European Network of
Transmission System Operators
for Electricity

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ENTSO-E HVDC UTILISATION AND UNAVAILABILITY STATISTICS 2022

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From: DISTAC Subgroup under Regional Group Nordic

ENTSO-E HVDC Utilisation and Unavailability Statistics 2022

Report rendered 15 November 2023

ENTSO-E Mission Statement

Who we are

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

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

Our mission

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

Our vision

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

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

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

Our values

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

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

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

Our contributions

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

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

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

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

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

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

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

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

Executive Summary

The HVDC links are important components for a stable operation of the Nordic and Baltic power system while supporting the commercial power trade in the European energy markets. Furthermore, the HVDC links can provide other important functions like voltage and emergency power support to the HVAC grid. Hence, the advantages of keeping the HVDC links in operation as much as possible are indisputable. The ENTSO-E HVDC Utilisation and Unavailability Statistics 2022 report provides an overview of the Nordic and Baltic HVDC links as well as a detailed view of transmission, limitations, and outages of each individual link.

In 2022, 66.8 TWh of electric energy was transmitted through the Nordic and Baltic HVDC links, as seen in Figure 1. The total number of disturbance outages was 67, preventing 5.7 TWh of potential energy transmission, and 5 % of the total technical capacity (E_{max}).

Maintenance outages amounted to 2.2 TWh, (2 % of the total technical capacity) (E_{max}), and limitations reduced the transmission capacity by 3.3 TWh (3 % of the transmission capacity).

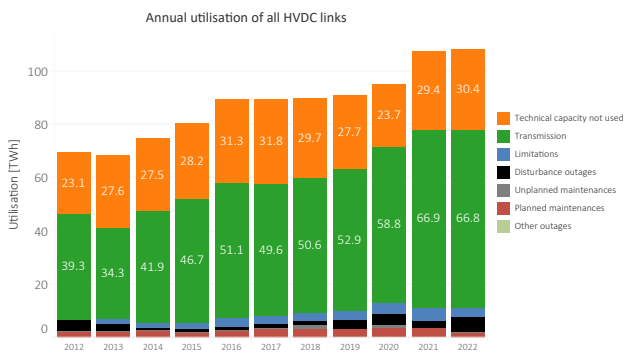

Figure 1: Annual utilisation of all HVDC links

The percentage of unavailable technical capacity (E_U) in 2022 was 10 % as shown in Figur 2. Disturbance outages had 5 % share in 2022 compared to 2 % in 2021. Limitations and planned maintenance dropped by one percentage point.

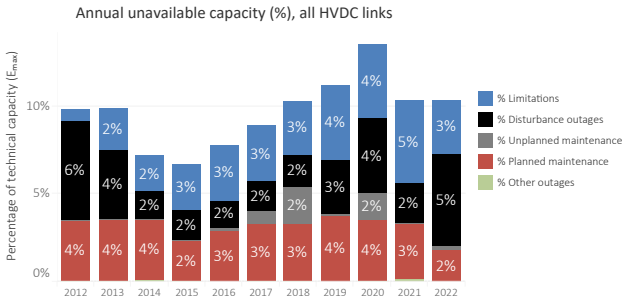

Figure 2: Annual unavailability (%), all HVDC links.

The most utilised market connections in 2022 were SE4-LT (80 %), FI-EE (78 %), SE4-PL (76 %) and FI-SE3 (72 %) as shown in Table 1. Five other market connections reached a utilisation rate of 60–70 % and four market connections were utilised between 50–60 % of the maximum technical capacity. Lowest utilisation had NO2–NL (35 %).

Table 1: The annual utilisation (%) of HVDC links per market connection.

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
DK1–NL								80%	51%	63%	65%
DK2–DE	70%	70%	73%	75%	67%	66%	53%	69%	47%	71%	65%
DK2–DK1	45%	54%	58%	70%	78%	64%	63%	58%	71%	57%	50%
FI–EE	59%	55%	41%	57%	42%	29%	37%	47%	75%	77%	78%
FI–SE3	54%	53%	76%	76%	78%	70%	72%	81%	85%	68%	72%
LT–PL					34%	47%	54%	61%	58%	55%	61%
NO2–DE										44%	58%
NO2–DK1	68%	61%	55%	54%	61%	54%	53%	46%	62%	67%	55%
NO2–NL	89%	72%	90%	94%	72%	83%	68%	61%	77%	63%	35%
NO2–UK											51%
RU–FI	34%	36%	25%	29%	46%	50%	67%	61%	23%	72%	
SE3–DK1	56%	40%	49%	49%	59%	52%	53%	50%	57%	49%	66%
SE4–DE	60%	32%	47%	31%	43%	46%	33%	36%	55%	48%	62%
SE4–LT					44%	51%	50%	63%	76%	60%	80%
SE4–PL	52%	34%	61%	67%	56%	62%	66%	62%	72%	69%	76%
Grand Total	57%	50%	56%	58%	57%	56%	57%	58%	62%	62%	62%

The HVDC links with most unavailable technical capacity due to outages and limitations were NorNed (49 %), Skagerrak 2 (40 %) and Skagerrak 3 (24 %). NorNed had a major cable fault on the Dutch side so the cable was out between May and October. Limitations are normal in Skagerrak 2 and 3 due to the careful operation of these links to maintain acceptable electrode current levels.

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1 Introduction and background

The ENTSO-E HVDC Utilisation and Unavailability Statistics 2022 presents the availability and utilisation of HVDC links connected to the Nordic and Baltic power system in 2022. This includes an overview of availability and utilisation for the HVDC links, information about disturbances and unavailability and individual presentations of the performance of each HVDC link. The report is made following the ENTSO-E Nordic and Baltic Guidelines for HVDC Statistics 2020 [1].

The first version of the HVDC statistics for utilisation and unavailability was published in 2011 as an addition to the Nordic Grid Disturbance and Fault Statistics 2010 [2]. At that time, the report covered only the Nordic power systems and presented 8 HVDC links. For the statistical year 2012, the HVAC Grid Disturbance Report and HVDC statistics were separated into two reports, which is the format of the reports today. In present time, this report includes 22 HVDC links connected to the Nordic and Baltic countries.

The trade of electricity between Russia and Finland ended on 14 May 2022 due to the geopolitical situation in Europe, as a result of Russia's invasion to Ukraine. The 400 kV connection between Finland and Russia is no longer available and the Vyborg link is not in the 2022 HVDC statistics.

1.1 Scope

The ENTSO-E HVDC Utilisation and Unavailability Statistics 2022 presents a macro view of the availability and utilisation of each HVDC link, including disturbance, maintenance and other outage events as well as limitations. Limitations originating from maintenance work done in the AC grid are also included if they affect the power transfer of an HVDC connection. Furthermore, disturbance outages are more thoroughly examined than other events.

The scope of the Report is different from the CIGRE performance survey data [3], which focuses mainly on outages, faults and disturbances of the HVDC systems. CIGRE statistics give more details about the condition and performance of the HVDC assets themselves, including forced and scheduled outages, thyristor and transistor failure rates, commutation failures, and so on. On the other hand, DISTAC HVDC statistics cover more divergent performance and availability data and partly going deeper into classification, consequences and outage reasons.

The HVDC WG of NordAM[1] and the DISTAC group have together developed the DISTAC HVDC outage and utilization data collection so that more detailed HVDC performance data analysis will be enabled in future. Together they also updated the HVDC performance data collection guidelines according to the new features.

1.2 Contact persons

Each country is represented by at least one contact person who is responsible for the statistical information of the corresponding country. The contact person can provide additional information concerning the HVDC availability and utilisation statistics. The relevant contact information is given in Appendix C.

[1]The five Nordic Transmission System Operators (TSOs) founded a Nordic Asset Management Forum (NordAM) in 2009 with the main goal to increase cooperation, jointly influence, build up knowledge, create networks as well as carry out agreed surveys and development tasks within the field of Asset Management. The HVDC working group was established after a very successful task force work done in 2017.

2 Methods and definitions

The statistics is made according to the ENTSO-E HVDC Guidelines [1]. To compare the utilisation and availability between HVDC links, different ways of using them must understood. This chapter explains the utilisation and availability categories used in the report. The categories are illustrated in Figure 2.1.

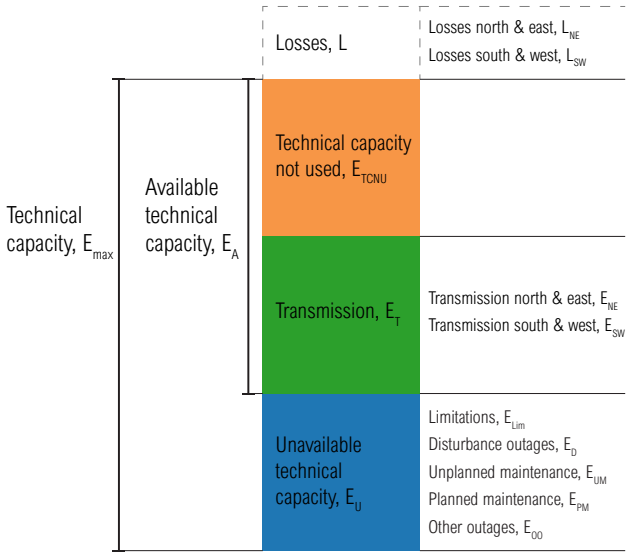

Figure 2.1: The hierarchy of the availability and utilisation categories used in the HVDC statistics.

The technical capacity (E_{max}) of an HVDC link is the maximum energy that can be physically received through the HVDC link to the converter station, excluding all HVDC link losses, during a year. The technical capacity is divided into two categories: *available technical capacity (E_A)* and *unavailable technical capacity (E_U)*.

The *available technical capacity (E_A)* is divided into technical capacity that has been *transmitted (E_T)* and into technical capacity that could have been transmitted/utilised that is, *technical capacity not used (E_{TCNU})*.

Transmitted energy (E_T) is the sum of transmitted energy in both directions of the HVDC link. Energy transferred to the north or east side of the HVDC link is called *transmission north and east (E_{NE})* (previously export), and energy transferred to the south or west side of the HVDC link is called *transmission south and west (E_{SW})* (previously import). It does not include *losses (L)* that is, the energy losses in any of the HVDC link components during transmission. It should be noted that these values are measurements and therefore considered factual.

Technical capacity not used (E_{TCNU}) is the residual energy after transmission, outages and limitations have been accounted for. The electricity market does not need the added transfer in most of these cases.

The *unavailable technical capacity (E_U)* is the part of the *technical capacity (E_{max})* that could not be utilised. It has five subcategories: *limitations (E_{Lim}), disturbance outages (E_D), unplanned maintenance (E_{UM}), planned maintenance (E_{PM})* and *other outages (E_{OO})*. An outage occurs when the HVDC link is fully disconnected from the system and the transfer capacity is reduced to zero. A limitation occurs when the capacity of the link has been reduced by between 0–100 %. Limitations and the outages are described in more detail below.

A *limitation (E_{Lim})* is a condition when the transmission capacity of an HVDC link is limited that is, the power transmission capacity of the link is less than the rated power. The limitation is always motivated from a technical perspective, but not always concerning the link itself. The most common causes of limitations are:

- faults on any HVDC link component that do not cause a total outage;
- faults, congestions or outages in the AC grid causing a limitation in the transmission capacity of the link;
- seasonal variations on the transmission capacity of the HVDC link.

Note that a limitation is counted for an hour only if there was transmission in the direction of the limitation and the sum of transmission and unavailable technical capacity is more than 90 % of the rated capacity. The reason to this is to only include limitations that have truly impacted the transmission of a HVDC link. Limitations that do not meet this requirement become *technical capacity not used (E_{TCNU})* instead.

Disturbance outages (E_D) are total outages due to a fault on the HVDC link or in the AC-grid causing a total outage of the link. A disturbance outage occurs when the protection trips the link or, in rare cases, disconnected manually. Manual disconnection is usually categorised as unplanned maintenance.

Unplanned maintenance outages (E_{UM}) occurs when the link is manually disconnected for emergency or urgent repair. In general, unplanned maintenance are outages that cannot wait until the next scheduled maintenance.

Planned maintenance outages (E_{PM}) are total outages due to all technically motivated actions on the HVDC link or in the AC grid intended to retain an entity in, or restore it to, a state where it can perform its required function.

Other outages (E_{OO}) are outages due to any other reason except those mentioned above. This could be, for example, black start or other tests or when the markets do not need the transmission capacity of the link and the link is disconnected.

3 Technical details of the HVDC links

Table 3.1 presents the main properties of the HVDC links while Table 3.2 presents the technical properties of the HVDC lines.

Schematic presentations of the HVDC links and their converter stations, both for line-commutated converters (LCC) and voltage-source converters (VSC) are presented in Appendix A.

Table 3.1: Main properties of the HVDC links.

Link	Commissioning year	Market connection	HVDC converter type	Rated power, monopolar (MW)	Parallel monopolar capacity (MW)	Bipolar capacity
Baltic Cable	1994	Yes	LCC	600		
COBRAcable	2019	Yes	VSC	700		
EstLink 1	2006	Yes	VSC	350	1000	
EstLink 2	2014	Yes	LCC	650		
Fenno-Skan 1	1989	Yes	LCC	400	1200	1200
Fenno-Skan 2	2011	Yes	LCC	800		
Kontek	1995	Yes	LCC	600		
Konti-Skan 1[1]	2008	Yes	LCC	357.5		715
Konti-Skan 2[1]	1988	Yes	LCC	357.5		
LitPol Link	2015	Yes	LCC	500		
NordBalt	2016	Yes	VSC	700		
NordLink 1	2020	Yes	VSC	700	1400	1400
NordLink 2	2020	Yes	VSC	700		
NorNed	2008	Yes	LCC	700		
North Sea Link 1	2022	Yes	VSC	700	1400	1400
North Sea Link 2	2022	Yes	VSC	700		
Skagerrak 1	1977	Yes	LCC	236	1000	1000
Skagerrak 2	1977	Yes	LCC	236		
Skagerrak 3	1993	Yes	LCC	478		
Skagerrak 4	2014	Yes	VSC	682		
Storebaelt	2010	Yes	LCC	600		
SwePol	2000	Yes	LCC	600		

[1] Konti-Skan bipole can export 740 MW and the import capacity is 715 MW. This counts in both directions since the reference-point is now on the importing side.

Table 3.2: Technical details of the HVDC links

Link	Physical length (km)	Length of mass cable (km)	Length of PEX cable (km)	Length of DC overhead line (km)	Length of DC back-to-back connection (km)
Baltic Cable	262	250		12	
COBRAcable	325	325	650 (2×325)	0	
EstLink 1	105		210 (2×105)		
EstLink 2	171	157		14	
Fenno-Skan 1	233	200		33	
Fenno-Skan 2	299	196		103	
Kontek	160		160		
Konti-Skan 1	150	89		61	
Konti-Skan 2	150	89		61	
LitPol Link	< 1				< 1
NordBalt	450		2×450		
NordLink 1	623			53	
NordLink 2	623			53	
NorNed	580	580			
North Sea Link 1	720	720			
North Sea Link 2	720	720			
Skagerrak 1	212.5	133.6		78.5	
Skagerrak 2	211.4	132.9		78.5	
Skagerrak 3	212.9	134.4		78.5	
Skagerrak 4	226	226			
Storebaelt	57	57			
SwePol	254	254			

4 Results

This chapter presents the utilisation and unavailability of all the HVDC links as well as individual presentations of each HVDC link connected to the Nordic and Baltic power system.

Section 4.1 provides an overview for each HVDC links in 2022 and Section 4.2 provides an overview of all links' summary for the years 2012–2022. Section 4.3 presents an overview of all market connections for 2012–2022. Section 4.4 presents the availability and utilisation of each HVDC link for the year 2022 as well as an annual overview of the utilisation and a trend of the utilisation and the number of outages for the years 2012–2022.

4.1 Overview for each HVDC link in 2022

Figure 4.1 presents the utilisation and unavailability (%) of each HVDC link in 2022. It should be noted that the usages of the links show big variations. Most links are market dependent, some are mostly used in one direction, and some are used for technical reasons to control power flow for system stability according to agreements. Sorted views of Figure 4.1 are shown in Appendix D.

In 2022, 66.8 TWh of electric energy was transmitted through the Nordic and Baltic HVDC links, as seen in Figure 1. The total number of disturbance outages was 67, preventing 5.7 TWh of potential energy transmission, and 5 % of the total technical capacity (E_{max}).

Maintenance outages amounted to 2.2 TWh, (2 % of the total technical capacity) (E_{max}), and limitations reduced the transmission capacity by 3.3 TWh (3 % of the transmission capacity).

Figure 4.2 presents the percentage unavailable technical capacity (E_U) of the annual technical capacity (E_{max}) due to the disturbance outages. Figure 4.3 presents the number of all disturbance, maintenance and other outages. The explanations for the most notable unavailability in 2022 are listed below. Further details are presented in Section 4.4.

Review of notable unavailable technical capacity 2022

The HVDC links with most unavailable technical capacity due to outages and limitations were NorNed (49 %), Skagerrak 2 (40 %), Skagerrak 3 (24 %), North Sea Link 1 (21 %) and Konti-Skan 2 (19 %). NorNed had a major cable fault on the Dutch side so the cable was out between May and October. Limitations are normal in Skagerrak 2 and 3 due to the careful operation of these links to maintain acceptable electrode current levels. North Sea Link 1 had two longer disturbance outages. During the second outage, the annual maintenance was done on both poles. Konti-Skan 2 suffered one major disturbance due to incident on the cable. The fault was caused by an anchor in the water.

