 present the 5-year moving average of 100–150 kV, 220–330 kV and 380–420 kV power transformer faults per 100 devices in each Nordic and Baltic country. Trend curves are used filter out the annual deviation and make it easier to follow on trends and decide on whether actions have to be taken in the future.

Table 6.8.1: Number of units, faults and permanent faults in power transformers per voltage level in each Nordic and Baltic country. The average number of faults is presented for the period 2009–2018 for the Nordic countries and Estonia and for the period 2012–2018 for Latvia and Lithuania. Iceland had no faults in their power transformers in 2018. One unit of power transformer is 1 device.

Number of units and faults in 2018, Power transformers

		100–150 kV			220–330 kV			380–420 kV		
Regions	Country	# units	# faults	10-year average # faults	# units	# faults	10-year average # faults	# units	# faults	10-year average # faults
Baltic	Estonia	211	11	7.2	26	2	2.5	0	0	0.0
	Latvia	248	3	5.4	26	2	1.6	0	0	0.0
	Lithuania	400	0	0.3	25	1	1.0	0	0	0.0
	Total	859	14	4.7	77	5	1.8	0	0	0.0
Nordic	Denmark	258	6	3.2	8	0	0.1	41	2	1.1
	Finland	847	15	6.9	15	2	0.9	61	1	1.4
	Iceland	38	0	1.0	15	0	0.8	0	0	0.0
	Norway	913	3	5.1	266	2	2.0	100	3	1.8
	Sweden	856	5	22.3	116	1	4.2	75	0	1.7
	Total	2,912	29	7.7	420	5	1.6	277	6	1.2
Grand Total		3,771	43	6.7	497	10	1.7	277	6	0.8

Table 6.8.2: Percentage distribution of faults per cause in the Nordic and Baltic countries in 2018. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

% distribution of faults per cause in 2018, Power transformers, all voltage levels

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	0%	0%	8%	23%	69%	0%	0%
	Latvia	0%	0%	20%	40%	40%	0%	0%
	Lithuania	0%	0%	0%	0%	0%	0%	100%
	Total	0%	0%	11%	26%	58%	0%	5%
Nordic	Denmark	0%	25%	0%	38%	25%	0%	13%
	Finland	0%	0%	6%	22%	6%	67%	0%
	Iceland	0%	0%	0%	0%	0%	0%	0%
	Norway	0%	50%	0%	0%	38%	13%	0%
	Sweden	17%	0%	0%	50%	17%	0%	17%
	Total	3%	15%	3%	25%	18%	33%	5%
Grand Total		2%	10%	5%	25%	31%	22%	5%

Table 6.8.3: Average distribution of faults per cause during 2009–2018 in each Nordic country and Estonia and during 2012–2018 in Latvia and Lithuania. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

10-year average % distribution of faults per cause, Power transformers, all voltage levels

Regions	Country	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Baltic	Estonia	1%	3%	3%	23%	69%	0%	1%
	Latvia	0%	0%	29%	31%	37%	0%	4%
	Lithuania	0%	0%	0%	33%	33%	0%	33%
	Total	1%	2%	11%	26%	57%	0%	4%
Nordic	Denmark	2%	23%	0%	30%	34%	5%	7%
	Finland	7%	2%	7%	23%	23%	24%	15%
	Iceland	0%	17%	0%	11%	72%	0%	0%
	Norway	7%	24%	1%	15%	24%	21%	9%
	Sweden	21%	1%	2%	22%	23%	6%	26%
	Total	14%	8%	2%	21%	26%	11%	18%
Grand Total		11%	6%	4%	22%	33%	9%	15%

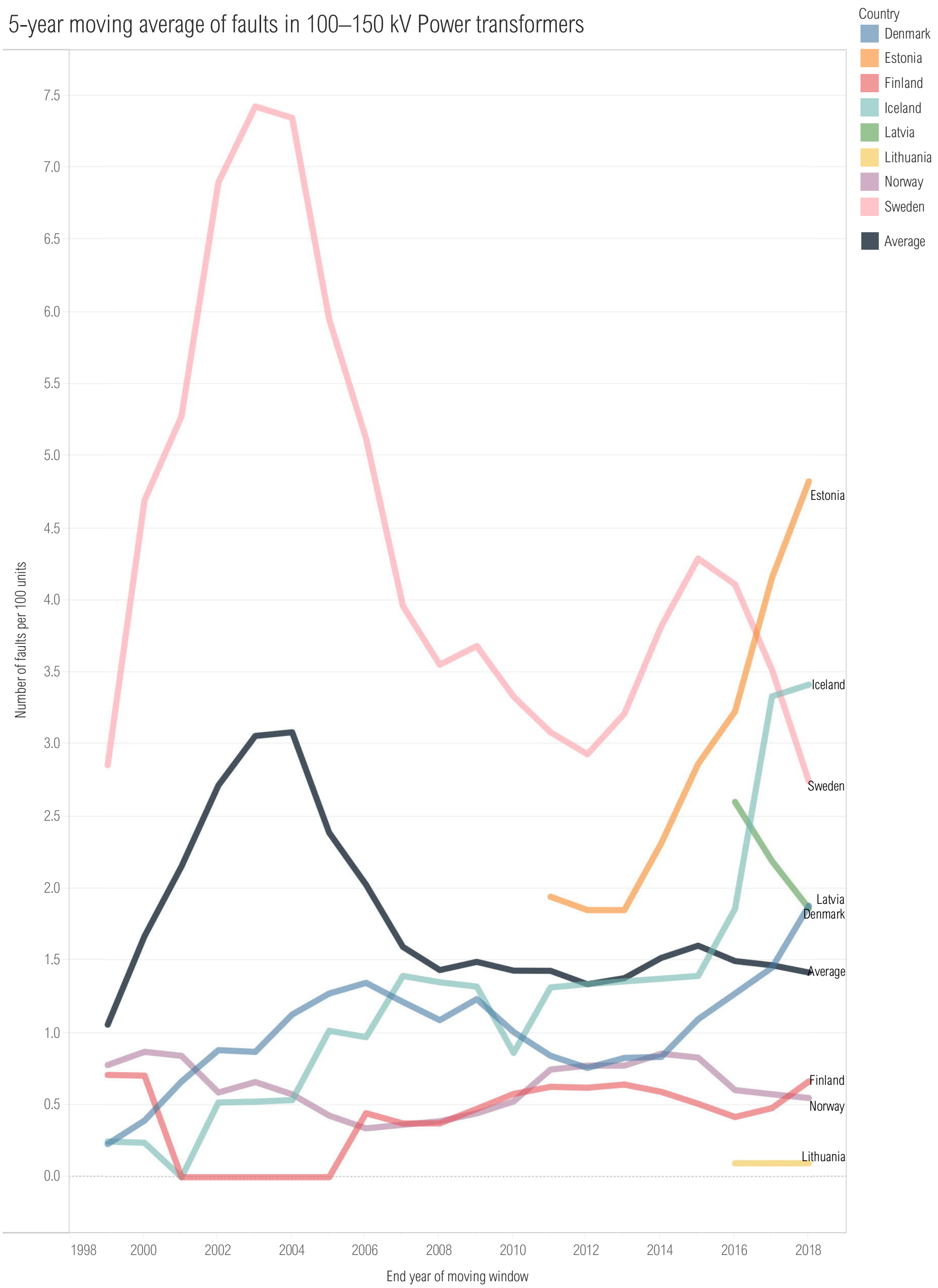


Figure 6.8.1: 5-year moving average of 100–150 kV power transformer faults per 100 devices in each Nordic and Baltic country. Estonia has data since 2007 and Latvia and Lithuania have data since 2012.