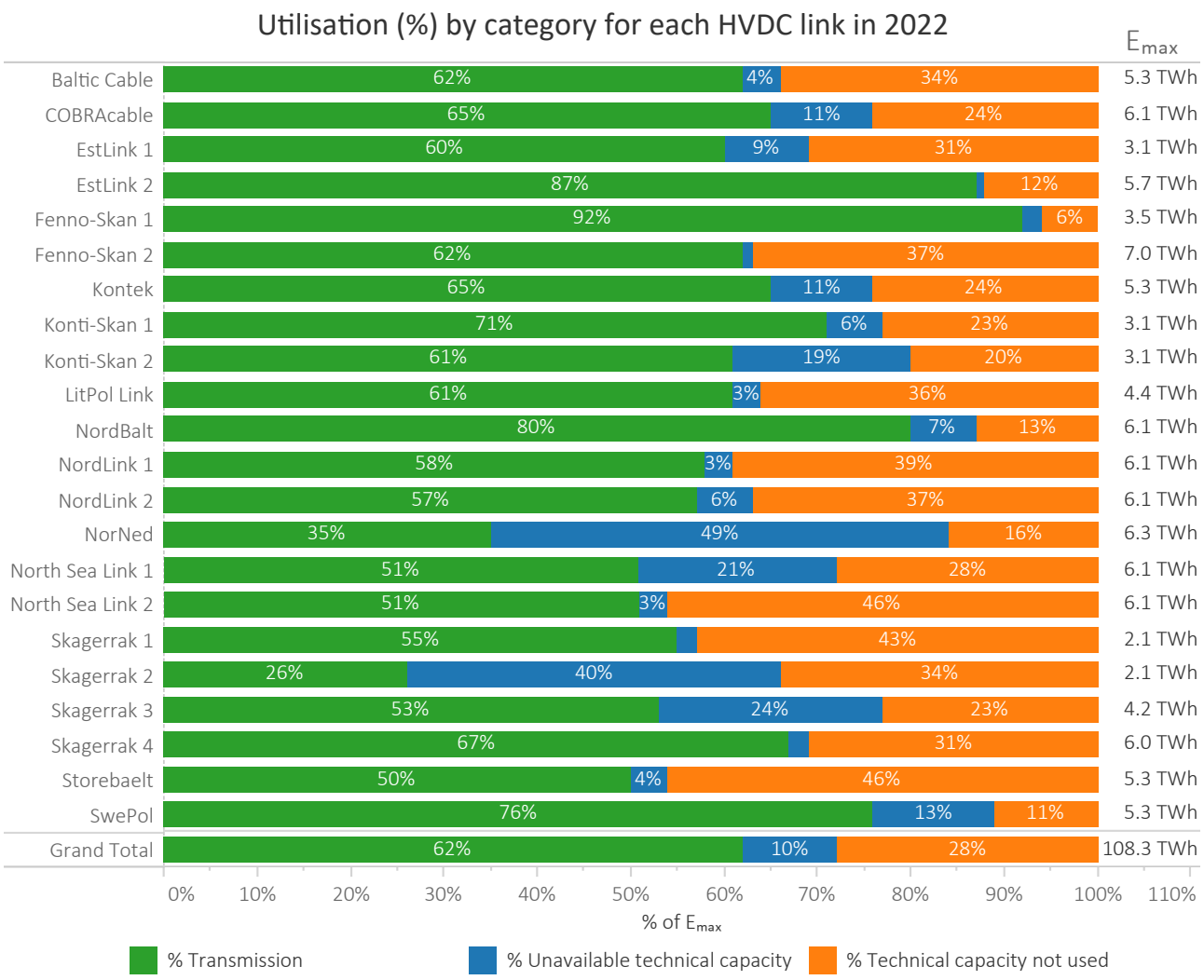

Figure 4.1: Utilisation (%) by category for each HVDC link in 2022. The unavailable technical capacity (E_U) is the amount of technical capacity (E_{max}) not available due to limitations or outages. Transmission (E_T) is the amount of technical capacity (E_{max}) transmitted through the HVDC link. Technical capacity not used (E_{TCNU}) is the amount of energy that has not been transmitted or been unavailable due to limitations or outages.

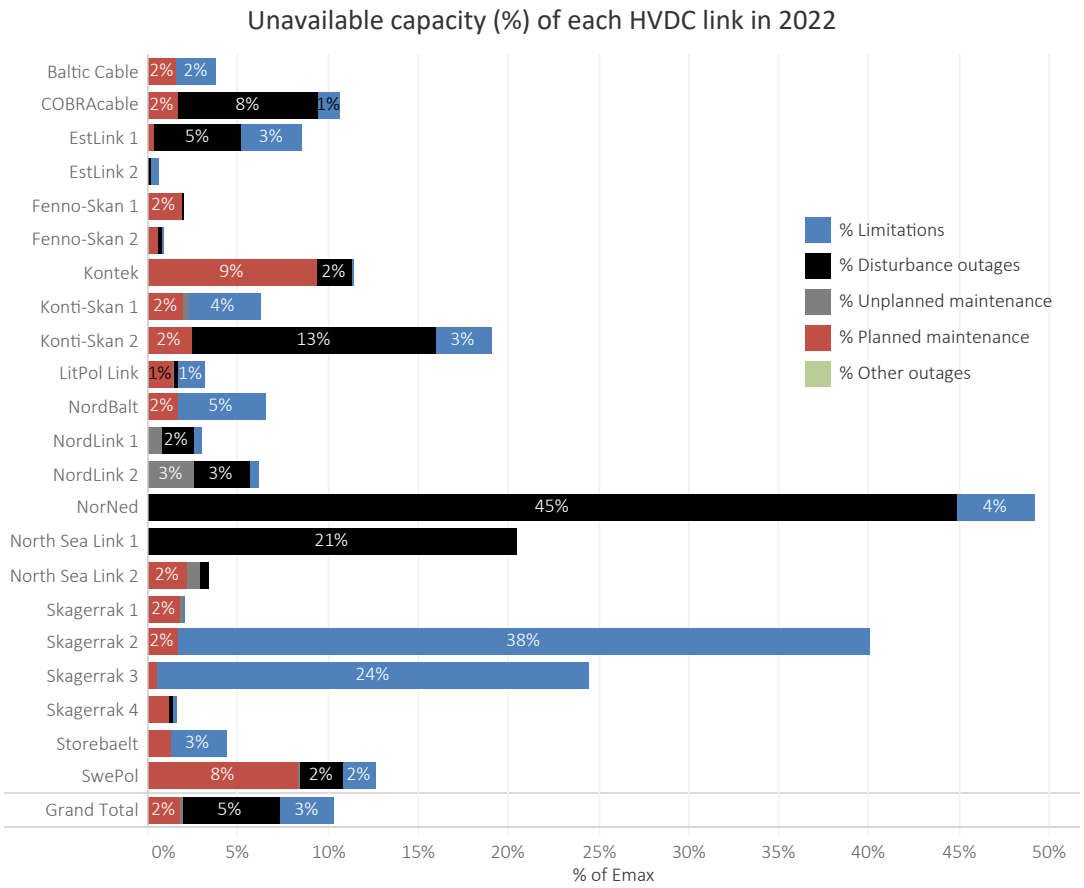

Figure 4.2: Unavailable technical capacity (%) for each HVDC link in 2022. The used unavailability categories are limitations, disturbance outages, unplanned and planned maintenances and other outages.

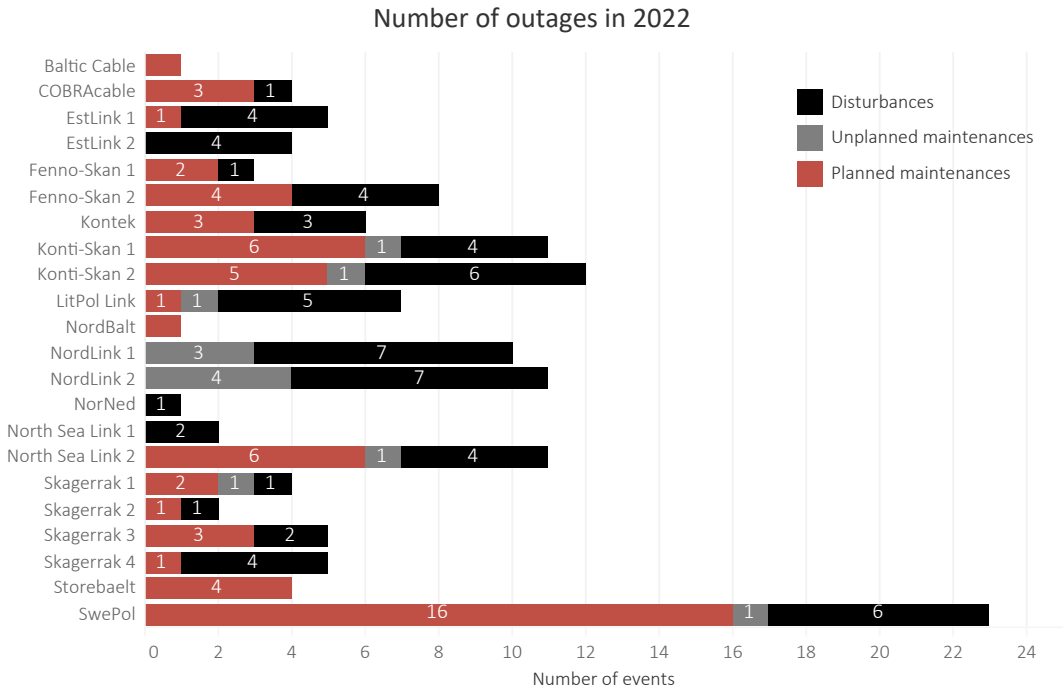

Figure 4.3: The number of disturbance outages, unplanned maintenance and planned maintenance outages and other outages for each link in 2022.

4.2 HVDC links: An overview of 2012–2022.

Figure 4.4 presents the annual utilisation (%) of all HVDC links and Figure 4.5 presents the annual utilisation with all utilisation categories.

The percentage of unavailable technical capacity (E_U) in 2022 was on the normal 10-year average 10 % level. The percentage of transmission (E_T) was high compared to 10 -year average.

Figure 4.5 shows annual utilisation of all HVDC links in MWhs. More HVDC capacity has been commissioned during the last years. Figure 4.6 presents the annual utilisation rate grouped by utilisation percentage for all HVDC links. Figure 4.7 presents the annual unavailable technical capacity (%) by unavailability category. Figure 4.8 presents the annual unavailability hours (%) of the HVDC links.

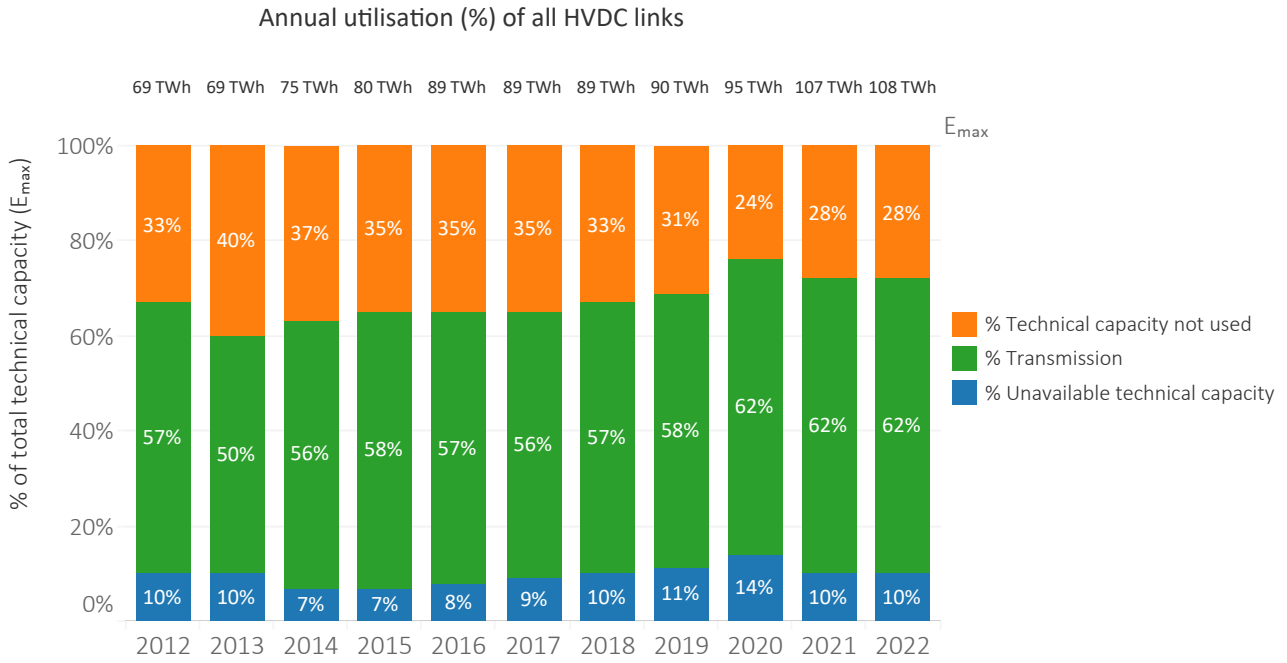

Figure 4.4: The annual utilisation percentage of all HVDC links since 2012. The unavailable technical capacity (E_U) is the amount of technical capacity (E_{max}) not available due to limitations or outages. Transmission (E_T) is the amount of technical capacity (E_{max}) transmitted through the HVDC links. Technical capacity not used (E_{TCNU}) is the residual energy that has neither been transmitted nor been unavailable due to limitations or outages.

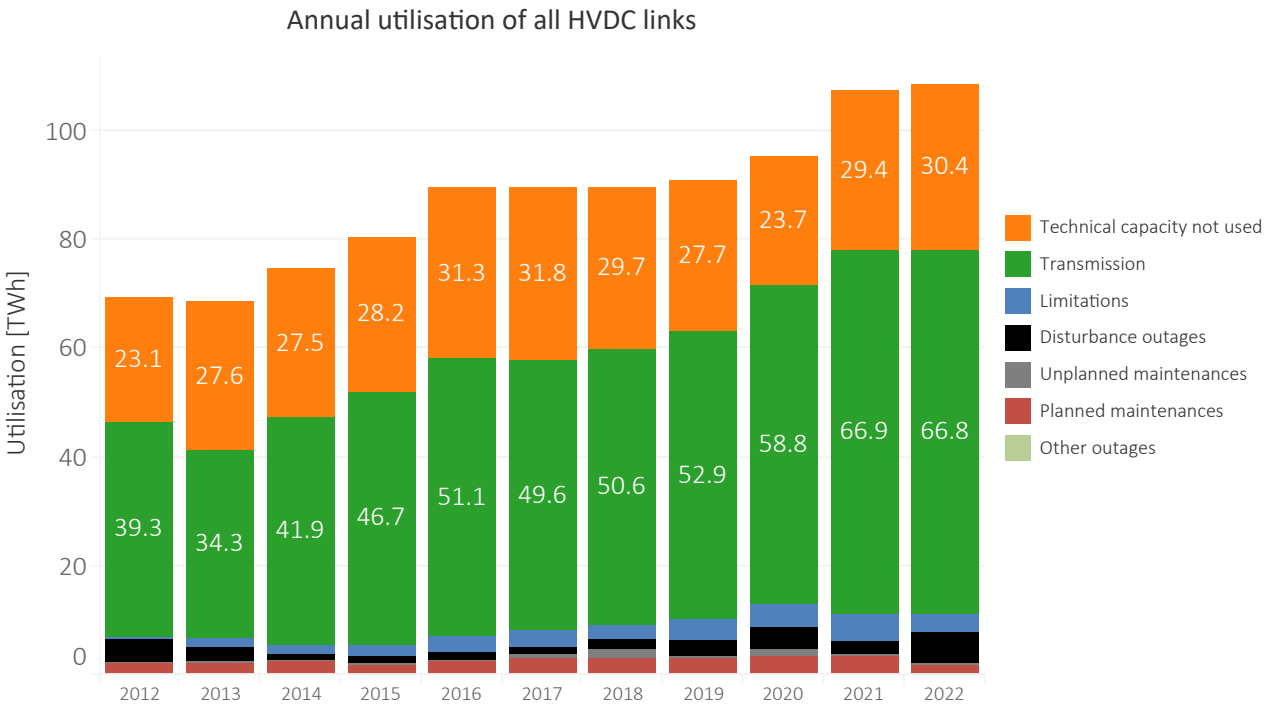

Figure 4.5: Annual utilisation (MWh) of all HVDC links. Transmission (E_T) is the amount of technical capacity (E_{max}) transmitted through the HVDC links. Limitations, disturbance outages, unplanned and planned maintenance outages and other outages form together the unavailable technical capacity (E_U). Technical capacity not used (E_{TCNU}) is the residual energy that has neither been transmitted nor been unavailable due to limitations or outages. The larger capacity increases in some years is due to new links being introduced to the report. The maximum technical capacity (E_{max}) is marginally higher on leap years due to one extra day of operation.

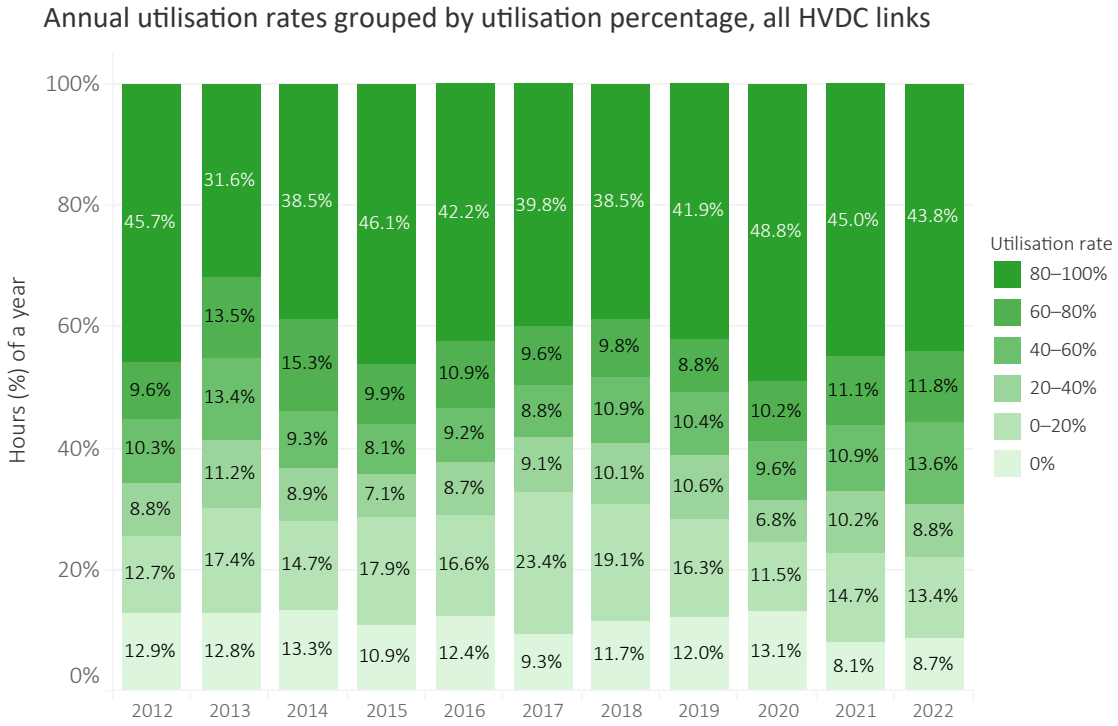

Figure 4.6: Annual utilisation rate grouped by utilisation percentage for all HVDC links. The HVDC links were utilised by more than 80 % of their respective maximum technical capacity 43.8 % of the time in 2022.