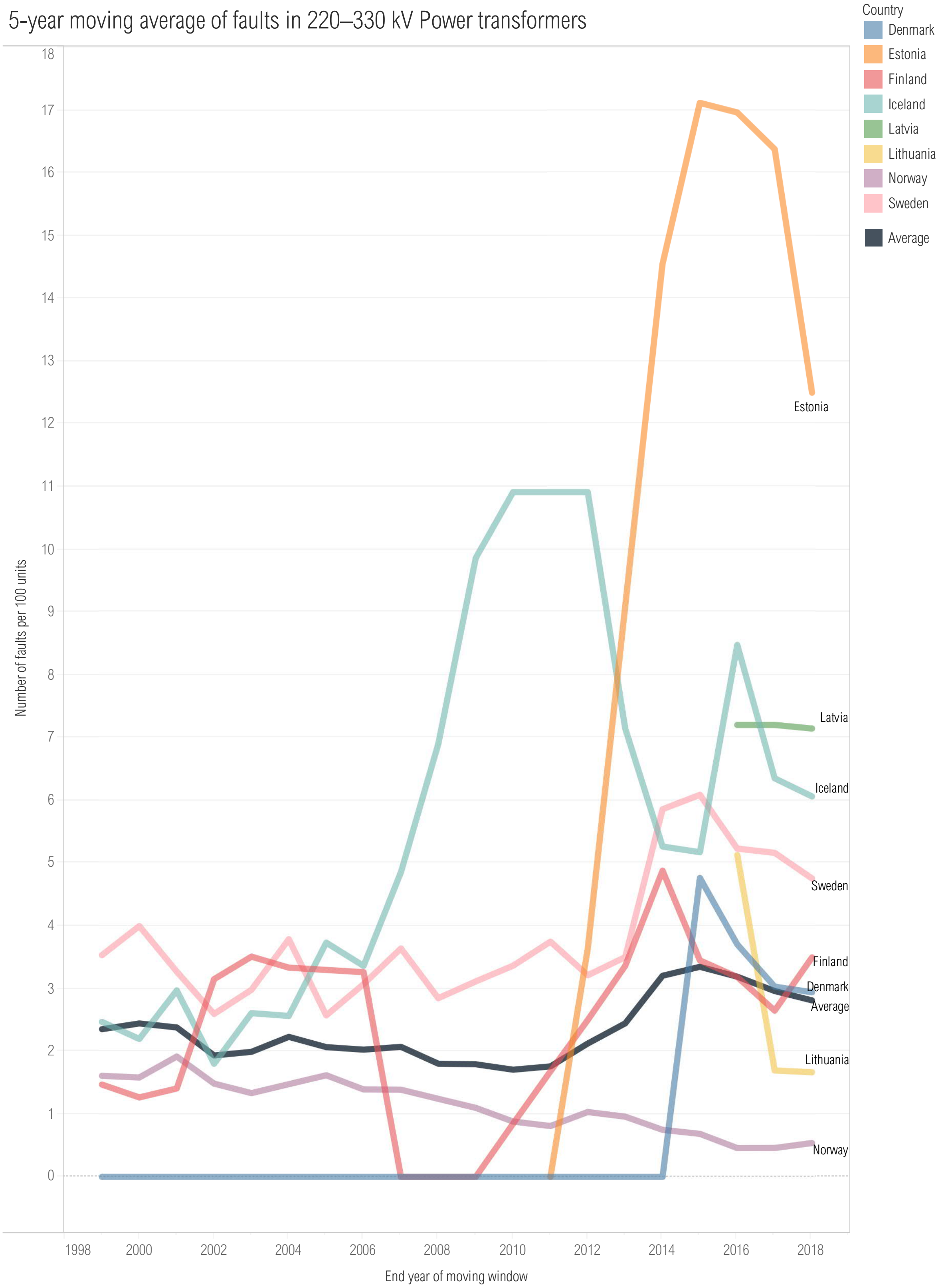


Figure 6.8.2: 5-year moving average of 220–330 kV power transformer faults per 100 devices in each Nordic and Baltic country. Estonia has data since 2007 and Latvia and Lithuania have data since 2012.

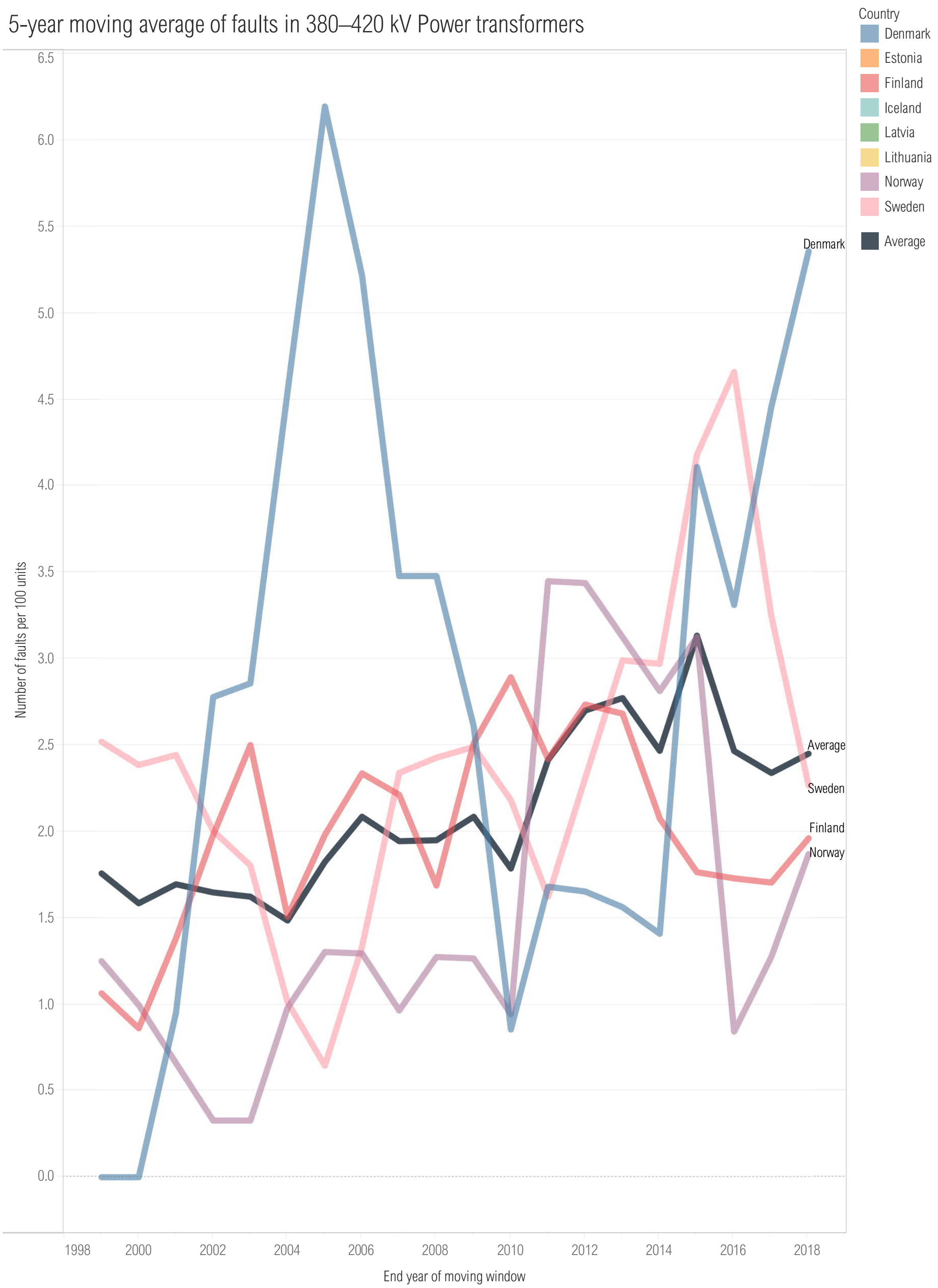


Figure 6.8.3: 5-year moving average of 380–420 kV power transformer faults per 100 devices in each Nordic and Baltic country. Estonia has data since 2007 and Latvia and Lithuania have data since 2012. 380–420 kV trend lines are missing for Estonia, Iceland, Latvia and Lithuania because they do not own power transformers in the 380–420 kV voltage range, as can be seen from Table 6.8.1.

6.9 Faults in compensation devices

The sections in this chapter present fault statistics for compensation devices. Compensation devices are used to reduce reactive and capacitive power and for stabilizing voltage and frequency in the power system. The following compensation devices are presented in this chapter: reactors, series capacitors, shunt capacitors and SVC devices. The statistics include the number of devices and faults in 2018, number of faults per 100 devices and ENS in 2018 and 2009–2018.

6.9.1 Faults in reactors

Reactors add reactance to the power grid and limit short circuit currents. Table 6.9.1 presents the number of reactors and faults in 2018, the number of faults per 100 devices and the amount of ENS in 2018 and 2009–2018.

Table 6.9.1: Overview of reactor faults. This includes number of devices and the number of reactor faults in 2018, the number of reactor faults per 100 devices and the amount of ENS in 2018 and 2009–2018.