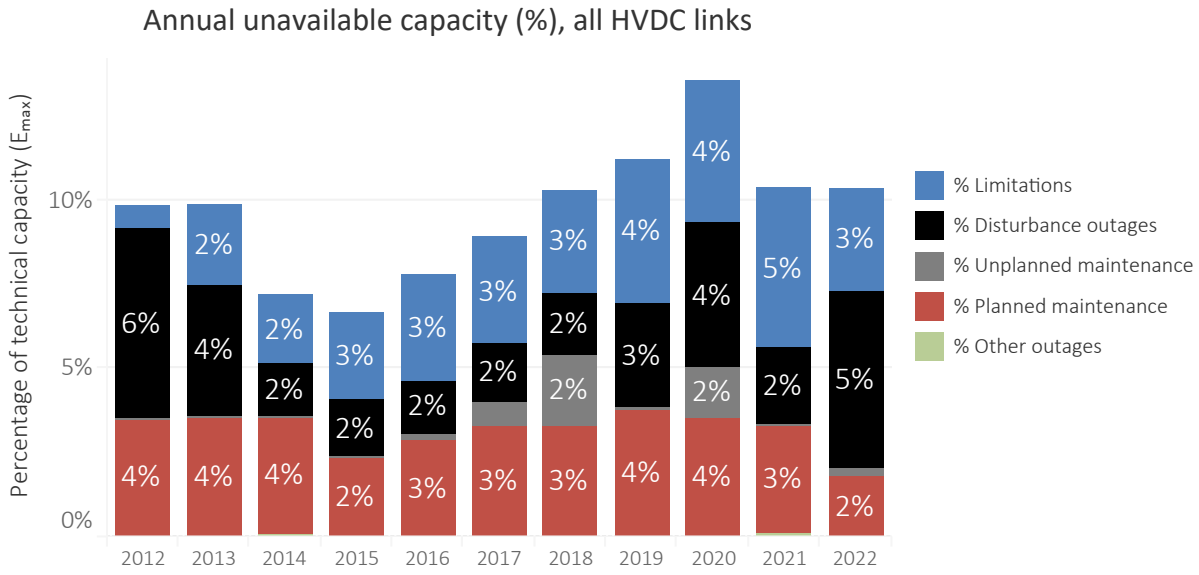

Figure 4.7: Unavailable technical capacity (%) by unavailability category for all HVDC links combined. The unavailability categories are limitations, disturbance outages, unplanned and planned maintenances and other outages.

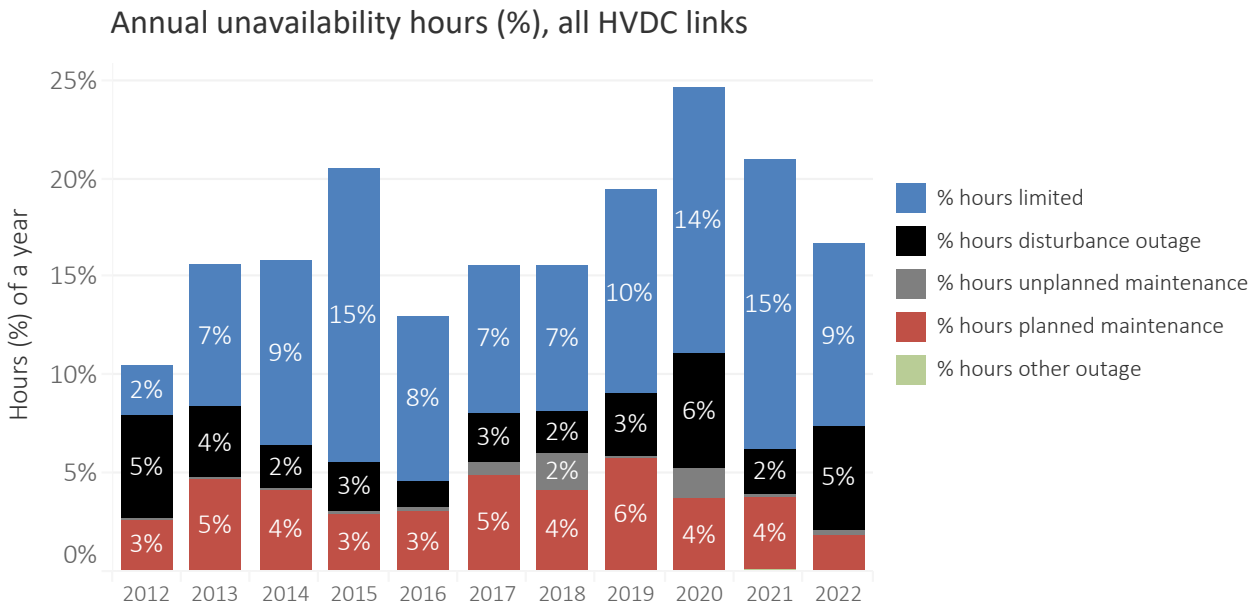

Figure 4.8: Annual unavailability hours (%) by unavailability category. The categories are limitation, unplanned or planned maintenance or a disturbance or other outage. The percentage is calculated by counting the number of hours with a limitation or outage and dividing it by the total number of hours in a year. It should be noted that any single hour can be affected by both an outage and a limitation. A higher value in the percentage of hours may indicate that the corresponding type of event has not fully disconnected the affected HVDC link from the system. A lower value may instead indicate that the corresponding event type has affected an HVDC link with a high rated capacity.

4.3 Markets connection: An overview of 2012–2022.

Figure 4.9 shows utilisation (%) by category for each market connection in 2022. The most utilised market connections in 2022 were SE4-LT (80 %), FI-EE (78 %), SE4-PL (76 %) and FI-SE3 (72 %) as shown in Table 1. Five other market connections reached a utilisation rate of 60–70 % and four market connections were utilised between 50–60 % of the maximum technical capacity. Lowest utilisation had NO2–NL (35 %). Annual utilisation (%), annual unavailability (%) and annual technical capacity not used (%) are presented in Table 4.1, Table 4.2, and Table 4.3 for different market connections.

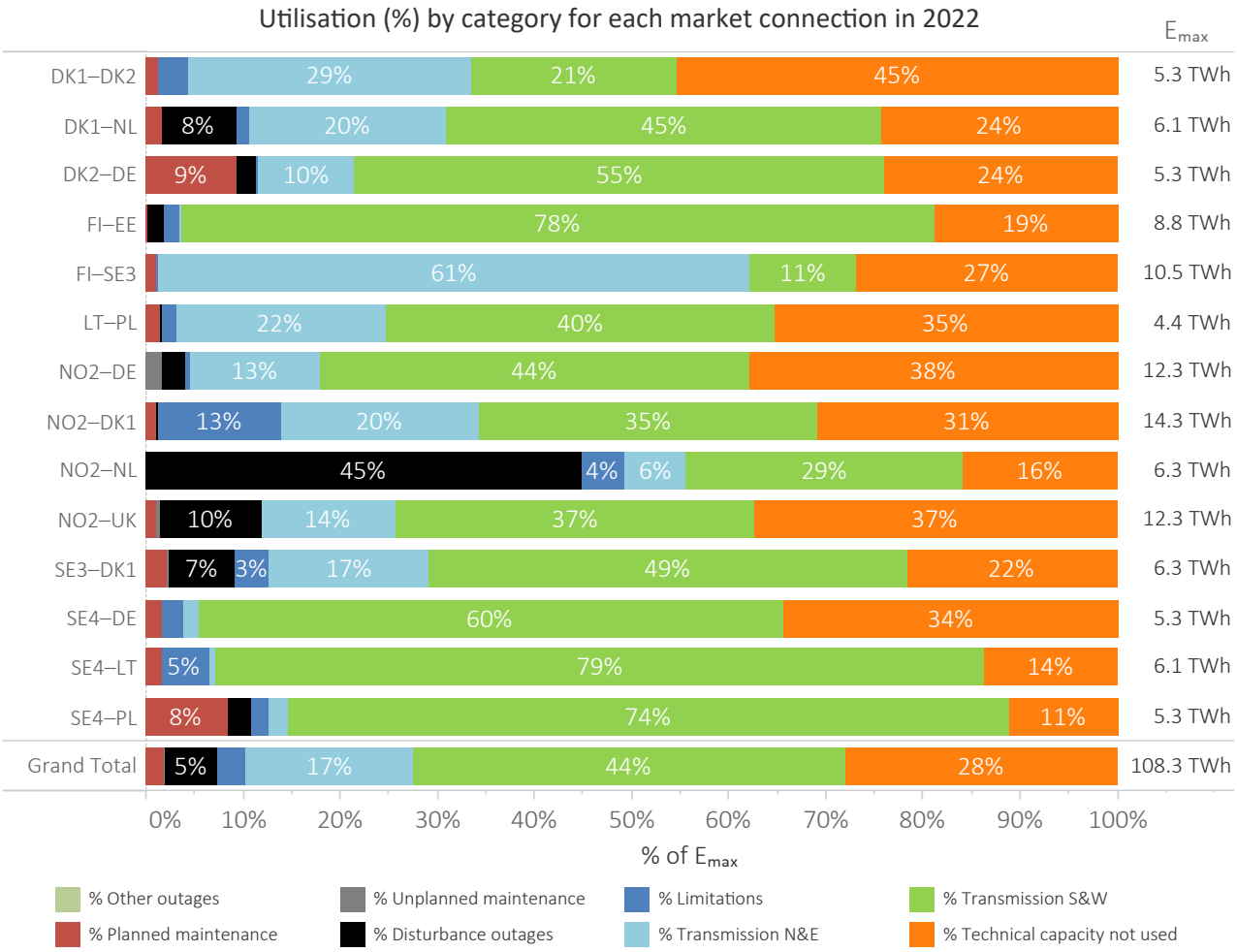

Figure 4.9: Utilisation (%) by category for each market connection in 2022.

Table 4.1: Presents the annual utilisation (%) of HVDC links per market connection.

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
DK1–NL								79.7%	50.6%	63.0%	65.1%
DK2–DE	70.0%	70.1%	73.2%	74.8%	66.8%	66.3%	53.3%	68.6%	47.4%	71.4%	64.6%
DK2–DK1	44.9%	54.4%	58.3%	70.1%	78.0%	63.7%	63.4%	58.3%	70.7%	57.2%	50.2%
FI–EE	58.6%	54.9%	40.7%	56.8%	42.3%	29.2%	37.0%	46.6%	75.3%	76.9%	77.7%
FI–SE3	53.8%	52.5%	76.2%	75.8%	77.7%	70.2%	71.8%	81.2%	84.6%	68.0%	71.9%
LT–PL					33.5%	46.7%	53.5%	61.5%	58.4%	54.8%	61.5%
NO2–DE										44.0%	57.5%
NO2–DK1	67.5%	60.7%	54.5%	54.0%	60.6%	54.1%	52.7%	46.2%	62.3%	67.0%	55.2%
NO2–NL	89.4%	71.6%	90.5%	93.9%	72.5%	82.8%	68.3%	61.3%	76.7%	62.7%	35.0%
NO2–UK											50.8%
RU–FI	33.8%	35.6%	25.4%	29.1%	45.8%	49.8%	66.7%	61.5%	23.1%	71.7%	
SE3–DK1	55.9%	40.5%	49.3%	48.7%	58.8%	51.8%	52.7%	50.1%	57.3%	49.0%	65.8%
SE4–DE	59.5%	32.1%	47.5%	30.5%	43.3%	45.6%	33.2%	36.0%	54.9%	47.9%	61.8%
SE4–LT					43.6%	51.5%	50.5%	62.9%	76.2%	60.4%	79.9%
SE4–PL	52.3%	33.9%	60.9%	67.2%	55.8%	62.3%	66.1%	62.1%	72.1%	69.3%	76.3%
Grand Total	56.8%	49.9%	56.1%	58.2%	57.2%	55.5%	56.5%	58.3%	61.6%	62.3%	61.6%

Table 4.2: Presents the annual unavailability (%) of HVDC links per market connection.

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
DK1–NL								5.1%	29.3%	10.8%	10.6%
DK2–DE	5.8%	3.9%	3.5%	5.2%	10.4%	14.3%	25.9%	3.8%	30.0%	5.0%	11.5%
DK2–DK1	2.9%	9.9%	4.6%	2.4%	2.8%	1.6%	2.2%	2.5%	0.3%	1.4%	4.4%
FI–EE	2.6%	5.0%	14.7%	5.8%	3.6%	0.6%	3.6%	2.2%	2.7%	1.5%	3.4%
FI–SE3	27.3%	17.2%	5.4%	9.5%	1.5%	1.2%	1.1%	4.7%	0.9%	13.1%	1.3%
LT–PL					14.0%	10.1%	6.1%	3.6%	8.6%	13.4%	3.2%
NO2–DE										9.8%	4.5%
NO2–DK1	2.4%	7.9%	10.5%	6.5%	4.8%	18.0%	12.7%	27.0%	23.6%	8.2%	13.9%
NO2–NL	3.4%	19.3%	4.5%	4.2%	8.1%	8.4%	13.8%	13.5%	16.9%	27.1%	49.2%
NO2–UK											11.9%
RU–FI	9.8%	1.3%	0.4%	0.0%	1.5%	2.3%	5.2%	5.4%	11.5%	8.1%	
SE3–DK1	4.7%	10.7%	16.1%	16.7%	5.5%	6.7%	4.3%	15.8%	16.7%	27.7%	12.7%
SE4–DE	22.1%	18.1%	6.6%	12.5%	20.4%	27.1%	36.3%	26.2%	18.7%	9.8%	3.8%
SE4–LT					25.7%	16.5%	22.0%	7.6%	5.5%	5.8%	6.5%
SE4–PL	0.2%	3.3%	7.1%	7.3%	15.3%	5.9%	4.2%	14.0%	12.8%	8.9%	12.6%
Grand Total	9.8%	9.9%	7.2%	6.7%	7.8%	8.9%	10.3%	11.2%	13.5%	10.4%	10.4%

Table 4.3: Presents the annual technical capacity not used (%) of HVDC links per market connection.

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
DK1–NL								15.2%	20.1%	26.3%	24.3%
DK2–DE	24.3%	26.1%	23.3%	20.1%	22.8%	19.4%	20.7%	27.7%	22.6%	23.6%	23.9%
DK2–DK1	52.1%	35.6%	37.1%	27.5%	19.3%	34.7%	34.5%	39.2%	29.1%	41.3%	45.4%
FI–EE	38.8%	40.0%	44.7%	37.3%	54.1%	70.2%	59.3%	51.2%	22.0%	21.6%	18.8%
FI–SE3	18.9%	30.3%	18.4%	14.8%	20.7%	28.6%	27.1%	14.1%	14.6%	18.8%	26.8%
LT–PL					52.5%	43.2%	40.3%	34.9%	33.0%	31.8%	35.4%
NO2–DE										46.2%	37.9%
NO2–DK1	30.1%	31.4%	34.9%	39.5%	34.6%	27.9%	34.6%	26.8%	14.2%	24.7%	30.8%
NO2–NL	7.2%	9.1%	5.0%	1.9%	19.4%	8.8%	17.9%	25.2%	6.4%	10.2%	15.8%
NO2–UK											37.3%
RU–FI	56.5%	63.1%	74.2%	70.9%	52.7%	47.9%	28.2%	33.1%	65.3%	20.3%	
SE3–DK1	39.3%	48.8%	34.6%	34.6%	35.8%	41.4%	43.0%	34.1%	26.0%	23.3%	21.5%
SE4–DE	18.4%	49.8%	45.9%	57.0%	36.3%	27.4%	30.6%	37.8%	26.4%	42.3%	34.4%
SE4–LT					30.7%	32.1%	27.6%	29.4%	18.3%	33.8%	13.6%
SE4–PL	47.5%	62.8%	32.0%	25.5%	28.9%	31.8%	29.7%	23.9%	15.1%	21.8%	11.0%
Grand Total	33.4%	40.2%	36.8%	35.1%	35.0%	35.5%	33.2%	30.5%	24.9%	27.3%	28.0%

4.4 Individual presentations of each HVDC link

This section presents the performance of each HVDC link. Figure 4.10 presents the geographical location of each HVDC link. The categories used in the following presentations of each separate HVDC link are presented and defined in Chapter 2.

Note that the sums in the tables for each link may show a technical capacity E_{max} higher than the E_{max} stated in the diagram. This is due to power flows that may momentarily be higher than rated technical capacity of the links. Other times, when power flow is below the rated technical capacity (and there is no limitation reported), the difference is registered in the category “technical capacity not used”.