	Units	Faults	Faults per 100 devices		ENS (MWh)	
Country	2018	2018	2018	2009–2018	2018	2009–2018
Estonia	26	2	7.69	8.73	0.0	0.0
Latvia[2]	17	0	0.00	6.19	0.0	0.0
Lithuania[2]	2	0	0.00	0.00	0.0	0.0
Baltic total	45	2	4.44	6.41	0.0	0.0
Denmark	93	4	4.30	1.99	0.0	0.2
Finland[1]	72	0	0.00	0.28	0.0	1.0
Iceland	0	0	0.00	0.00	0.0	0.0
Norway	36	0	0.00	2.22	0.0	0.0
Sweden	777	6	0.77	5.75	0.0	0.0
Nordic total	978	10	1.02	3.39	0.0	1.2
Nordic & Baltic	1023	12	1.17	3.68	0.0	1.2

[1] In Finland, reactors compensating the reactive power of 380–420 kV lines are connected to the 20 kV tertiary winding of the 380–420/100–150/20 kV power transformers.
[2] The average values of Latvia and Lithuania use the period 2012–2018.

6.9.2 Faults in series capacitors

Series capacitors compensate for the inductance created by long transmission lines. This reduces voltage drop and transmission losses, increases the transmission capacity and improves voltage stability. Table 6.9.2 presents the number of series capacitors and faults in 2018, the number of faults per 100 devices and the amount of ENS in 2018 and 2009–2018.

Table 6.9.2: Overview of series capacitor faults. This includes number of devices and the number of series capacitor faults in 2018, the number of series capacitor faults per 100 devices and the amount of ENS in 2018 and 2009–2018.

	Units	Faults	Faults per 100 devices		ENS (MWh)	
Country	2018	2018	2018	2009–2018	2018	2009–2018
Estonia	14	0	0.00	0.00	0.0	0.0
Latvia[1]	0	0	0.00	0.00	0.0	0.0
Lithuania[1]	0	0	0.00	0.00	0.0	0.0
Baltic total	14	0	0.00	0.00	0.0	0.0
Denmark	0	0	0.00	0.00	0.0	0.0
Finland	11	5	45.45	57.73	0.0	1.9
Iceland	1	1	100.00	20.00	0.0	0.0
Norway	3	0	0.00	3.33	0.0	0.0
Sweden	9	1	11.11	152.38	0.0	0.0
Nordic total	24	7	29.17	90.50	0.0	1.9
Nordic & Baltic	38	7	18.42	85.55	0.0	1.9

[1] The average values of Latvia and Lithuania use the period 2012–2018.

6.9.3 Faults in shunt capacitors

Shunt capacitors provide the grid with reactive power to the grid, thus decreasing transmission losses and increasing transmission capacity. Table 6.9.3 presents the number of shunt capacitors and faults in 2018, the number of faults per 100 devices and the amount of ENS in 2018 and 2009–2018.

Table 6.9.3: Overview of shunt capacitor faults. This includes number of devices and the number of shunt capacitor faults in 2018, the number of shunt capacitor faults per 100 devices and the amount of ENS in 2018 and 2009–2018.

Country	Units 2018	Faults 2018	Faults per 100 devices 2018	Faults per 100 devices 2009–2018	ENS (MWh) 2018	ENS (MWh) 2009–2018
Estonia	0	0	0.00	7.94	0.0	3.0
Latvia[1]	2	0	0.00	0.00	0.0	0.0
Lithuania[1]	2	0	0.00	0.00	0.0	0.0
Baltic total	4	0	0.00	6.02	0.0	3.0
Denmark	26	0	0.00	0.47	0.0	0.0
Finland	62	3	4.84	3.33	0.0	0.0
Iceland	13	0	0.00	5.93	0.0	0.0
Norway	194	5	2.58	1.86	0.0	0.0
Sweden	179	1	0.56	0.70	0.0	7.0
Nordic total	474	9	1.90	1.63	0.0	7.0
Nordic & Baltic	478	9	1.88	1.78	0.0	10.0

[1] The average values of Latvia and Lithuania use the period 2012–2018.

6.9.4 Faults in SVC devices

SVCs, or static VAR compensators, provide the power grid with fast and dynamic reactive power to stabilize the voltage levels, the power factor and harmonics. However, SVC devices are often subjects to temporary faults. A typical fault is an error in the computer of the control system that leads to the tripping of the circuit breaker of the SVC device. After the computer is restarted, the SVC device works normally. This explains the high number of faults in SVC devices.

Table 6.9.4 presents the number of shunt capacitors and faults in 2018, the number of faults per 100 devices and the amount of ENS in 2018 and 2009–2018.

Table 6.9.4: Overview of SVC device faults. This includes number of devices and the number of SVC faults in 2018, the number of SVC faults per 100 devices and the amount of ENS in 2018 and 2009–2018.

Country	Units 2018	Faults 2018	Faults per 100 devices 2018	Faults per 100 devices 2009–2018	ENS (MWh) 2018	ENS (MWh) 2009–2018
Estonia	0	0	0.00	0.00	0.0	0.0
Latvia[1]	0	0	0.00	0.00	0.0	0.0
Lithuania[1]	11	0	0.00	2.68	0.0	0.0
Baltic total	11	0	0.00	2.68	0.0	0.0
Denmark	1	1	100.00	30.00	0.0	0.0
Finland	5	1	20.00	16.67	0.0	0.0
Iceland	2	0	0.00	16.67	0.0	0.0
Norway	25	15	60.00	85.56	0.0	0.0
Sweden	3	2	66.67	320.00	0.0	0.0
Nordic total	36	19	52.78	99.24	0.0	0.0
Nordic & Baltic	47	19	40.43	71.30	0.0	0.0

[1] The average values of Latvia and Lithuania use the period 2012–2018.

References

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

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

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

[4] International Electrotechnical Commission, *International Electrotechnical Vocabulary*, iec 60050-191:1990 ed. Note that the IEC standard 60050-191 Dependability and quality of service was canceled on 27 April 2015. Since the statistics have been prepared by using this defintion, it is used as a reference.

Appendices

A Calculation of energy not supplied

Every country calculates their energy not supplied (ENS) in their own way. This appendix describes how the calculations are done.

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.

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

In Finland, the ENS in the transmission grid is counted for those faults that caused 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.

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. In the distribution systems, the outages in the transmission and distribution systems that affect the end user and ENS are also registered. Common rules for registration of faults and ENS in all grids are used in Iceland.

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

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

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 standardized method that has been established by the authority.

In Sweden, the ENS of the transmission grid is calculated by using the outage duration and the cut-off power that was detected at the instant when the outage occurred. Because the cut-off power is rarely registered, some companies multiply the rated power at the point of supply by the outage duration.

B Policies for examining the cause of line faults

This appendix is added to explain the effort each TSO puts into finding the most probable cause of each disturbance.

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.

In Estonia, the causes of line faults are found by inspections or by some identifying or highly probable signs. Fault location is usually categorised as it is measured by disturbance recorders although the accuracy may vary a lot. The 110 kV lines have many trips with a successful automatic reclosing at nights during summer months. The reasons were examined and it was found out that stork contamination on insulators causes these flashovers. In these cases, the fault sites are not always inspected. Elering has access to lightning detection system, which allows identifying the line faults caused by lightning. If there are no signs referring to a certain cause, the reason for a fault is unknown.

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 reported cause will be lightning. Additionally, the category other environmental cause is used more often. Therefore, the number of unknown faults has decreased.

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. Every month the listings for interference are analysed by the staff of system operation 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 originally reported. This also leads to a better understanding how disturbances are listed in the disturbance database for these parties.

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

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.

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 will normally be 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.

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

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D Contact persons for the distribution network statistics

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

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

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E Additional figures

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

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

E.1 Trends of faults per cause

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

Figure E.1.1 shows the trend curves for other environmental causes for each Nordic and Baltic country. Figure E.1.2 shows the same but for operation and maintenance causes. The trends are calculated by 5-year moving averages during 1995–2018. With the help of the trend curve, it may be possible to estimate the number of faults in the future.

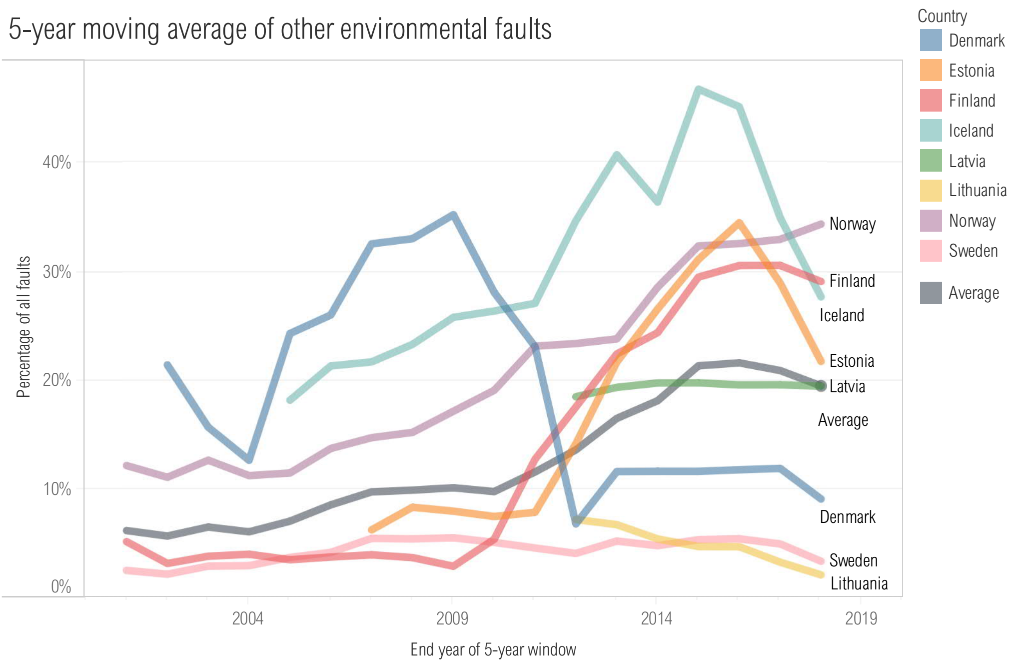

Figure E.1.1: Fault trends as 5-year rolling averages for other environmental faults in each Nordic and Baltic country. Other environmental causes are the main reason for higher maintenance costs and depends significantly on the weather conditions in a country. Furthermore, faults due to other environmental causes can be decreased through increased maintenance and by improving work procedures.

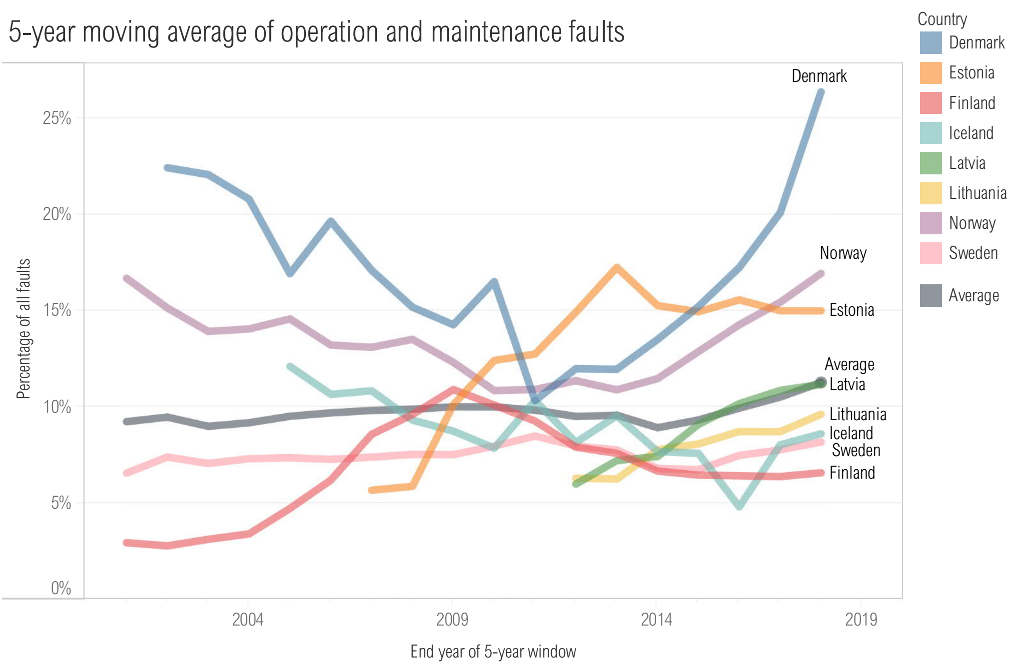

Figure E.1.2: Fault trends as 5-year rolling averages for operation and maintenance faults in each Nordic and Baltic country. Operation and maintenance faults are directly connected to changes in work procedures and grid investments. Furthermore, trend curves for operation and maintenance might be connected to the increase in digital technology inside the substations and to the amount of work orders being performed in the grids.

E.2 Overhead line fault trends per cause

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

Overhead line fault trends for other environmental causes and operation and maintenance causes are shown in Figure E.2.1 and Figure E.2.2, respectively. The trends are calculated by 5-year moving averages for the period 1995–2018 for the Nordic countries, 2007–2018 for Estonia and 2012–2018 for Latvia and Lithuania. With the help of the trend curve, it may be possible to estimate the number of faults in the future.

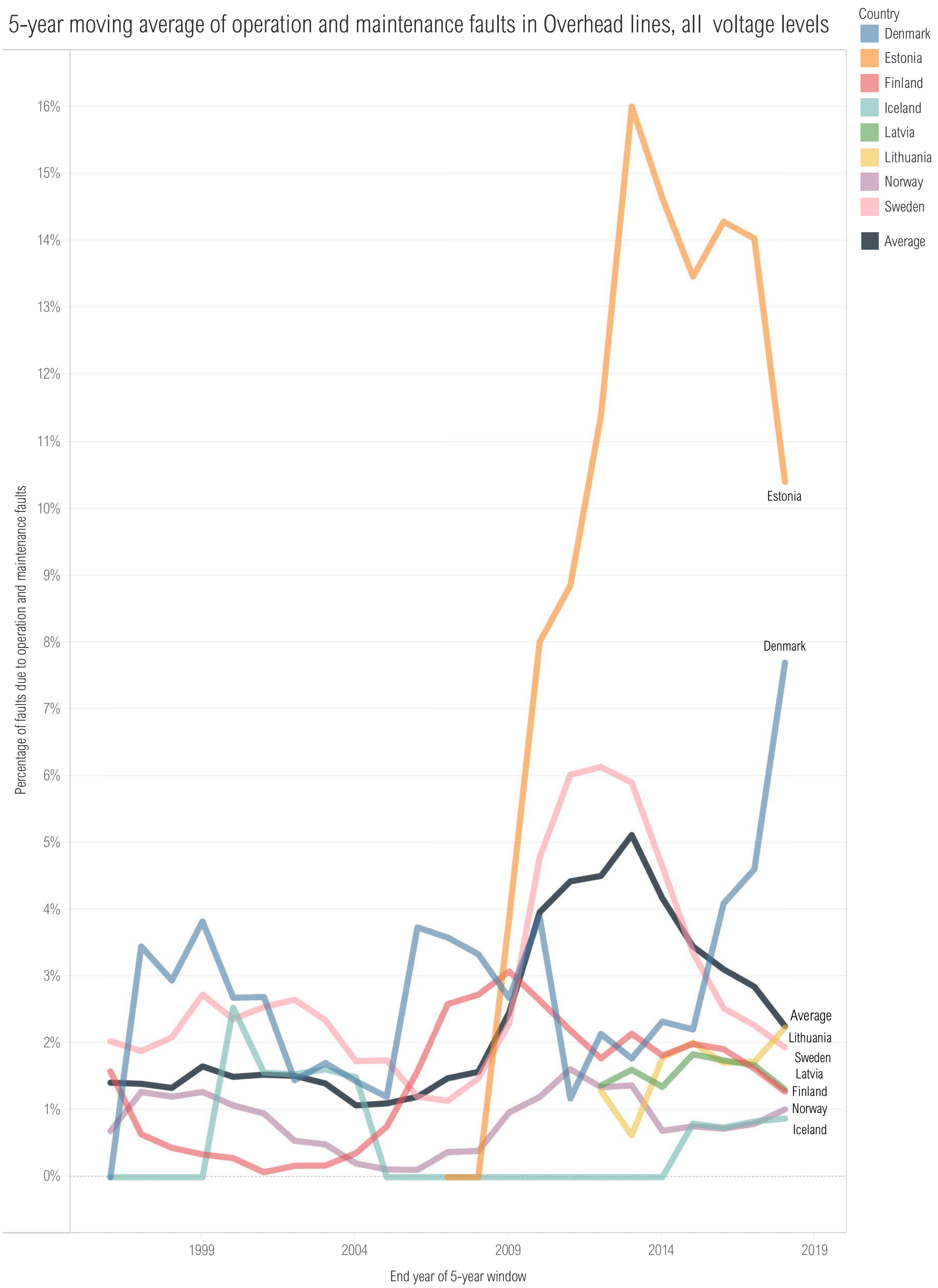

Figure E.2.1: Fault trends as 5-year rolling averages for overhead line other environmental causes in each Nordic and Baltic country. Other environmental causes are the main reason for higher maintenance costs and depends significantly on the weather conditions in a country. Furthermore, faults due to other environmental causes can be decreased through increased maintenance and by improving work procedures.