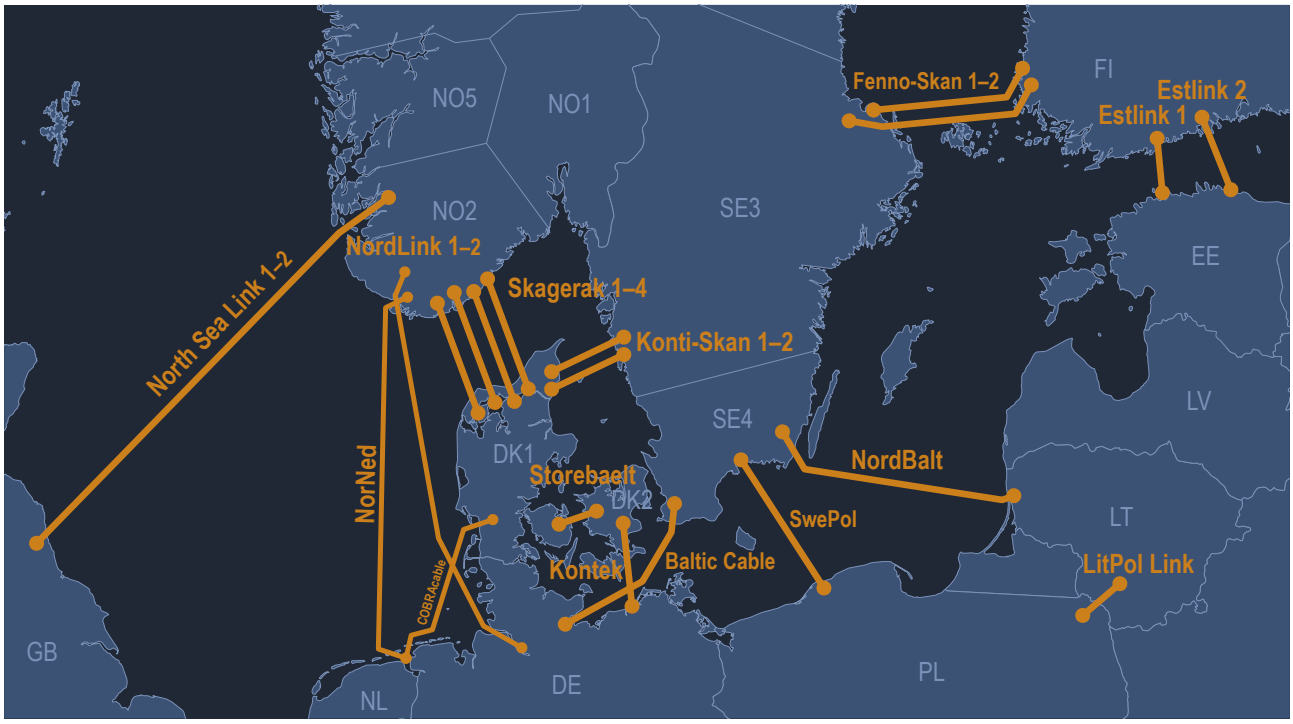

Figure 4.10: A map of the bidding zones and the 22 HVDC links included in this report.

4.4.1 Baltic Cable

Figure 4.11 presents the availability and utilisation of Baltic Cable for 2022 and Table 4.4 presents the numerical values behind it. Baltic Cable is connected between southern Sweden (bidding zone SE4) and Germany (bidding zone DE-TenneT). The operations started in 1994 and the transmission capacity is 600 MW.

In 2022, there was a single outage for the annual maintenance of Baltic Cable, which spanned a duration of 6 days in October. During the rest of the year, the technical available capacity of the link remained consistent and comparable to the levels observed last year, hovering around 98 %.

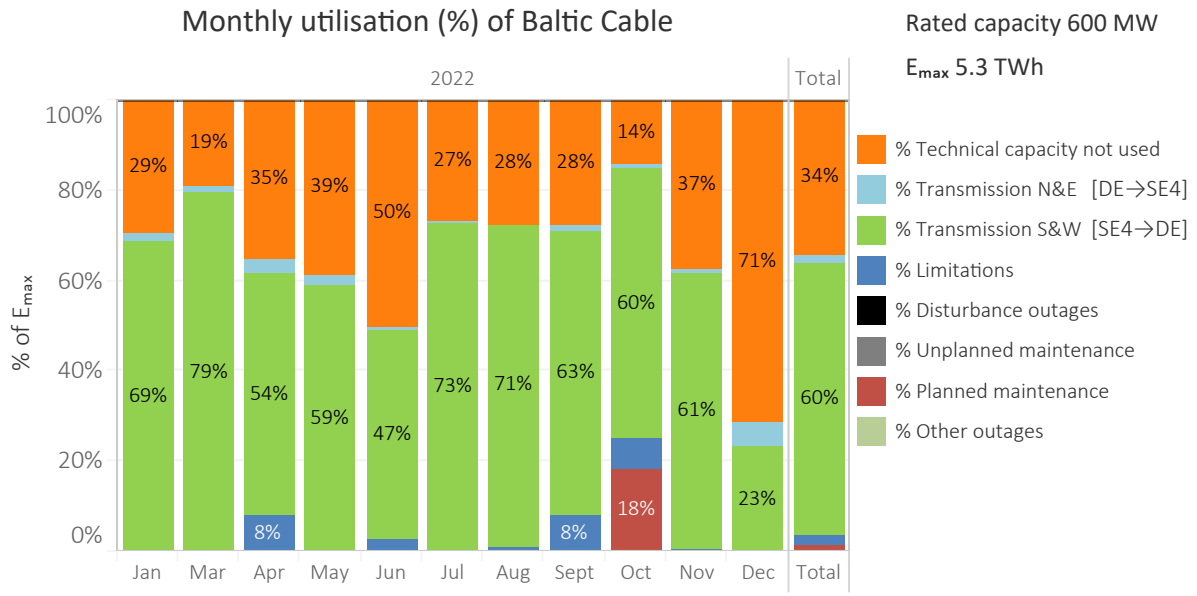

Figure 4.11: Monthly percentage allocation of utilisation by category for Baltic Cable in 2022.

Table 4.4: Monthly allocation of technical capacity (E_{max}) for The Baltic Cable in 2022. Note that losses are not included in the technical capacity (E_{max}), as is shown in Figure 2.1.

Monthly utilisation of Baltic Cable (South & West direction SE4→DE)

	Jan	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	% total
Technical capacity not used, GWh	329.6	33.0	151.6	172.8	217.4	118.9	124.2	119.6	63.4	161.9	318.0	1810.4	34.4%
Transmission N&E, GWh	22.7	2.7	13.5	10.2	2.5	0.5	-	6.1	5.1	4.2	25.1	92.5	1.8%
Transmission S&W, GWh	770.4	137.2	233.0	263.5	201.0	327.0	317.8	270.9	267.5	263.7	103.3	3155.2	60.0%
Limitations, GWh	-	-	34.0	-	11.2	-	4.4	35.7	29.0	2.3	-	116.6	2.2%
Disturbance outages, GWh	-	-	-	-	-	-	-	-	-	-	-	-	
Unplanned maintenance., GWh	-	-	-	-	-	-	-	-	-	-	-	-	-
Planned maintenance, GWh	-	-	-	-	-	-	-	-	82.1	-	-	82.1	1.6%
Other outages, GWh	-	-	-	-	-	-	-	-	-	-	-	-	-
Total, GWh	1122.7	172.8	432.1	446.4	432.0	446.5	446.4	432.2	447.1	432.1	446.4	5256.8	100.0%
Losses SW, GWh	20.8	3.4	6.5	7.1	5.2	7.5	8.0	7.3	7.4	7.2	6.0	86.5	1.6%
Losses NE, GWh	0.5	-	0.3	0.2	0.1	-	-	0.2	0.1	0.1	0.5	2.0	0.0%

Figure 4.12 presents the annual utilisation of Baltic Cable per utilisation and unavailability category for the years 2012–2022.

Figure 4.13 presents the percentage of hours of a year Baltic Cable has been affected by either a limitation, a disturbance outage, an unplanned or planned maintenance outage or other outage annually during the years 2012–2022. Figure 4.14 presents the annual number of disturbance outages, unplanned and planned maintenances and other outages during the years 2012–2022.

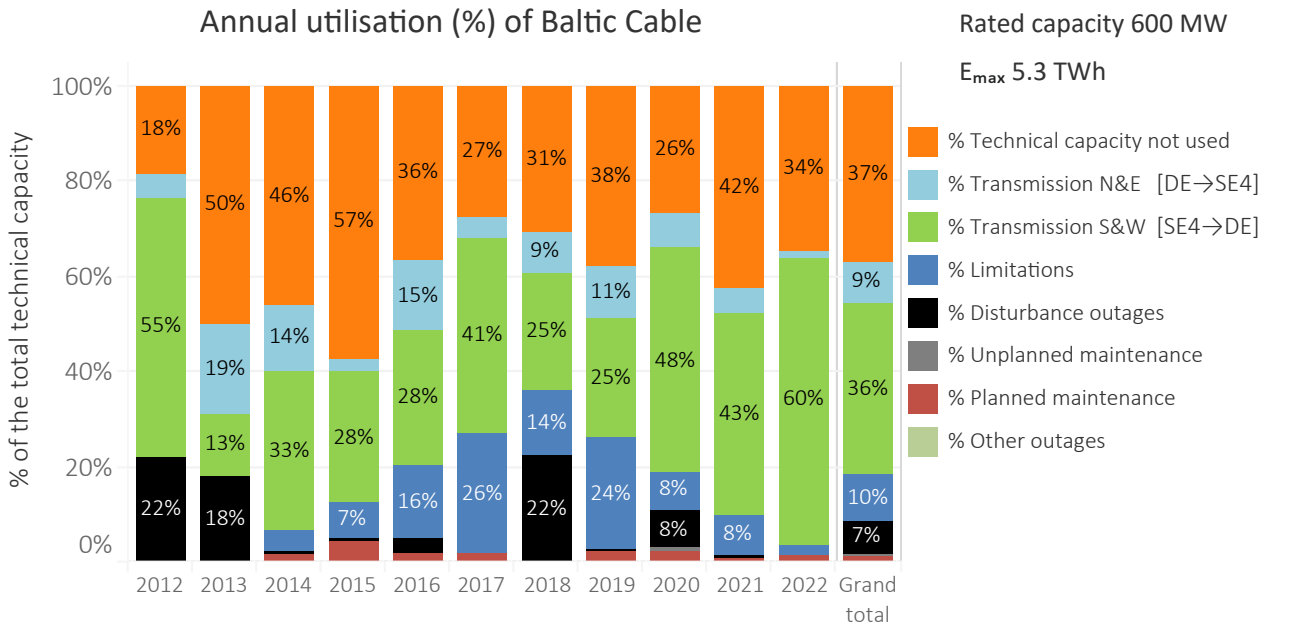

Figure 4.12: Annual utilisation of Baltic Cable per the utilisation and unavailability categories for the years 2012–2022.

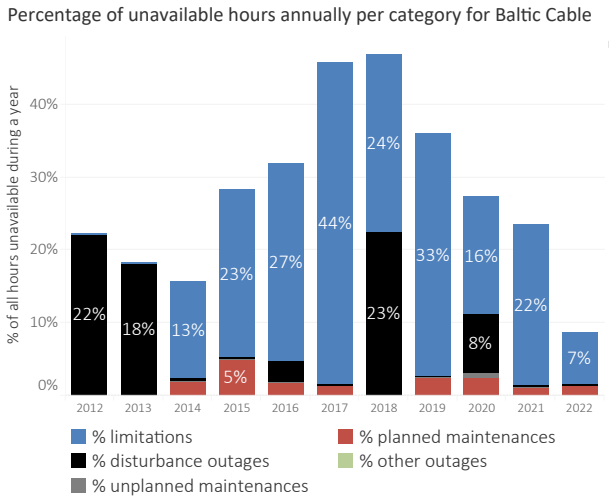

Figure 4.13: Percentage of hours Baltic Cable has been affected by either a limitation or an outage annually since 2012. The percentage is calculated by counting the number of hours with a limitation or outage and dividing it by the total number of hours in a year. It should be noted that any single hour can be affected by both an outage and a limitation.

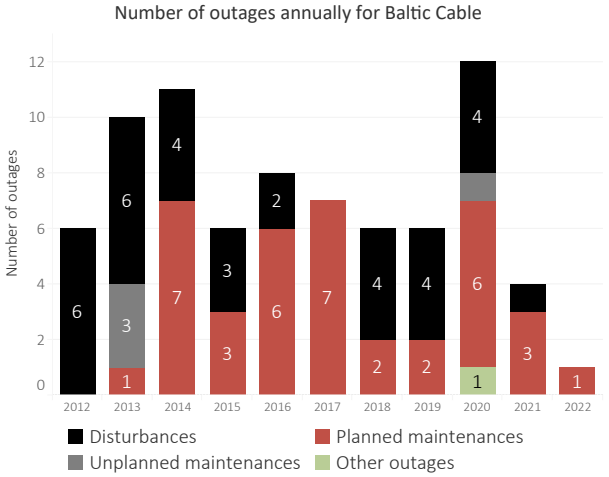

Figure 4.14: The annual number of disturbances, unplanned and planned maintenance outages and other outages for Baltic Cable for the years 2012–2022. Baltic cable has not had any other outages during the years 2012–2022.

4.4.2 COBRAcable

Figure 4.15 presents the availability and utilisation of COBRAcable for 2022 and Table 4.5 presents the numerical values behind it. COBRAcable has been in operation since 2019. In Denmark (bidding zone DK1) it is connected to Endrup substation and in Netherlands to Eemshaven (bidding zone APX NL). COBRAcable was commissioned 5 November and has a transmission capacity of 700 MW.

In 2022, COBRAcable had an available technical capacity of 89 %. The technical capacity not used was 24 %. Totally, 2.7 TWh (45 % of the technical capacity) was transmitted south to the Netherlands (DK1→APX NL) and 1.3 TWh (20 % of the technical capacity) was transmitted north to Denmark (APX NL→DK1).

COBRAcable annual maintenance lasted 5 days in November. Furthermore there were two minor maintenance outages in 2022. One were a repair of a leak in the cooling system and the other were warranty maintenance in both stations. There were one major disturbances outage lasting 29 days, which was caused by a cable joint failure.

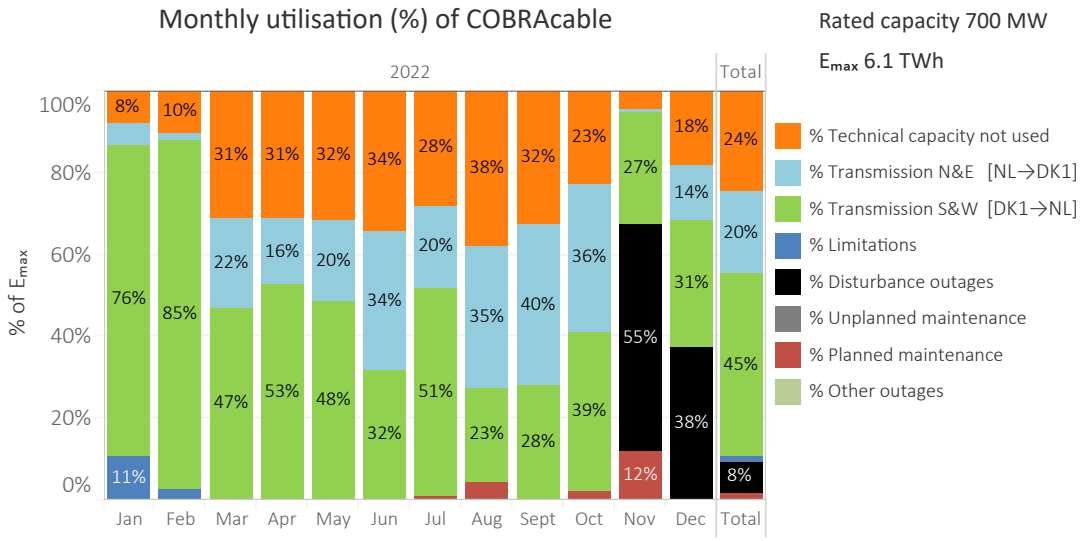

Figure 4.15: Monthly percentage allocation of utilisation by category for COBRAcable in 2022.

Table 4.5: Monthly allocation of technical capacity (E_{max}) for COBRAcable in 2022. Note that losses are not included in the technical capacity (E_{max}), as is shown in Figure 2.1.

Monthly utilisation of COBRAcable (South & West direction DK1→NL)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	% total
Technical capacity not used, GWh	40.9	48.7	163.2	157.6	166.0	173.0	146.3	197.6	163.5	118.8	21.7	94.6	1492.0	24.3%
Transmission N&E, GWh	29.0	7.7	112.9	80.2	102.1	171.3	103.8	181.6	199.2	188.6	5.4	70.6	1252.3	20.4%
Transmission S&W, GWh	394.0	400.3	244.0	266.2	251.9	159.5	265.5	118.1	141.3	201.5	136.2	159.8	2738.3	44.7%
Limitations, GWh	56.9	13.7	-	-	0.8	0.2	-	-	-	-	-	-	71.5	1.2%
Disturbance outages, GWh	-	-	-	-	-	-	-	-	-	-	279.1	195.8	474.9	7.7%
Unplanned maintenance., GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Planned maintenance, GWh	-	-	-	-	-	-	5.3	23.5	-	12.6	61.6	-	103.0	1.7%
Other outages, GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total, GWh	520.8	470.4	520.1	504.0	520.8	504.0	520.8	520.8	504.0	521.5	504.0	520.8	6132.0	100.0%
Losses SW, GWh	10.9	11.6	7.1	7.7	7.3	4.6	7.7	3.5	4.1	5.9	4.0	4.5	78.8	1.3%
Losses NE, GWh	0.7	0.2	2.7	2.0	2.4	4.2	2.6	4.6	4.8	4.7	0.1	1.7	30.7	0.5%

Figure 4.16 presents the annual utilisation of COBRAcable per utilisation and unavailability category for the years 2019–2022.

Figure 4.17 presents the percentage of hours of a year COBRAcable has been affected by either a limitation, a disturbance outage, an unplanned or planned maintenance outage or other outage annually during the years 2019–2022. Figure 4.18 presents the annual number of disturbance outages, unplanned and planned maintenances and other outages during the years 2019–2022.

Data for 2019 does not cover the whole year because COBRAcable was commissioned in September 2019.