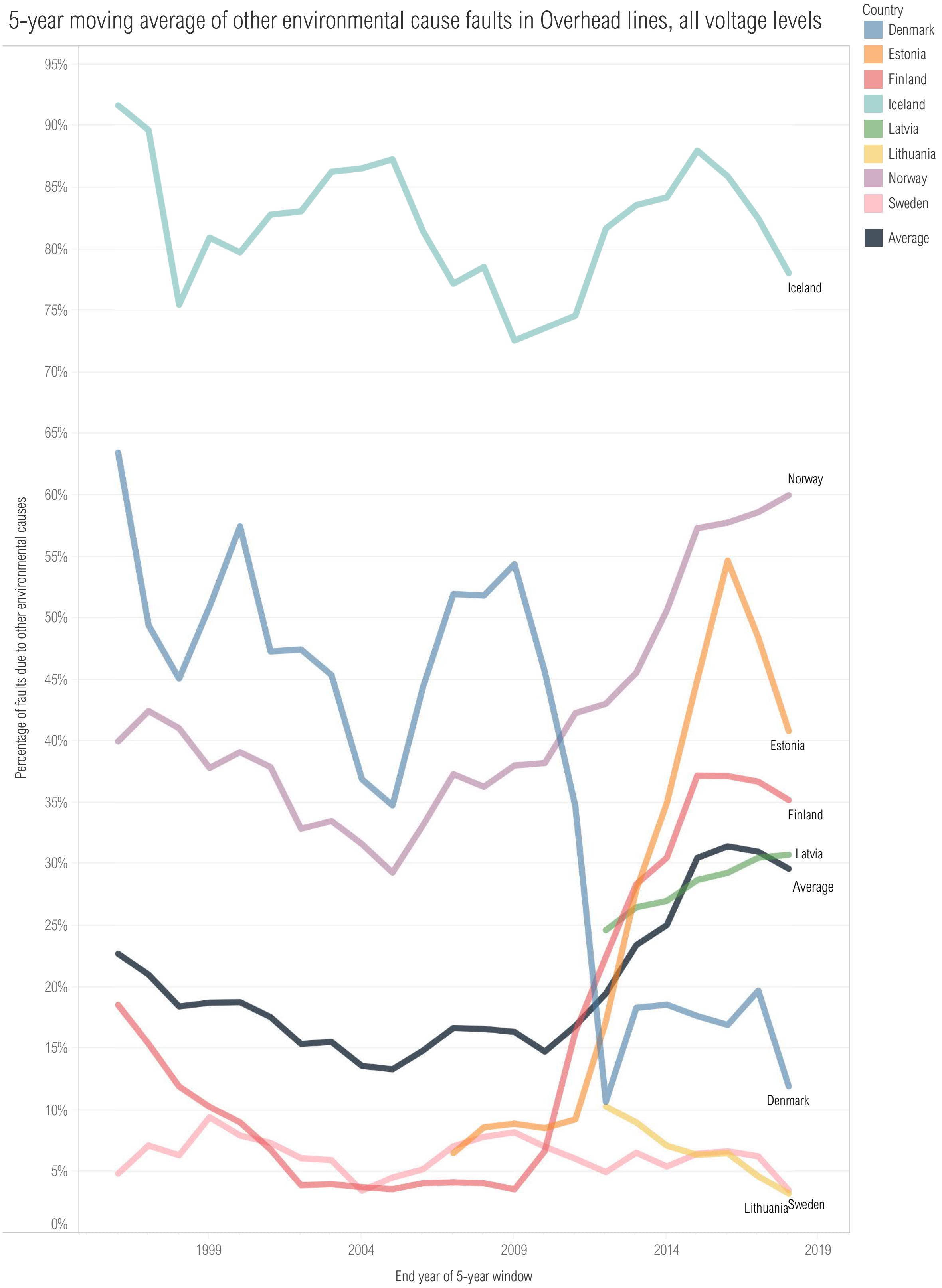

Figure E.2.2: Fault trends as 5-year rolling averages for overhead line operation and maintenance faults in each Nordic and Baltic country. Operation and maintenance faults are directly connected to changes in work procedures and grid investments. Furthermore, trend curves for operation and maintenance might be connected to the increase in digital technology inside the substations and to the amount of work orders being performed in the grids.

E.3 Annual number of units per HVAC component

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

Figure E.3.1 presents the length of installed cables in kilometres, with all voltage levels combined, in each Nordic and Baltic country. Figure E.3.2 presents the number of installed circuit breakers, with all voltage levels combined, in each Nordic and Baltic country. Figure E.3.3 presents the number of installed control equipment, with all voltage levels combined, in each Nordic and Baltic country. Figure E.3.4 presents the number of installed instrumental transformers, with all voltage levels combined, in each Nordic and Baltic country. Figure E.3.5 presents the length of installed overhead lines in kilometres, with all voltage levels combined, in each Nordic and Baltic country. Figure E.3.6 presents the number of installed power transformers, with all voltage levels combined, in each Nordic and Baltic country.

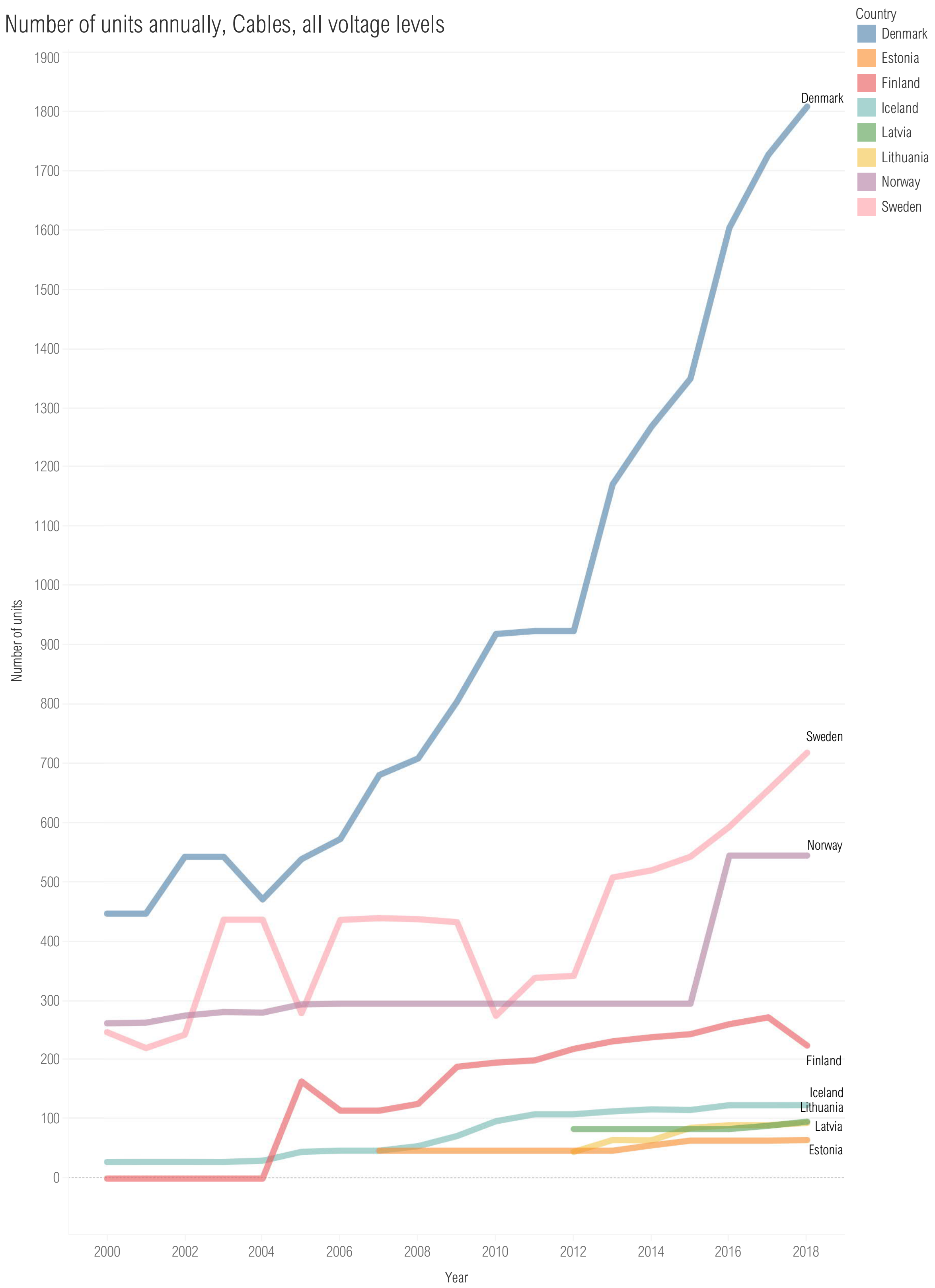

Figure E.3.1: Annual installed length of cables in kilometres, with all voltage levels combined, in each Nordic and Baltic country. Estonia has data since 2007 and Latvia and Lithuania have data since 2012.