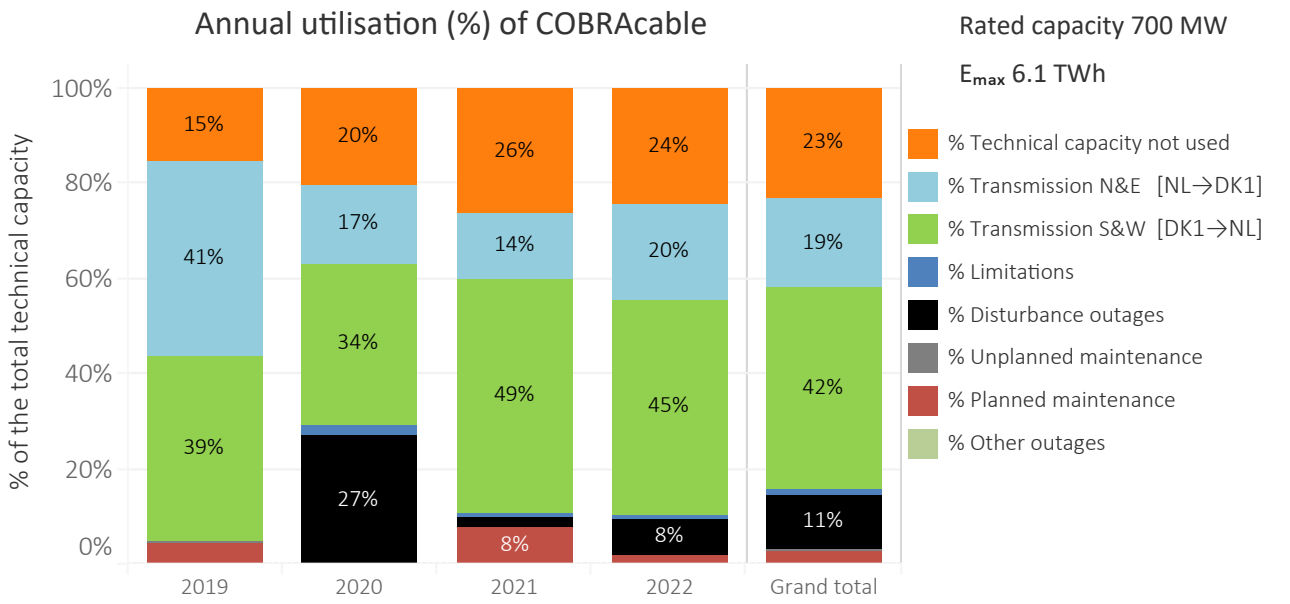

Figure 4.16: Annual utilisation of COBRAcable per the utilisation and unavailability categories for the years 2019–2022.

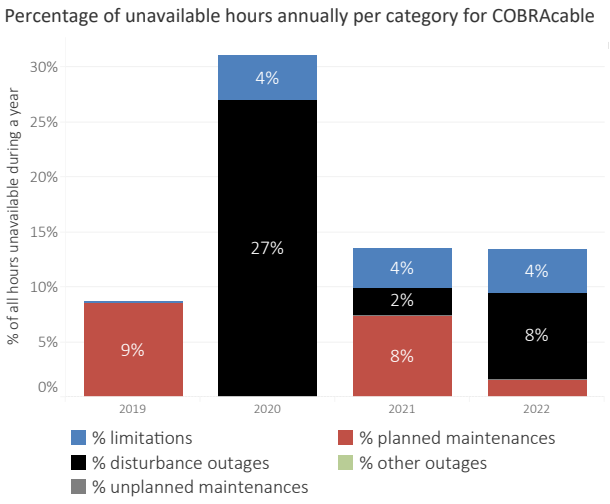

Figure 4.17: Percentage of hours COBRAcable has been affected by either a limitation or an outage annually since 2019. The percentage is calculated by counting the number of hours with a limitation or outage and dividing it by the total number of hours in a year. It should be noted that any single hour can be affected by both an outage and a limitation.

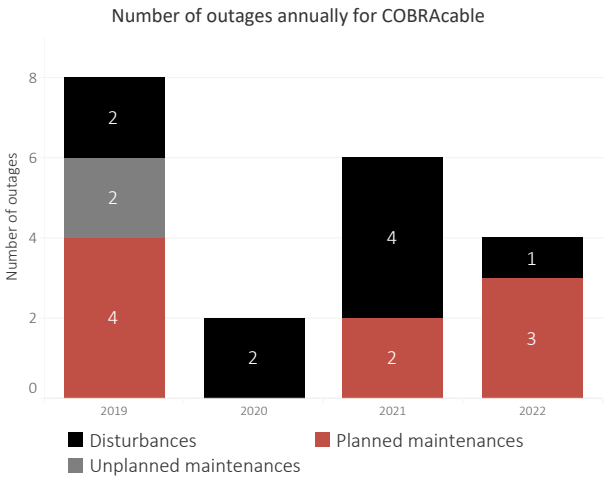

Figure 4.18: The annual number of disturbances, unplanned and planned maintenance outages and other outages for COBRAcable for the years 2019–2022.

4.4.3 EstLink 1

Figure 4.19 presents the availability and utilisation of EstLink 1 for 2022 and Table 4.6 presents the numerical values behind it. EstLink 1 has been in operation since 2006 and is the first HVDC connection between Finland and Estonia. In Finland, it is connected to Espoo substation (bidding zone FI) and in Estonia, it is connected to Harku substation (bidding zone EE). The transmission capacity of EstLink 1 is 350 MW.

In 2022, EstLink 1 had an available technical capacity of 91 %. The technical capacity not used was 32 % because EstLink 2 is prioritised due to its lower transmission losses and because EstLink 1 is often used in Automatic Frequency Control Mode. Totally, 1.8 TWh (59 % of the technical capacity) was transmitted south (FI→EE) and less than 0.02 TWh (0.4 % of the technical capacity) was transmitted north (EE→FI). EstLink 1 had no annual maintenance due to the geopolitical and price risks on the Baltic electricity systems. Only some of the most critical maintenance tasks that could not be postponed one year were performed in a 2-day outage in July. In April, EstLink 1 tripped three times due to snubber capacitor fault in one IGBT valve in Harku, which was very difficult to find visually. In November there was an AC phase reactor failure in Harku that damaged the reactor of one phase. It totally took 18 days of forced outage to replace the reactor.

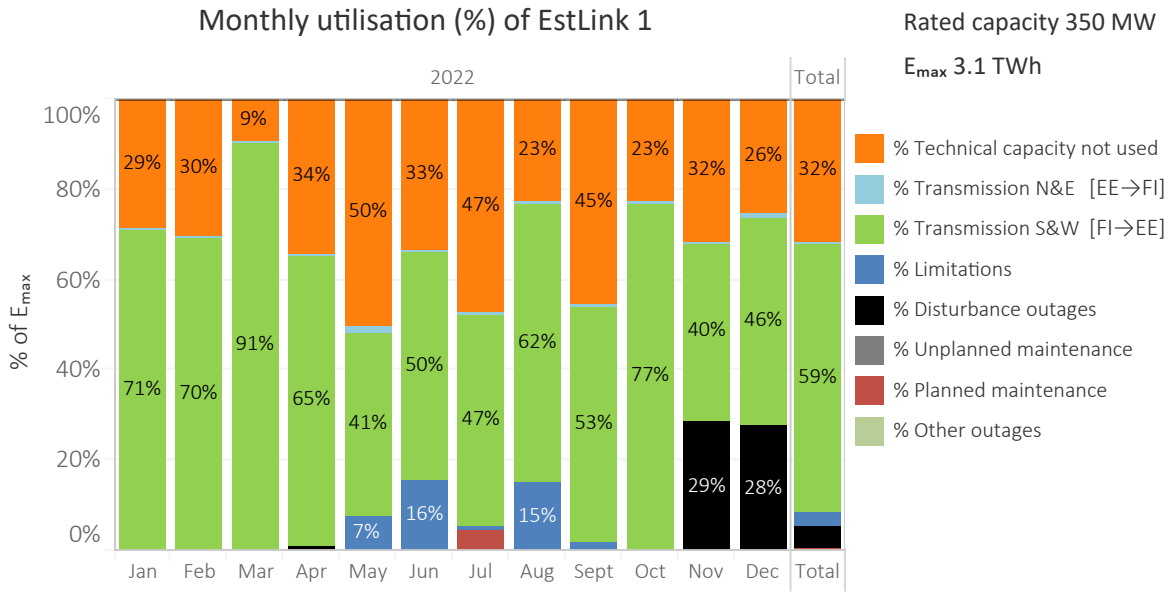

Figure 4.19: Monthly percentage allocation of utilisation by category for EstLink 1 in 2022.

Table 4.6: Monthly allocation of technical capacity (E_{max}) for EstLink 1 in 2022.

Monthly utilisation of EstLink 1 (South & West direction FI→EE)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	% total
Technical capacity not used, GWh	75.5	71.5	24.2	86.6	131.3	84.3	123.5	60.1	114.5	59.4	79.8	67.0	977.7	31.7%
Transmission N&E, GWh	0.7	0.6	0.1	0.6	3.9	1.8	1.4	0.8	0.7	0.4	0.9	1.8	13.7	0.4%
Transmission S&W, GWh	186.1	164.7	239.6	164.0	106.4	126.8	121.9	161.1	132.7	202.6	100.0	120.0	1825.8	59.2%
Limitations, GWh	-	-	-	-	19.3	39.9	2.9	39.7	4.5	-	-	-	106.3	3.4%
Disturbance outages, GWh	-	-	-	2.1	-	-	-	-	-	-	72.2	72.6	147.0	4.8%
Unplanned maintenance., GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Planned maintenance, GWh	-	-	-	-	-	-	11.6	-	-	-	-	-	11.6	0.4%
Other outages, GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total, GWh	262.3	236.9	263.9	253.4	261.0	252.7	261.1	261.7	252.4	262.3	252.8	261.4	3081.9	100.0%
Losses SW, GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Losses NE, GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Figure 4.20 presents the annual utilisation of EstLink 1 per utilisation and unavailability category for the years 2012–2022.

Figure 4.21 presents the percentage of hours of a year EstLink 1 has been affected by either a limitation, a disturbance outage, an unplanned or planned maintenance outage or other outage annually during the years 2012–2022. Figure 4.22 presents the annual number of disturbance outages, unplanned and planned maintenances and other outages during the years 2012–2022.

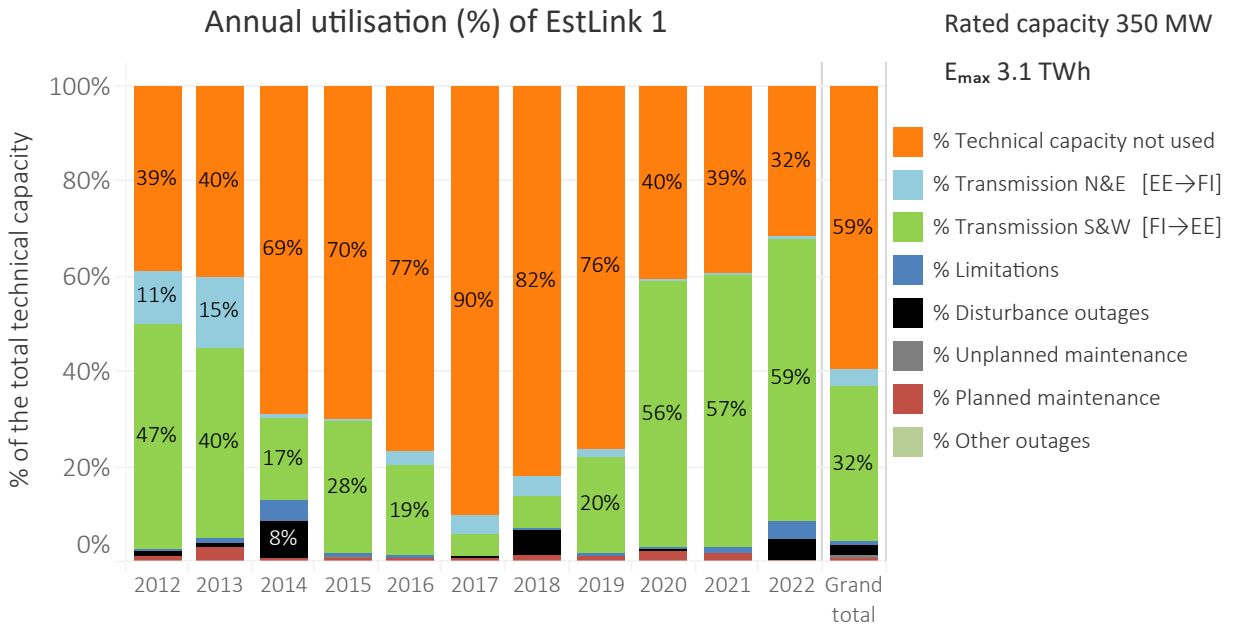

Figure 4.20: Annual utilisation of EstLink 1 per the utilisation and unavailability categories for the years 2012–2022.

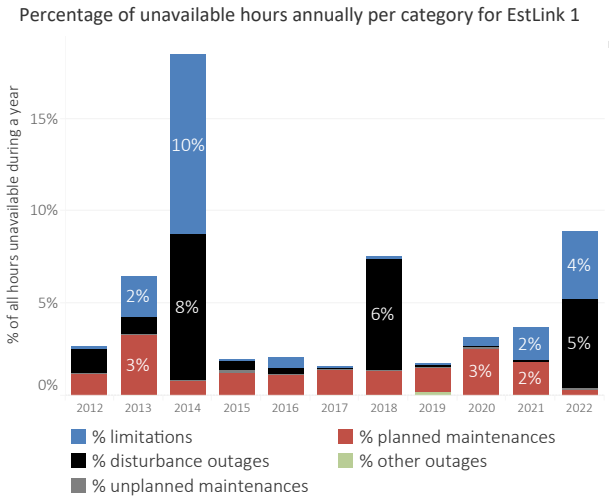

Figure 4.21: Percentage of hours EstLink 1 has been affected by either a limitation or an outage annually since 2012. The percentage is calculated by counting the number of hours with a limitation or outage and dividing it by the total number of hours in a year. It should be noted that any single hour can be affected by both an outage and a limitation.

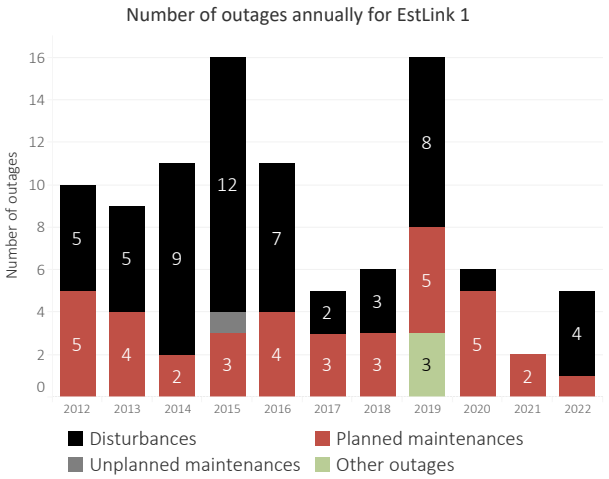

Figure 4.22: The annual number of disturbances, unplanned and planned maintenance outages and other outages for EstLink 1 for the years 2012–2022.

4.4.4 EstLink 2

Figure 4.23 presents the availability and utilisation of EstLink 2 for 2022 and Table 4.7 presents the numerical values behind it. EstLink 2 was commissioned in February 2014 and is the second HVDC connection between Finland and Estonia. In Finland, it is connected to Anttila substation (bidding zone FI) and in Estonia, it is connected to Püssi substation (bidding zone EE). The transmission capacity of EstLink 2 is 650 MW.

In 2022, EstLink 2 had an available technical capacity of 99 %. The technical capacity not used was 11 %. Totally, 5.0 TWh (87 % of the technical capacity) was transmitted south (FI→EE) and less than 0.01 TWh (0.0 % of the technical capacity) was transmitted north (EE→FI). EstLink 2 had no annual nor any other planned maintenance due to the geopolitical and price risks on the Baltic electricity systems.

EstLink 2 tripped four times during 2022. Fortunately, these forced outages were very short, only one of them caused a little longer outage (replacement of a faulty snubber capacitor in the thyristor valve hall). Twice, a power reduction was required, one due to flashover at the DC cable end terminal in Finland (link running with 80 % voltage for one week until it was suitable to take a planned outage to visually check the cable end termination thoroughly) and the other short one due to AC filter trip in Estonia.

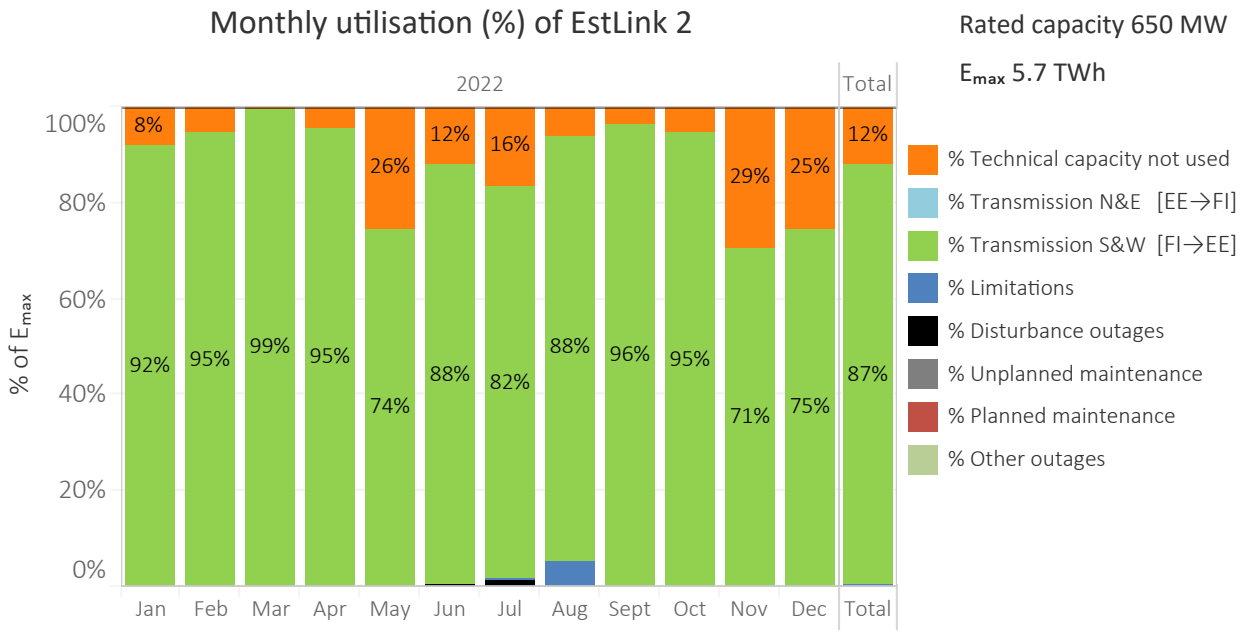

Figure 4.23: Monthly percentage allocation of utilisation by category for EstLink 2 in 2022.