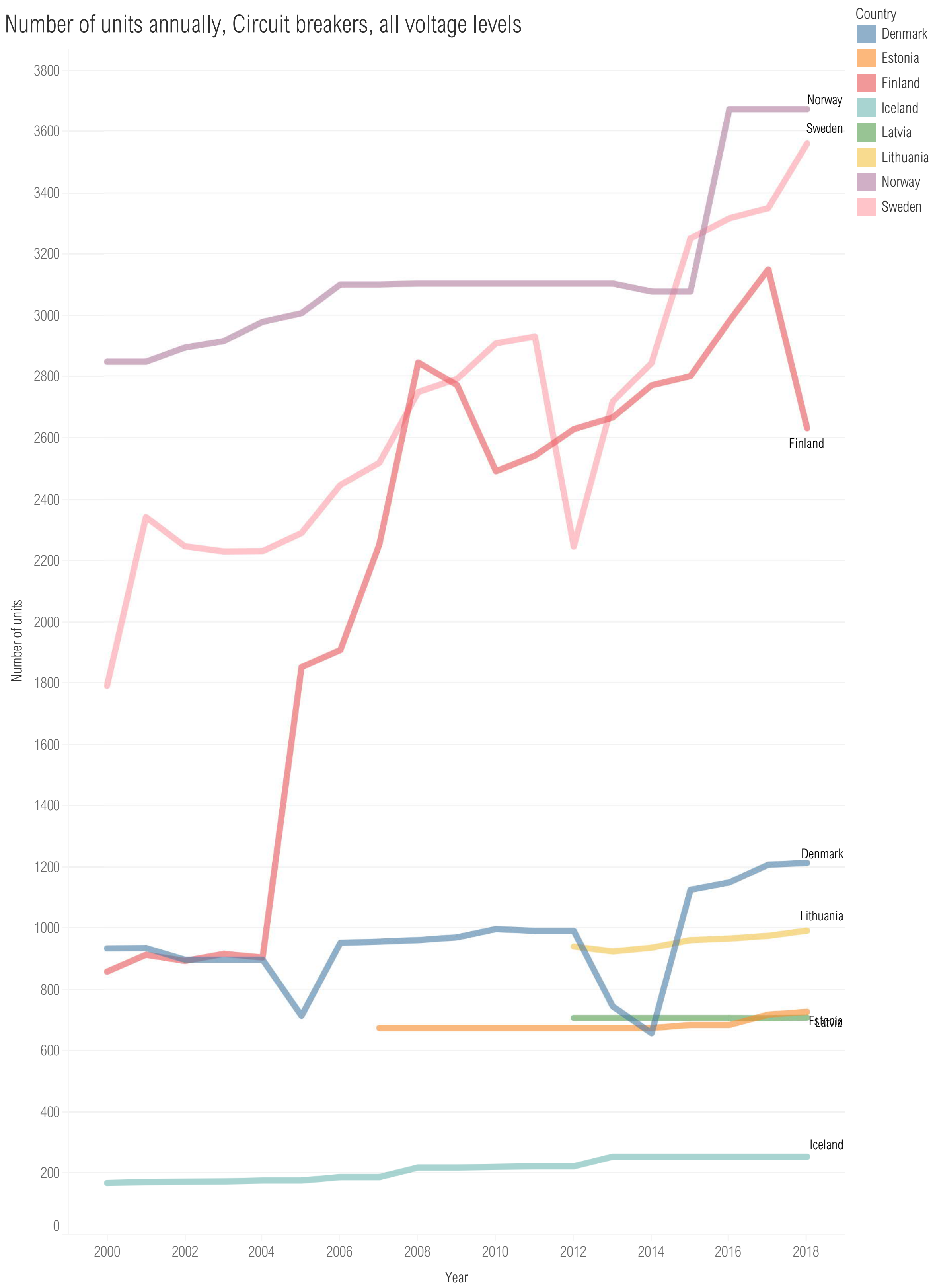

Figure E.3.2: Annual number of installed circuit breakers, with all voltage levels combined, in each Nordic and Baltic country. Estonia has data since 2007 and Latvia and Lithuania have data since 2012.

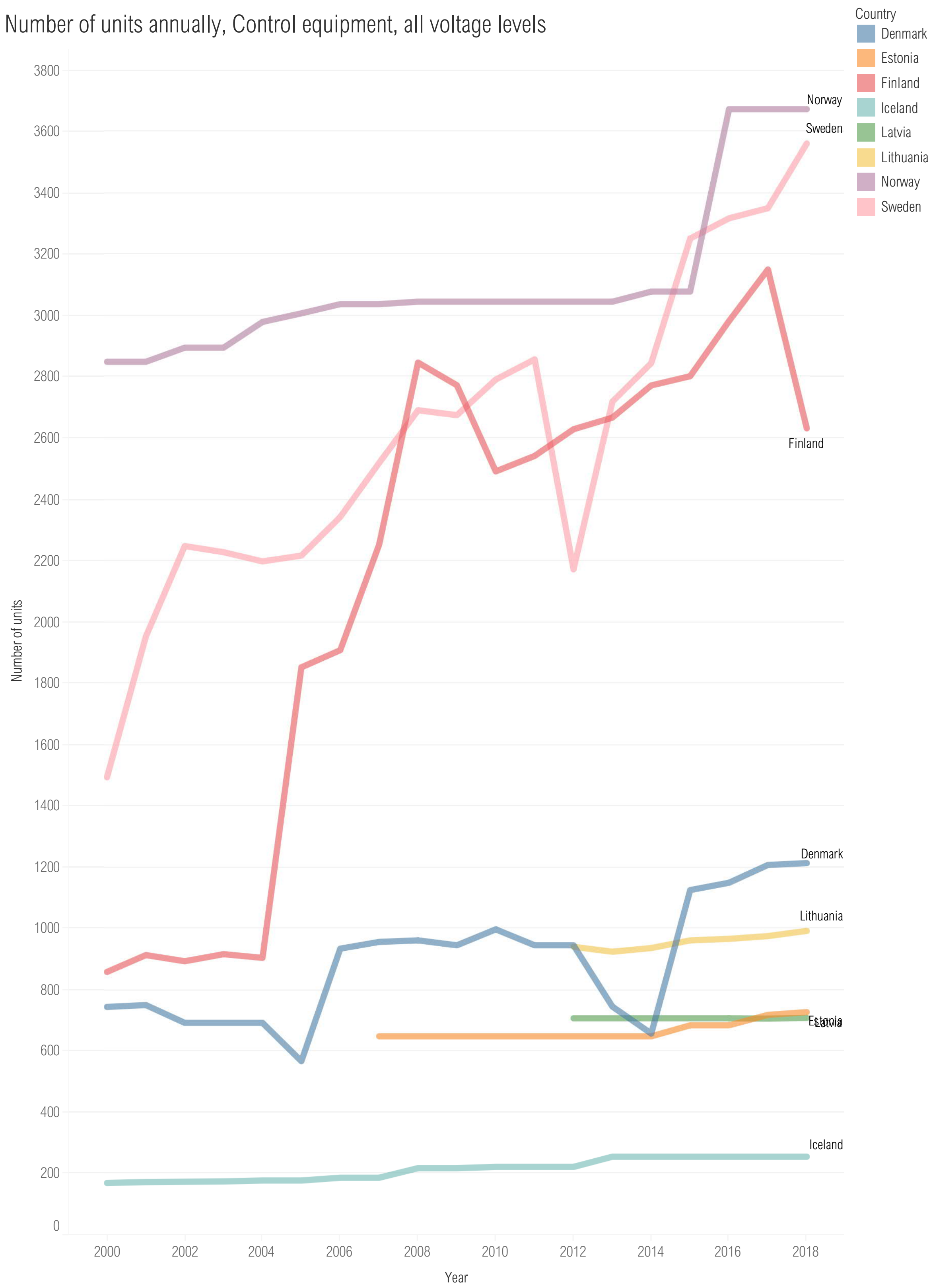

Figure E.3.3: Annual number of installed control equipment, with all voltage levels combined, in each Nordic and Baltic country. Estonia has data since 2007 and Latvia and Lithuania have data since 2012.

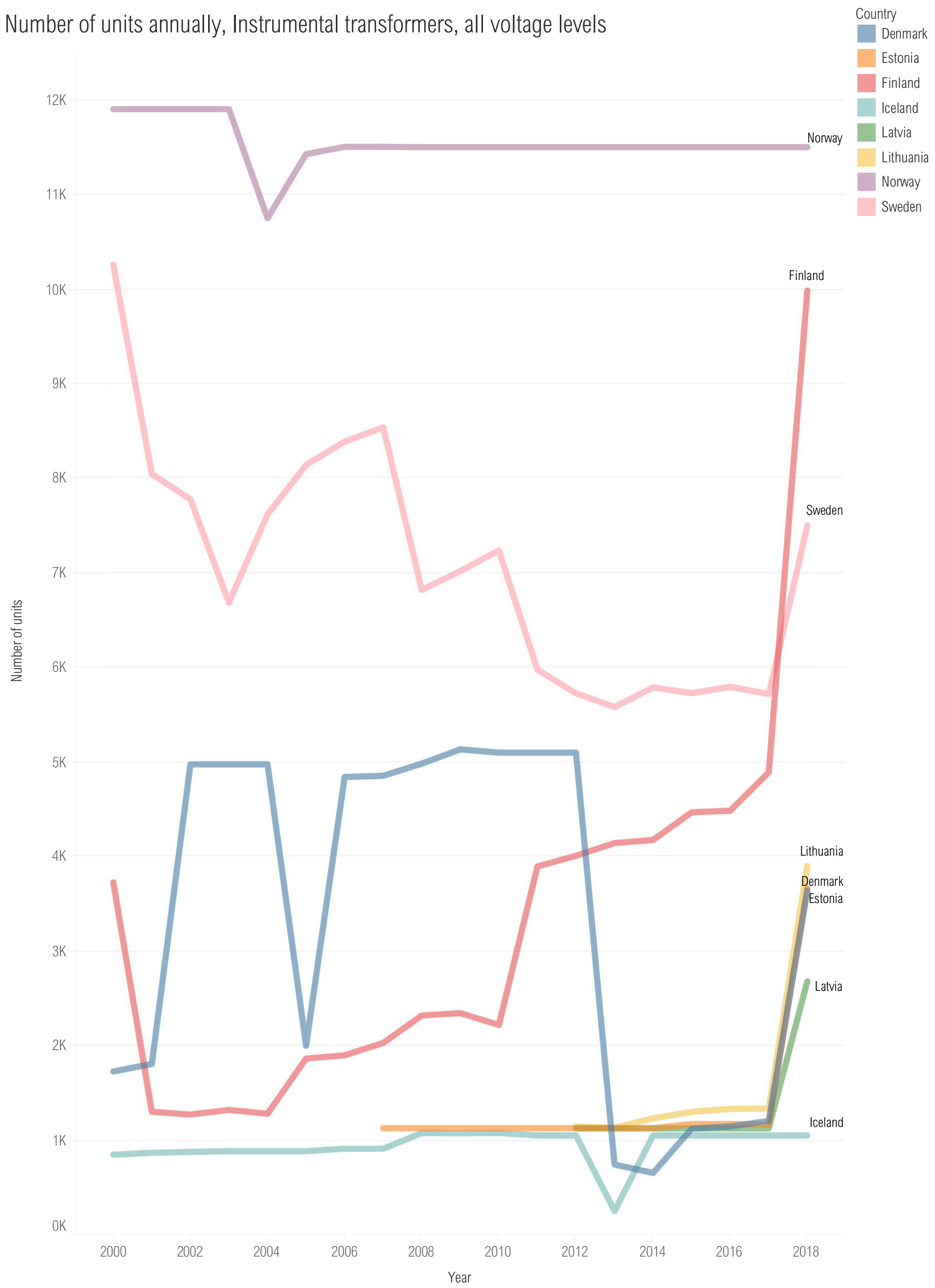

Figure E.3.4: Annual number of installed instrumental transformers, with all voltage levels combined, in each Nordic and Baltic country. Estonia has data since 2007 and Latvia and Lithuania have data since 2012.

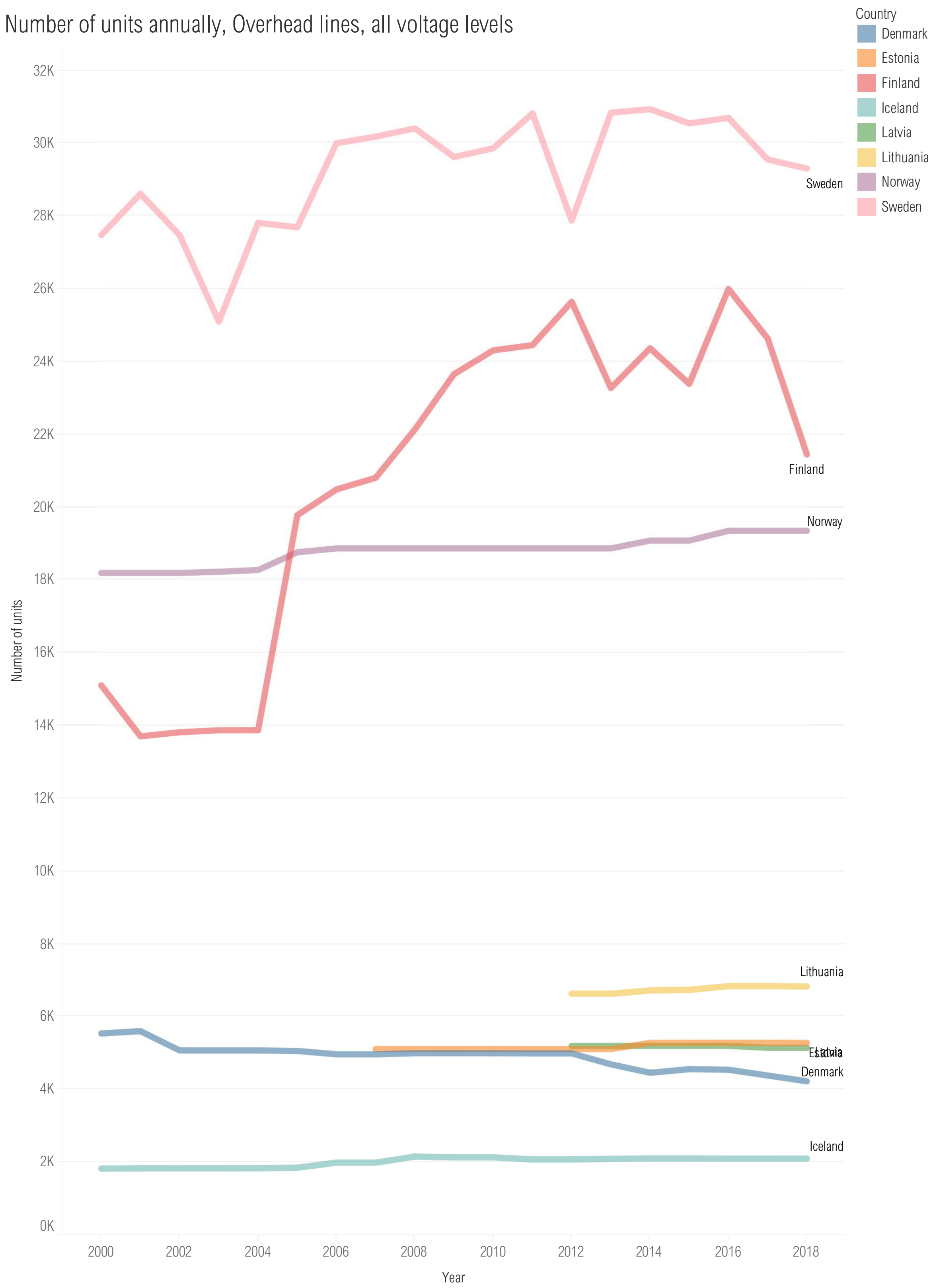

Figure E.3.5: Annual installed length of overhead lines in kilometres, with all voltage levels combined, in each Nordic and Baltic country. Estonia has data since 2007 and Latvia and Lithuania have data since 2012.