Table 4.7: Monthly allocation of technical capacity (E_{max}) for EstLink 2 in 2022. Note that losses are not included in the technical capacity (E_{max}), as is shown in Figure 2.1.

Monthly utilisation of EstLink 2 (South & West direction FI→EE)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	% total
Technical capacity not used, GWh	39.7	23.8	3.0	21.9	124.4	56.4	79.6	30.7	16.9	25.2	137.2	122.9	681.6	11.9%
Transmission N&E, GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Transmission S&W, GWh	448.1	417.0	485.1	450.2	361.9	413.1	399.2	428.0	455.3	460.9	330.8	361.9	5011.7	87.5%
Limitations, GWh	-	-	-	-	-	-	0.7	26.7	-	-	-	-	27.5	0.5%
Disturbance outages, GWh	-	-	-	0.2	-	1.9	7.1	-	-	-	-	-	9.2	0.2%
Unplanned maintenance., GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Planned maintenance, GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other outages, GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total, GWh	487.8	440.7	488.1	472.3	486.4	471.4	486.7	485.4	472.2	486.1	468.0	484.8	5729.9	100.0%
Losses SW, GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Losses NE, GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Figure 4.24 presents the annual utilisation of EstLink 2 per utilisation and unavailability category for the years 2014–2022.

Figure 4.25 presents the percentage of hours of a year EstLink 2 has been affected by either a limitation, a disturbance outage, an unplanned or planned maintenance outage or other outage annually during the years 2014–2022. Figure 4.26 presents the annual number of disturbance outages, unplanned and planned maintenances and other outages during the years 2014–2022.

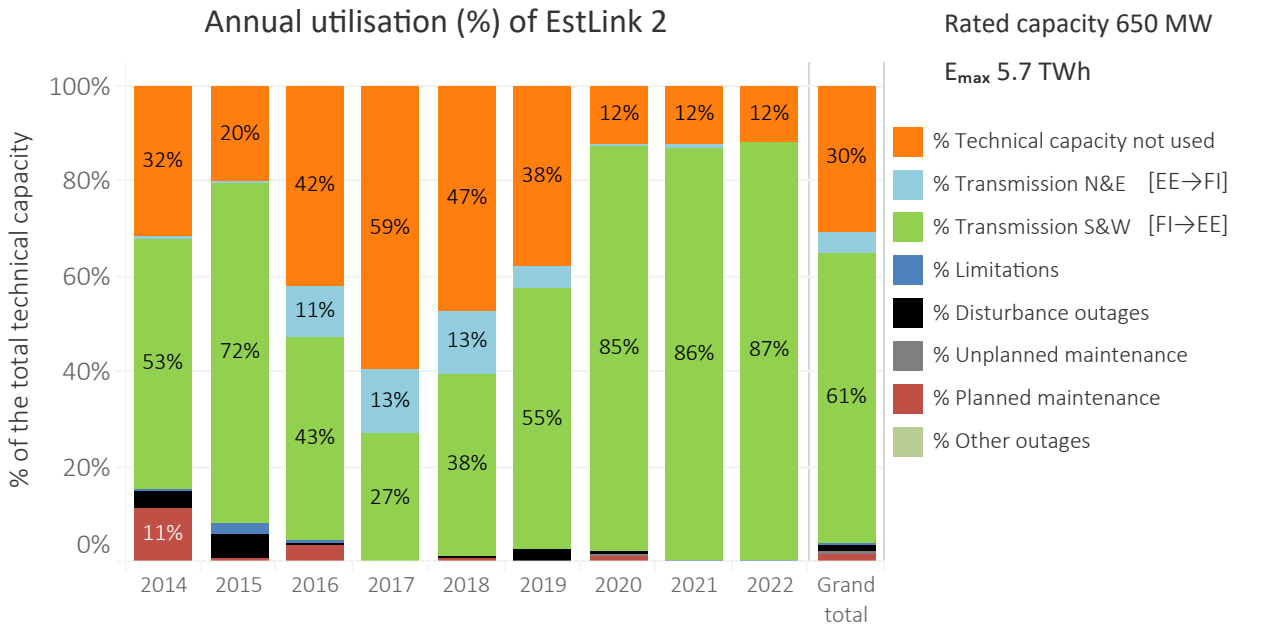

Figure 4.24: Annual utilisation of EstLink 2 per the utilisation and unavailability categories for the years 2014–2022.

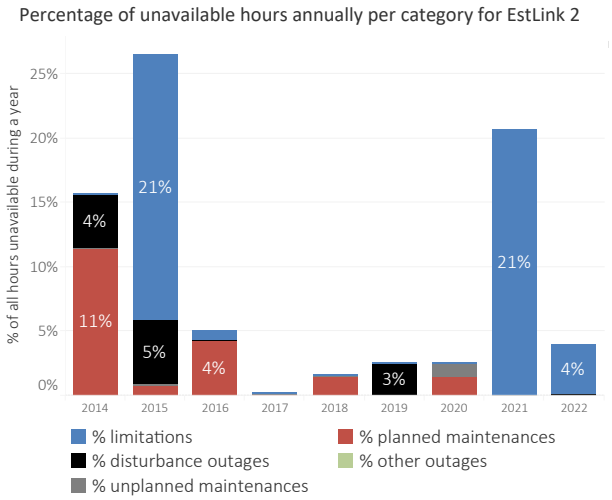

Figure 4.25: Percentage of hours EstLink 2 has been affected by either a limitation or an outage annually since 2014. The percentage is calculated by counting the number of hours with a limitation or outage and dividing it by the total number of hours in a year. It should be noted that any single hour can be affected by both an outage and a limitation.

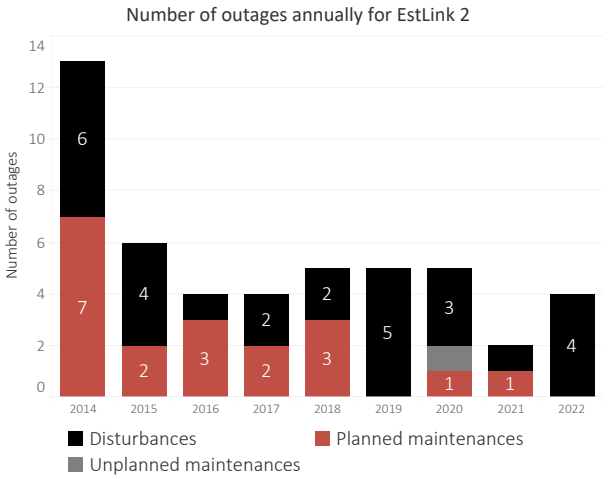

Figure 4.26: The annual number of disturbances, unplanned and planned maintenance outages and other outages for EstLink 2 for the years 2014–2022. EstLink 2 had neither unplanned maintenance nor other outages during this period.

4.4.5 Fenno-Skan 1

Figure 4.27 presents the availability and utilisation of Fenno-Skan 1 for 2022 and Table 4.8 presents the numerical values behind it. Fenno-Skan 1 has been in operation since 1989 and is the first HVDC connection between Finland and Sweden. In Finland (bidding zone FI), Fenno-Skan 1 is connected to Rauma and in Sweden to Dannebo (bidding zone SE3). The transmission capacity of Fenno-Skan 1 is 400 MW.

In 2022, Fenno-Skan 1 had an available technical capacity of 98 %. The technical capacity not used was 6 %. Totally, 0.04 TWh (1.0 % of the technical capacity) was transmitted west (FI→SE3) and 3.2 TWh (91 % of the technical capacity) was transmitted east (SE3→FI).

Fenno-Skan 1 had a 7-day annual maintenance outage at the end of September and one 1-day maintenance for adding oil to the DC cable 1 month after the annual maintenance. FS1 tripped once in 2022, as the converter transformer cooling system suffered from an auxiliary fault, which led to a short, forced outage.

It should be noted that Fenno-Skan 1 and 2 are sometimes operated at equivalent transmission levels but with reversed directions to keep the temperature of Fenno-Skan 1 at adequate levels. The utilisation is still regarded as transmission even though the resulting net exchange between Finland and Sweden is zero.

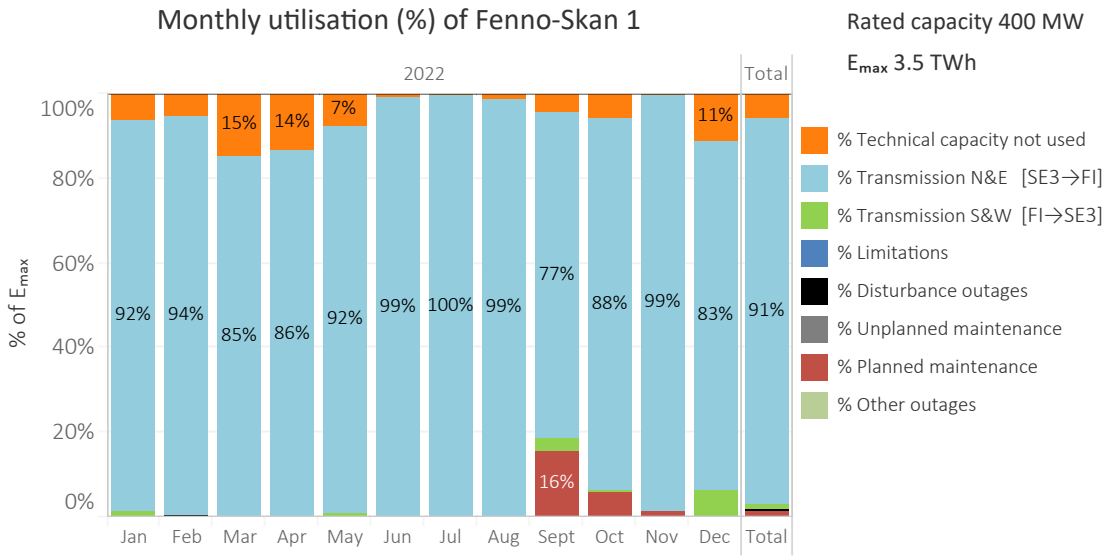

Figure 4.27: Monthly percentage allocation of utilisation by category for Fenno-Skan 1 in 2022.

Table 4.8: Monthly allocation of technical capacity (E_{max}) for Fenno-Skan 1 in 2022. Note that losses are not included in the technical capacity (E_{max}), as is shown in Figure 2.1.

Monthly utilisation of Fenno-Skan 1 (South & West direction FI→SE3)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	% total
Technical capacity not used, GWh	19.1	14.4	43.7	39.0	22.0	2.7	1.1	4.3	13.4	17.1	0.1	33.4	210.2	6.0%
Transmission N&E, GWh	275.1	253.5	253.1	249.1	272.7	285.5	296.7	293.4	221.0	262.3	285.3	246.5	3194.1	91.1%
Transmission S&W, GWh	3.8	-	0.5	-	3.0	-	-	-	8.3	1.4	-	18.0	35.1	1.0%
Limitations, GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Disturbance outages, GWh	-	1.3	-	-	-	-	-	-	-	-	-	-	1.3	0.0%
Unplanned maintenance., GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Planned maintenance, GWh	-	-	-	-	-	-	-	-	45.5	17.5	3.3	-	66.3	1.9%
Other outages, GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total, GWh	298.0	269.2	297.3	288.1	297.8	288.2	297.8	297.8	288.1	298.4	288.7	297.9	3507.1	100.0%
Losses SW, GWh	0.1	-	-	-	0.1	-	-	-	0.4	0.1	-	0.5	1.2	0.0%
Losses NE, GWh	7.0	6.5	5.9	6.1	6.6	7.5	7.3	7.6	5.8	6.7	7.0	6.1	80.0	2.3%

Figure 4.28 presents the annual utilisation of Fenno-Skan 1 per utilisation and unavailability category for the years 2012–2022.

Figure 4.29 presents the percentage of hours of a year Fenno-Skan 1 has been affected by either a limitation, a disturbance outage, an unplanned or planned maintenance outage or other outage annually during the years 2012–2022. Figure 4.30 presents the annual number of disturbance outages, unplanned and planned maintenances and other outages during the years 2012–2022.

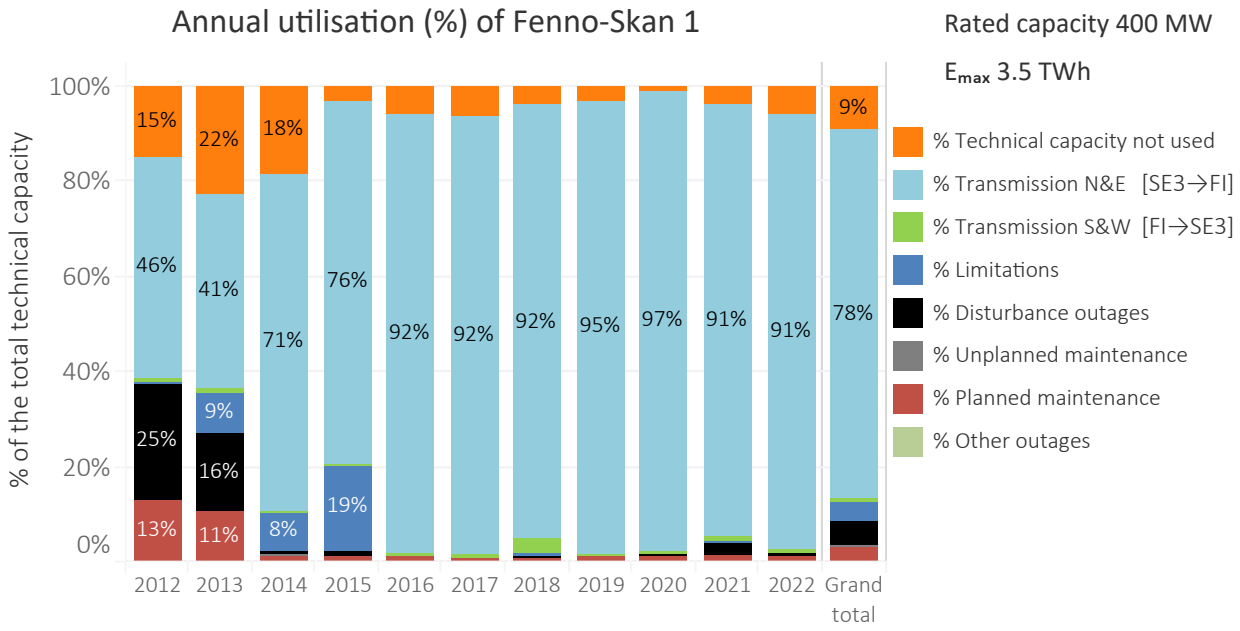

Figure 4.28: Annual utilisation of Fenno-Skan 1 per the utilisation and unavailability categories for the years 2012–2022.

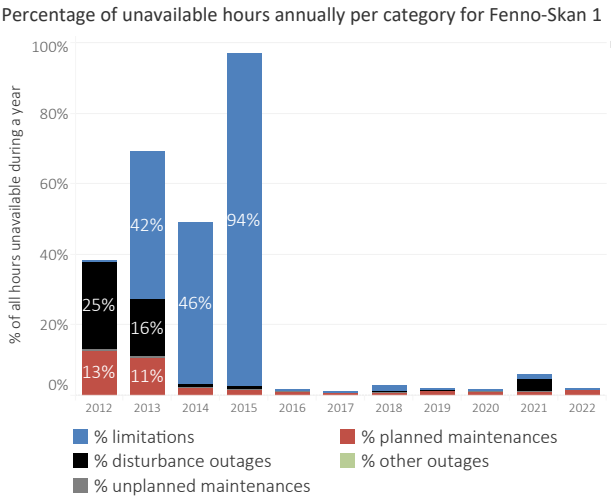

Figure 4.29: Percentage of hours Fenno-Skan 1 has been affected by either a limitation or an outage annually since 2012. The percentage is calculated by counting the number of hours with a limitation or outage and dividing it by the total number of hours in a year. It should be noted that any single hour can be affected by both an outage and a limitation.

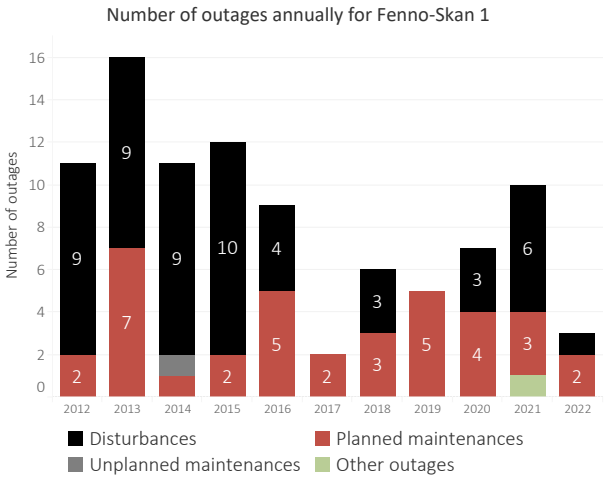

Figure 4.30: The annual number of disturbances, unplanned and planned maintenance outages and other outages for Fenno-Skan 1 during 2012–2022. Fenno-Skan 1 had no other outages during the years 2012–2022.

4.4.6 Fenno-Skan 2

Figure 4.31 presents the availability and utilisation of Fenno-Skan 2 for 2022 and Table 4.9 presents the numerical values behind it. Fenno-Skan 2 has been in operation since 2011 and is the second HVDC connection between Finland and Sweden. In Finland (bidding zone FI) Fenno-Skan 2 is connected to Rauma and in Sweden to Finnböle (bidding zone SE3). The transmission capacity of Fenno-Skan 2 is 800 MW.

In 2022, Fenno-Skan 2 had an available technical capacity of 99 %. The technical capacity not used was 37 %. Totally, 3.2 TWh (46 % of the technical capacity) was transmitted east (SE3→FI) and 1.1 TWh (16 % of the technical capacity) was transmitted west (FI→SE3).

Fenno-Skan 2 had three planned outages for corrective maintenance and a 2-day annual maintenance. Fenno-Skan suffered from four trips in 2022, two related to small leakages in the valve cooling systems in the pump room on the Swedish side. In Finland, a faulty I/O board of the control and protection system prevented power transmission after a power reversal situation.