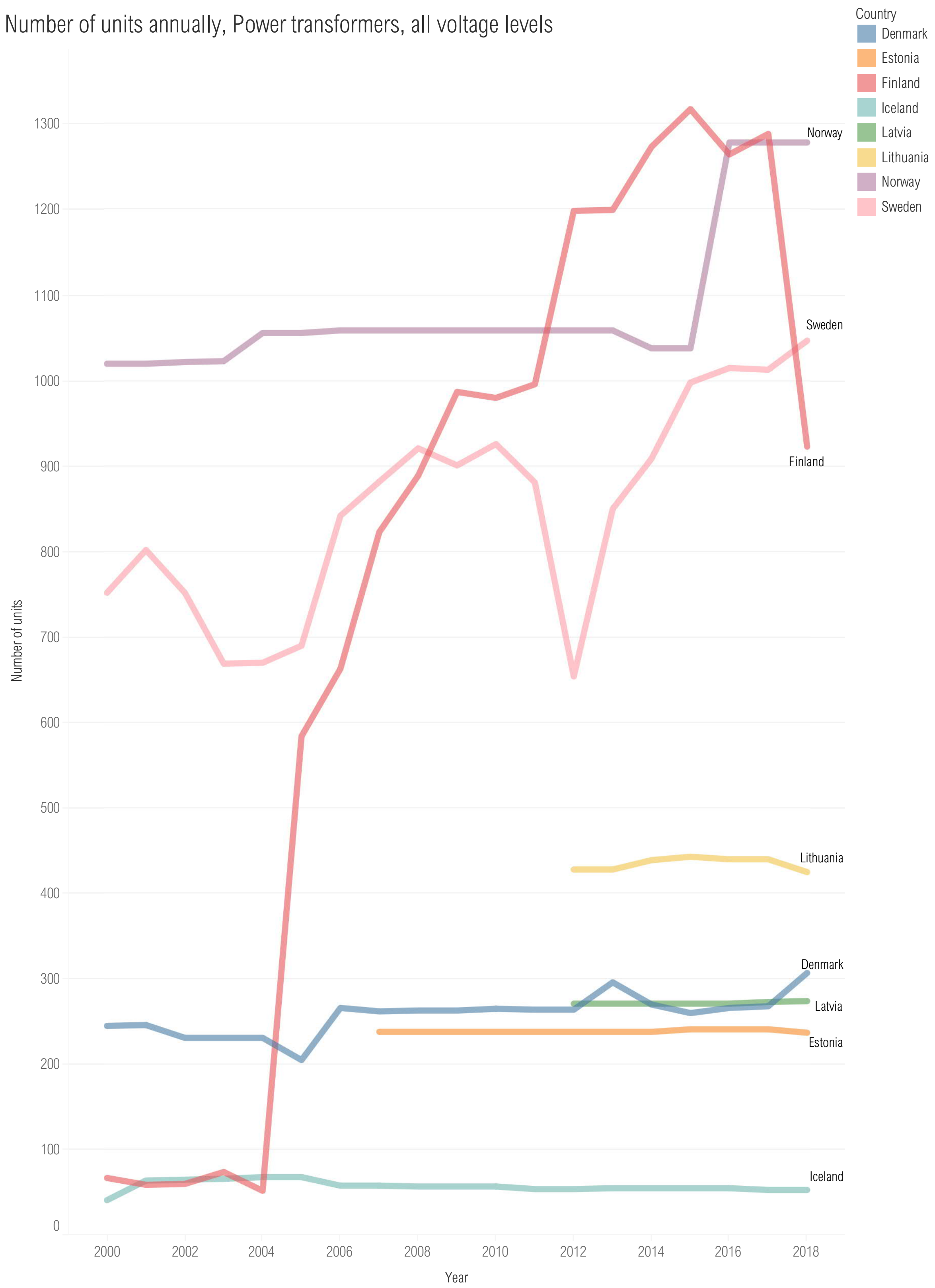

Figure E.3.6: Annual number of installed power transformers, with all voltage levels combined, in each Nordic and Baltic country. Estonia has data since 2007 and Latvia and Lithuania have data since 2012.

E.4 ENS compared to consumption and line length

Figure E.4.1 presents the annual amount of ENS compared against the total length of lines and consumption during 2009–2018 in the Nordic countries and Estonia and during 2012–2018 in Latvia and Lithuania. The total line length is the sum of the lengths of overhead lines and cables. All voltage level ranges have been included, that is 100–150 kV, 220–330 kV and 380–420 kV.

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

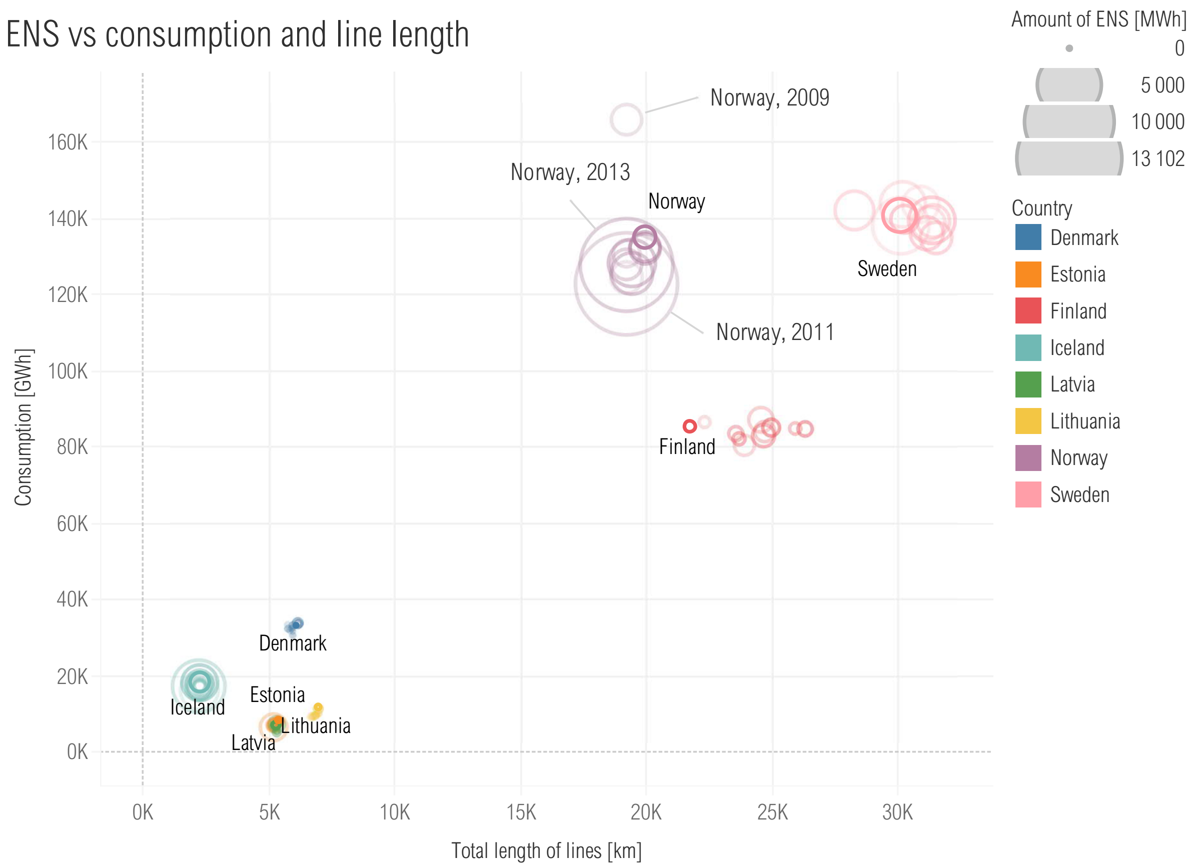

Figure E.4.1: The annual amount of ENS compared against the total length of lines (x-axis) and consumption (y-axis) during 2009–2018 in the Nordic countries and Estonia and during 2012–2018 in Latvia and Lithuania. The most recent statistical year 2018 is show with the darkest colour with each succeeding previous year show in a slightly lighter colour. The value of ENS is the total amount of ENS caused by all faults, that is, faults inside the statistical area and faults in adjacent grids that have caused ENS in the statistical area. This figure has the following remarks:

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