It should be noted that Fenno-Skan 1 and 2 is sometimes operated at equivalent transmission levels but with reversed directions to keep the temperature of Fenno-Skan 1 at adequate levels. The utilisation is still regarded as transmission even though the resulting net exchange between Finland and Sweden is zero.

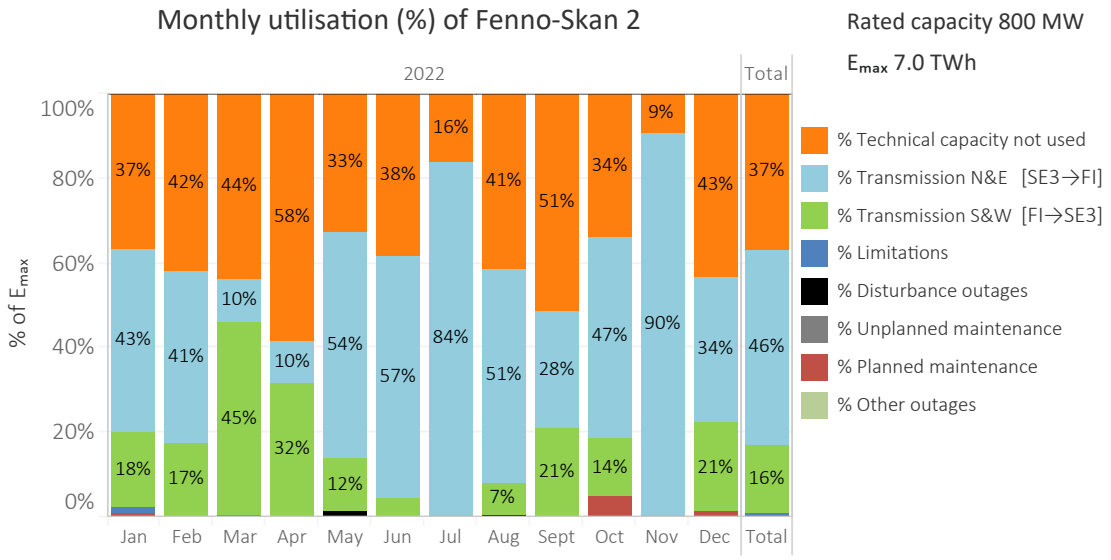

Figure 4.31: Monthly percentage allocation of utilisation by category for Fenno-Skan 2 in 2022.

Table 4.9: Monthly allocation of technical capacity (E_{max}) for Fenno-Skan 2 in 2022. Note that losses are not included in the technical capacity (E_{max}), as is shown in Figure 2.1.

Monthly utilisation of Fenno-Skan 2 (South & West direction FI→SE3)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	% total
Technical capacity not used, GWh	217.7	225.3	259.5	336.2	193.7	221.6	95.5	246.9	295.7	203.4	54.6	257.6	2607.6	37.2%
Transmission N&E, GWh	257.3	218.6	61.9	58.3	319.7	329.0	498.4	300.8	159.8	280.3	519.7	203.7	3207.3	45.8%
Transmission S&W, GWh	106.0	93.8	269.9	181.6	73.5	25.6	1.9	43.8	120.6	83.9	2.2	127.4	1130.1	16.1%
Limitations, GWh	7.7	-	0.5	-	-	-	-	-	-	-	-	-	8.2	0.1%
Disturbance outages, GWh	-	-	0.6	-	8.4	-	-	3.9	-	-	-	-	12.9	0.2%
Unplanned maintenance., GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Planned maintenance, GWh	6.2	-	2.1	-	-	-	-	-	-	28.7	-	6.7	43.7	0.6%
Other outages, GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total, GWh	595.0	537.7	594.4	576.0	595.3	576.2	595.8	595.3	576.1	596.2	576.6	595.3	7009.8	100.0%
Losses SW, GWh	2.1	1.9	5.4	3.2	1.4	0.4	-	0.7	2.3	1.7	-	2.4	21.6	0.3%
Losses NE, GWh	5.2	4.2	1.1	1.0	6.7	6.7	11.0	5.9	3.3	5.9	11.7	4.1	66.7	1.0%

Figure 4.32 presents the annual utilisation of Fenno-Skan 2 per utilisation and unavailability category for the years 2012–2022.

Figure 4.33 presents the percentage of hours of a year Fenno-Skan 2 has been affected by either a limitation, a disturbance outage, an unplanned or planned maintenance outage or other outage annually during the years 2012–2022. Figure 4.34 presents the annual number of disturbance outages, unplanned and planned maintenances and other outages during the years 2012–2022.

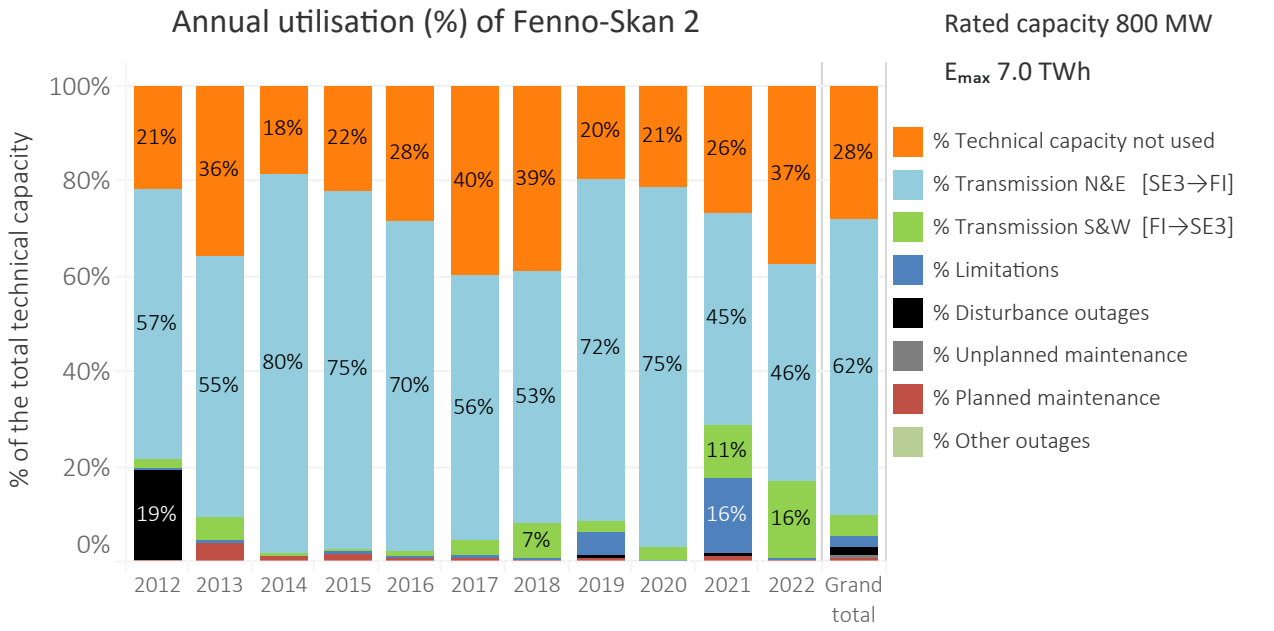

Figure 4.32: Annual utilisation of Fenno-Skan 2 per the utilisation and unavailability categories for the years 2012–2022.

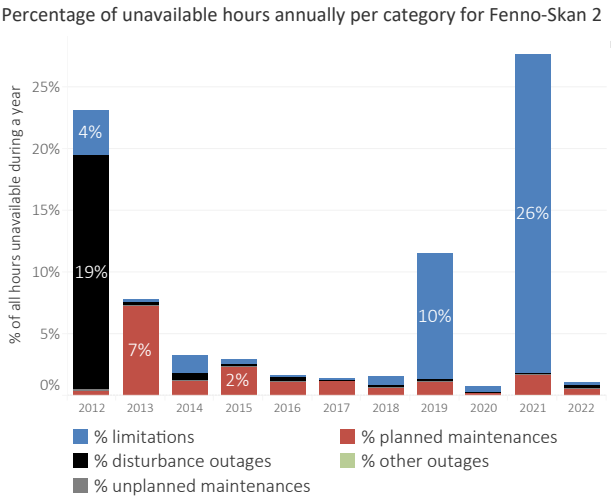

Figure 4.33: Percentage of hours Fenno-Skan 2 has been affected by either a limitation or an outage annually since 2012. The percentage is calculated by counting the number of hours with a limitation or outage and dividing it by the total number of hours in a year. It should be noted that any single hour can be affected by both an outage and a limitation.

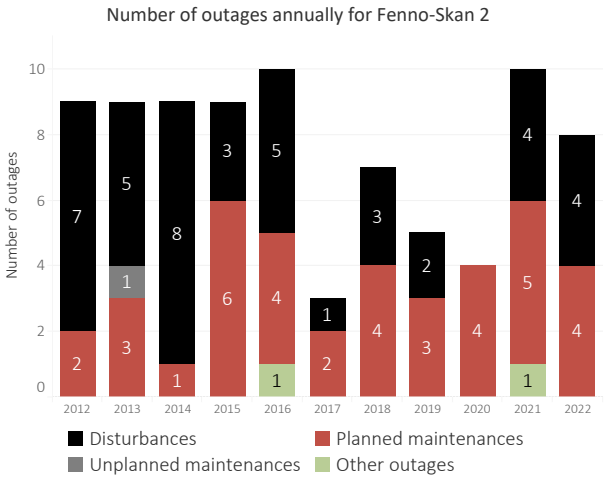

Figure 4.34: The annual number of disturbances, unplanned and planned maintenance outages and other outages for Fenno-Skan 2 for the years 2012–2022.

4.4.7 Kontek

Figure 4.35 presents the availability and utilisation of Kontek for 2022 and Table 4.10 presents the numerical values behind it. Kontek has been in operation since 1995. In Denmark it is connected to Bjaeverskov (bidding zone DK2) and in Germany to Bentwisch (bidding zone DE-50Hertz). The transmission capacity of Kontek is 600 MW.

In 2022, Kontek had an available technical capacity of 89 %. The technical capacity not used was 24 %. Totally, 2.9 TWh (55 % of the technical capacity) was transmitted south from Denmark to Germany and 0.5 TWh (10 % of the technical capacity) was transmitted north to Denmark.

Annual maintenance for Kontek lasted 12 days. Furthermore there were two planned maintenance outages, both were preparation to exchange 400 kV land cable. There were three disturbance outages. Two outages were due to flashovers at a cable terminal and the last one was caused by fault in the auxiliary power supply.

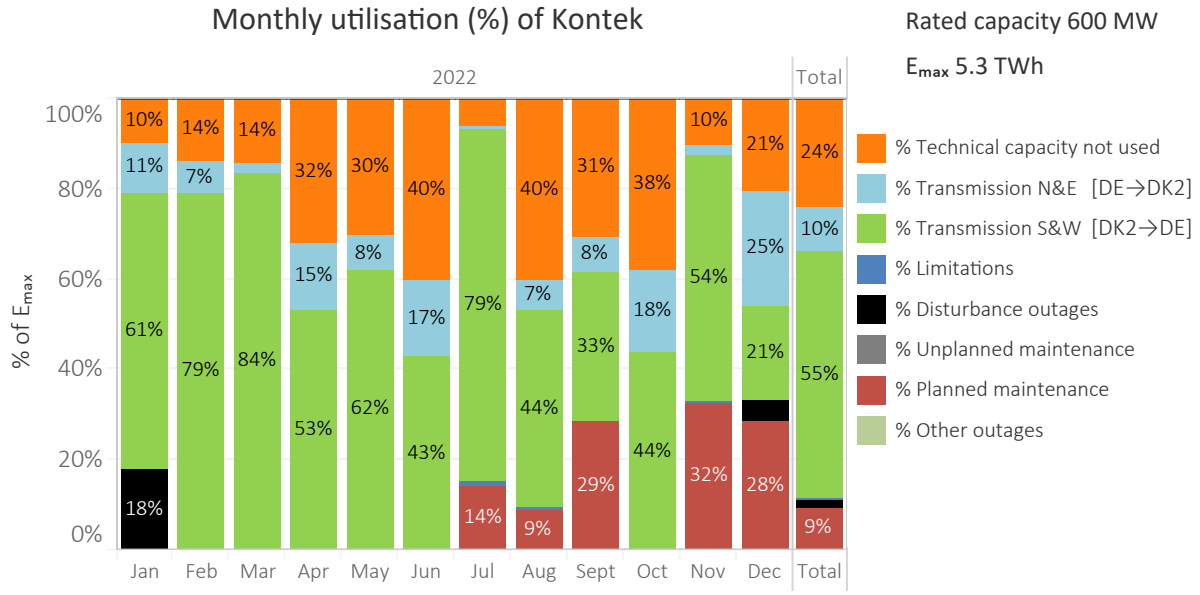

Figure 4.35: Monthly percentage allocation of utilisation by category for Kontek in 2022.

Table 4.10: Monthly allocation of technical capacity (E_{max}) for Kontek in 2022. Note that losses are not included in the technical capacity (E_{max}), as is shown in Figure 2.1.

Monthly utilisation of Kontek (South & West direction DK2→DE)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	% total
Technical capacity not used, GWh	44.2	56.2	64.0	139.4	134.6	174.1	26.9	179.3	132.4	169.0	44.5	91.7	1256.3	23.9%
Transmission N&E, GWh	48.5	29.0	8.7	63.5	35.6	72.6	1.3	30.9	33.7	81.8	10.3	113.6	529.4	10.1%
Transmission S&W, GWh	274.0	318.1	373.1	229.1	276.2	185.3	350.8	194.7	141.8	196.2	235.3	93.1	2867.8	54.6%
Limitations, GWh	-	-	-	-	-	-	2.6	2.0	-	-	1.5	-	6.1	0.1%
Disturbance outages, GWh	79.7	-	-	-	-	-	-	-	-	-	-	21.3	101.0	1.9%
Unplanned maintenance., GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Planned maintenance, GWh	-	-	-	-	-	-	64.7	39.6	124.1	-	140.4	126.6	495.3	9.4%
Other outages, GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total, GWh	446.4	403.2	445.8	432.0	446.4	432.0	446.4	446.4	432.0	447.0	432.0	446.4	5256.0	100.0%
Losses SW, GWh	6.1	7.1	8.3	5.0	6.1	4.0	8.0	4.2	3.0	4.3	5.3	2.0	63.5	1.2%
Losses NE, GWh	1.0	0.5	0.2	1.2	0.7	1.3	-	0.5	0.6	1.5	0.2	2.1	9.8	0.2%

Figure 4.36 presents the annual utilisation of Kontek per utilisation and unavailability category for the years 2012–2022.

Figure 4.37 presents the percentage of hours of a year Kontek has been affected by either a limitation, a disturbance outage, an unplanned or planned maintenance outage or other outage annually during the years 2012–2022. Figure 4.38 presents the annual number of disturbance outages, unplanned and planned maintenances and other outages during the years 2012–2022.

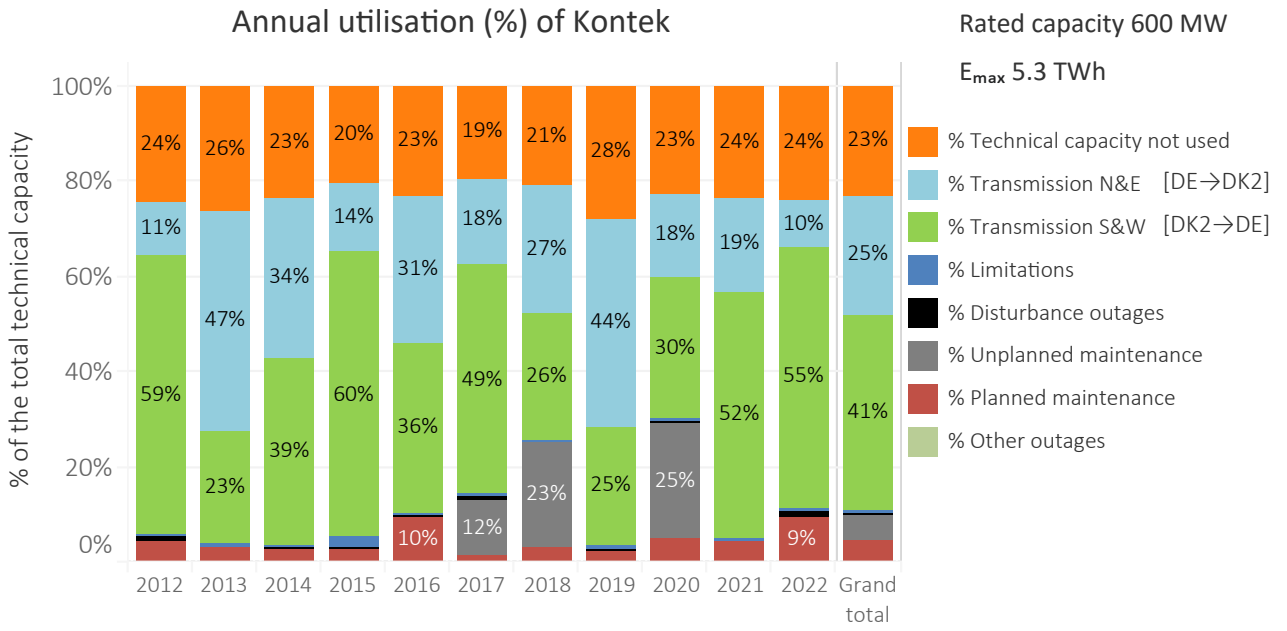

Figure 4.36: Annual utilisation of Kontek per the utilisation and unavailability categories for the years 2012–2022.

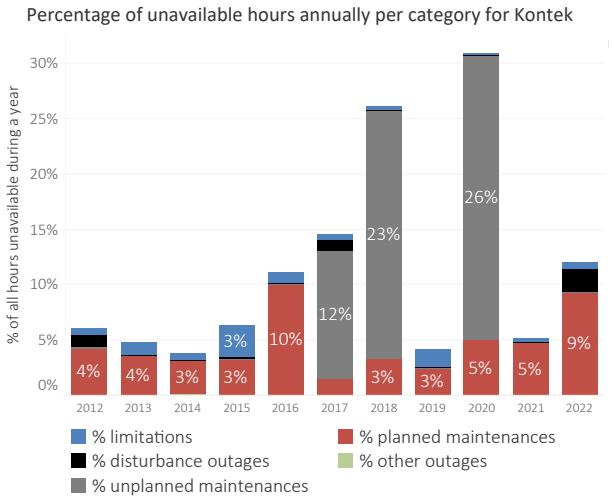

Figure 4.37: Percentage of hours Kontek has been affected by either a limitation or an outage annually since 2012. The percentage is calculated by counting the number of hours with a limitation or outage and dividing it by the total number of hours in a year. It should be noted that any single hour can be affected by both an outage and a limitation.

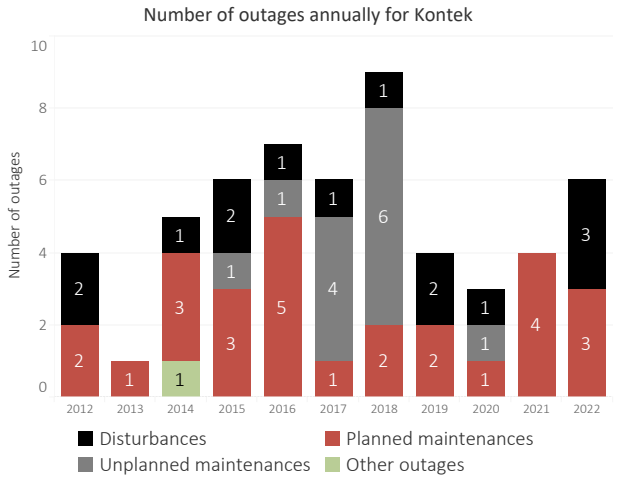

Figure 4.38: The annual number of disturbances, unplanned and planned maintenance outages and other outages for Kontek for the years 2012–2022.

4.4.8 Konti-Skan 1

Figure 4.39 presents the availability and utilisation of Konti-Skan 1 for 2022 and Table 4.11 presents the numerical values behind it. Konti-Skan 1 has been in operation since 1965 and it is connected in south-western Sweden to Lindome (bidding zone SE3) and in Denmark to Vester Hassing (bidding zone DK1).

The rated capacity of Konti-Skan 1 and 2 was updated to 715 MW in both directions on 1 February 2020 (357.5 MW per link). The rated capacity was previously asymmetric depending on the flow direction: 740 MW towards east (370+370) and 680 MW towards west (340+340). The reason of the asymmetric rated capacity was due to historical limitations and reserve requirements, along with transmission measurements only being done in DK1.

In 2022, Konti-Skan 1 had an available technical capacity of 94 % and the technical capacity not used was 23 %. Totally, 1.7 TWh (54 % of the technical capacity) was transmitted west to Denmark (SE3→DK1) and 0.5 TWh (17 % of the technical capacity) was transmitted east to Sweden (DK1→SE3).

In 2022, a total of 11 outages occurred, with auxiliary power issues being responsible for 4 disturbances. Additionally, a scheduled yearly maintenance period took place in September, lasting for 6 days. Within the same year, 6 maintenance outages were carried out, with 3 of them specifically addressing the corrective maintenance of the neutral line due to the detection of a hot spot. Despite the increased number of outages in 2022 compared to the previous year, their impact on the overall unavailable capacity of the link was relatively low, amounting to only 3.1 %.

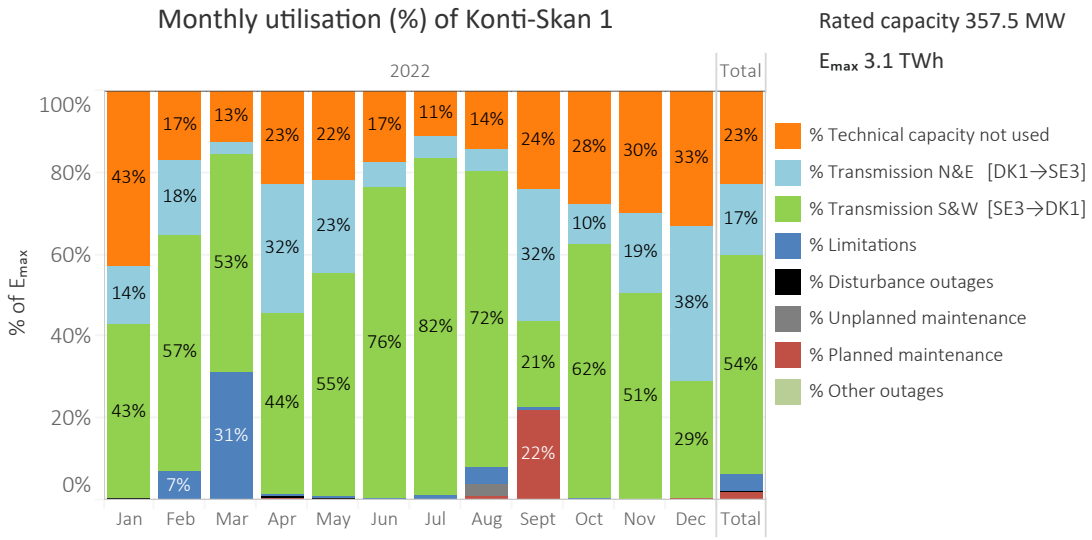

Figure 4.39: Monthly percentage allocation of utilisation by category for Konti-Skan 1 in 2022.

Table 4.11: Monthly allocation of technical capacity (E_{max}) for Konti-Skan 1 in 2022. Note that losses are not included in the technical capacity (E_{max}), as is shown in Figure 2.1.

Monthly utilisation of Konti-Skan 1 (South & West direction SE3→DK1)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	% total
Technical capacity not used, GWh	114.3	41.0	33.7	58.9	57.8	44.6	29.8	38.2	62.5	73.5	77.6	87.4	719.3	22.9%
Transmission N&E, GWh	37.3	43.8	8.0	81.7	61.1	16.5	14.4	14.1	82.4	26.3	49.8	101.5	536.8	17.1%
Transmission S&W, GWh	113.8	137.8	140.8	113.0	145.0	196.1	218.9	192.0	53.5	165.6	130.2	75.9	1682.5	53.7%
Limitations, GWh	-	17.7	83.0	1.0	1.4	1.6	3.7	10.5	2.6	1.3	-	-	122.7	3.9%
Disturbance outages, GWh	0.6	-	-	0.7	0.7	-	-	-	-	-	-	-	2.0	0.1%
Unplanned maintenance., GWh	-	-	-	-	-	-	-	8.7	-	-	-	-	8.7	0.3%
Planned maintenance, GWh	-	-	0.1	2.1	-	-	-	2.5	56.4	-	-	1.2	62.3	2.0%
Other outages, GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total, GWh	266.0	240.2	265.6	257.5	266.0	258.7	266.7	266.1	257.4	266.7	257.5	266.0	3134.5	100.0%
Losses SW, GWh	2.6	3.9	3.1	2.6	3.3	4.6	5.1	4.4	1.4	3.8	2.9	1.7	39.3	1.3%
Losses NE, GWh	0.9	1.5	0.2	1.9	1.5	0.4	0.3	0.4	2.0	0.6	1.1	2.4	13.1	0.4%

Figure 4.40 presents the annual utilisation of Konti-Skan 1 per utilisation and unavailability category for the years 2012–2022.

Figure 4.41 presents the percentage of hours of a year Konti-Skan 1 has been affected by either a limitation, a disturbance outage, an unplanned or planned maintenance outage or other outage annually during the years 2012–2022. Figure 4.42 presents the annual number of disturbance outages, unplanned and planned maintenances and other outages during the years 2012–2022.

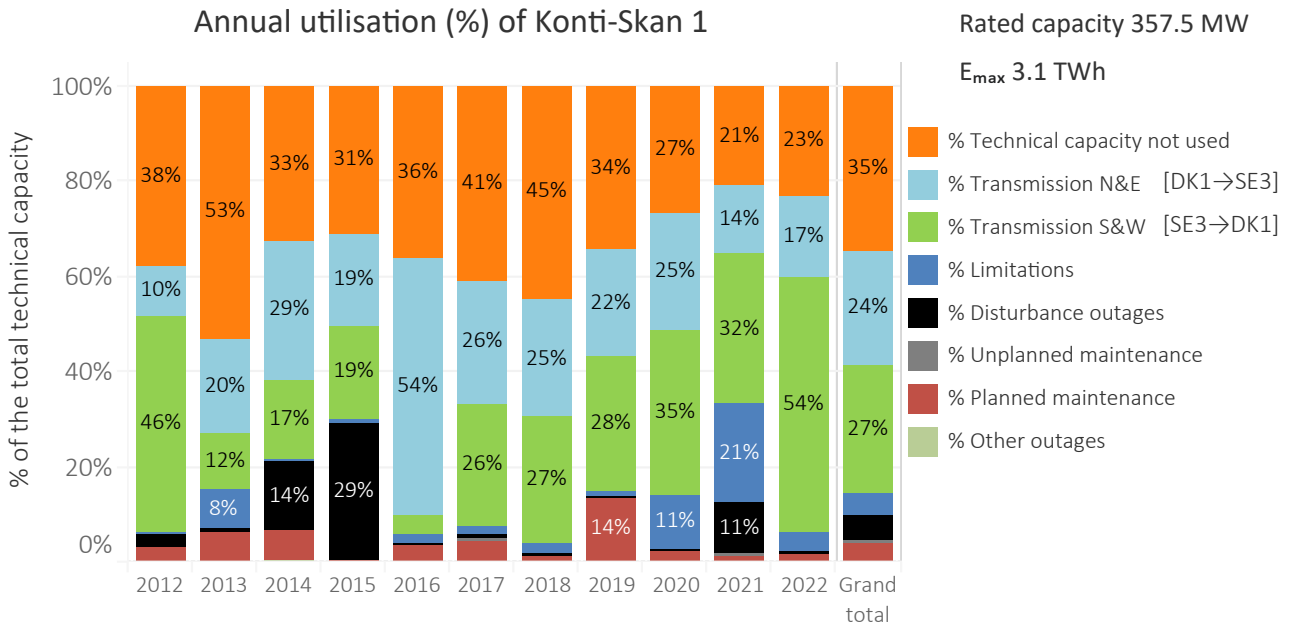

Figure 4.40: Annual utilisation of Konti-Skan 1 per the utilisation and unavailability categories for the years 2012–2022.

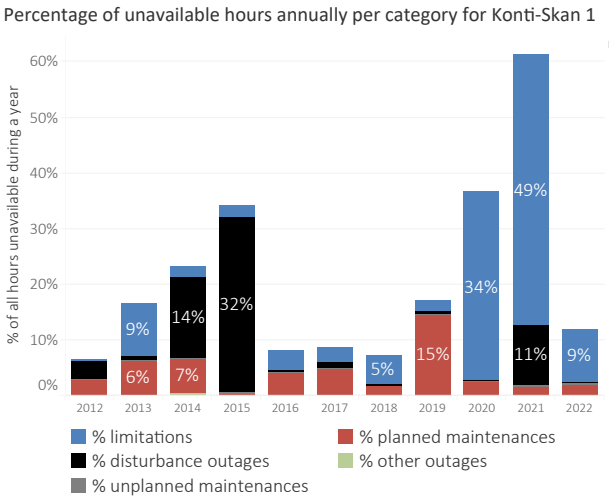

Figure 4.41: Percentage of hours Konti-Skan 1 has been affected by either a limitation or an outage annually since 2012. The percentage is calculated by counting the number of hours with a limitation or outage and dividing it by the total number of hours in a year. It should be noted that any single hour can be affected by both an outage and a limitation.

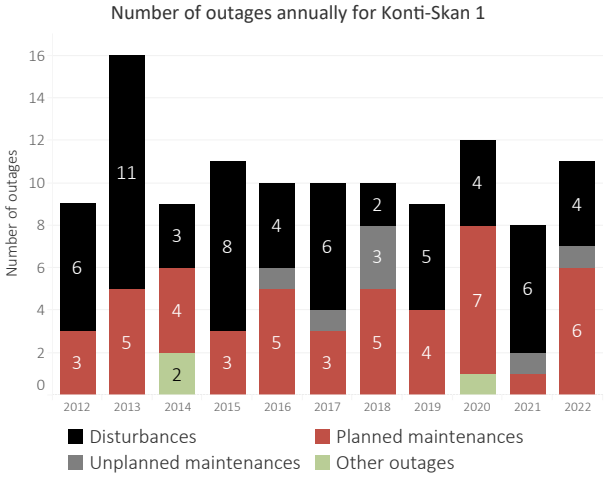

Figure 4.42: The annual number of disturbances, unplanned and planned maintenance outages and other outages for Konti-Skan 1 for the years 2012–2022.

4.4.9 Konti-Skan 2

Figure 4.43 presents the availability and utilisation of Konti-Skan 2 for 2022 and Table 4.12 presents the numerical values behind it. Konti-Skan 2 is connected between Sweden and Denmark in parallel to Konti-Skan 1 and has been in operation since 1988.

The rated capacity of Konti-Skan 1 and 2 was updated to 715 MW in both directions on 1 February 2020 (357.5 MW per link). The rated capacity was previously asymmetric depending on the flow direction: 740 MW towards east (370+370) and 680 MW towards west (340+340). The reason of the asymmetric rated capacity was due to historical limitations and reserve requirements, along with transmission measurements only being done in DK1.

In 2022, Konti-Skan 2 had an available technical capacity of 81 % and the technical capacity not used was 20 %. Totally, 1.4 TWh (45 % of the technical capacity) was transmitted west to Denmark (SE3→DK1) and 0.5 TWh (16 % of the technical capacity) was transmitted east to Sweden (DK1→SE3).

In 2022, there were a total of 12 outages. 6 of these outages were categorized as disturbances, while the remaining 6 were maintenance outages, of which 1 were unplanned. However, the impact of one particular disturbance on the DC cable of Konti-Skan 2 resulted in a significant reduction in its available capacity. This incident on the cable was caused by an anchor in the water. Additionally, during the maintenance activities, a hot spot was detected on the neutral lines, leading to three separate corrective maintenance outages.

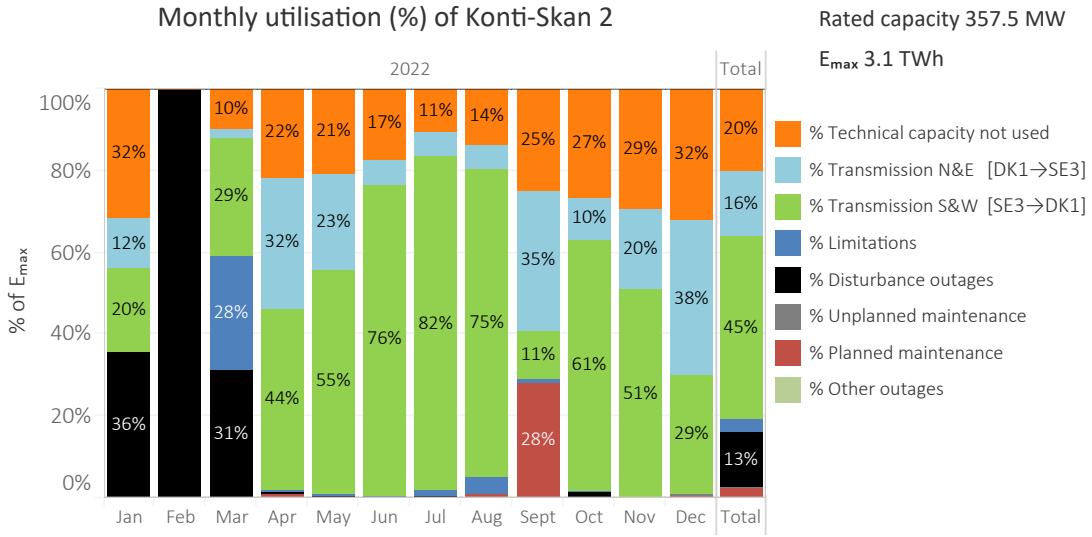

Figure 4.43: Monthly percentage allocation of utilisation by category for Konti-Skan 2 in 2022.

Table 4.12: Monthly allocation of technical capacity (E_{max}) for Konti-Skan 2 in 2022. Note that losses are not included in the technical capacity (E_{max}), as is shown in Figure 2.1.

Monthly utilisation of Konti-Skan 2 (South & West direction SE3→DK1)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	% total
Technical capacity not used, GWh	83.8	0.3	26.2	56.9	55.7	44.5	28.9	37.4	64.4	71.1	75.6	85.1	630.0	20.1%
Transmission N&E, GWh	33.0	-	6.1	82.3	62.0	16.9	14.6	14.9	88.9	27.4	50.5	101.7	498.5	15.9%
Transmission S&W, GWh	54.4	-	77.0	114.5	146.6	195.2	218.7	200.7	29.5	163.8	131.8	77.4	1409.4	44.9%
Limitations, GWh	-	-	73.7	1.0	1.4	1.6	3.7	10.8	2.5	1.3	-	-	96.0	3.1%
Disturbance outages, GWh	94.7	239.9	82.6	0.7	0.8	-	0.9	-	-	3.7	-	-	423.3	13.5%
Unplanned maintenance., GWh	-	-	-	-	-	-	-	-	-	-	-	0.7	0.7	0.0%
Planned maintenance, GWh	-	-	-	2.5	-	-	-	2.5	72.1	-	-	1.2	78.3	2.5%
Other outages, GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total, GWh	266.0	240.2	265.7	257.9	266.5	258.1	266.8	266.3	257.4	267.3	257.8	266.1	3136.2	100.0%
Losses SW, GWh	1.1	-	1.4	2.9	3.6	4.9	5.6	5.1	0.7	4.1	3.1	1.7	34.1	1.1%
Losses NE, GWh	0.8	-	0.1	2.0	1.5	0.4	0.4	0.4	2.2	0.6	1.2	2.5	12.3	0.4%

Figure 4.44 presents the annual utilisation of Konti-Skan 2 per utilisation and unavailability category for the years 2012–2022.

Figure 4.45 presents the percentage of hours of a year Konti-Skan 2 has been affected by either a limitation, a disturbance outage, an unplanned or planned maintenance outage or other outage annually during the years 2012–2022. Figure 4.46 presents the annual number of disturbance outages, unplanned and planned maintenances and other outages during the years 2012–2022.

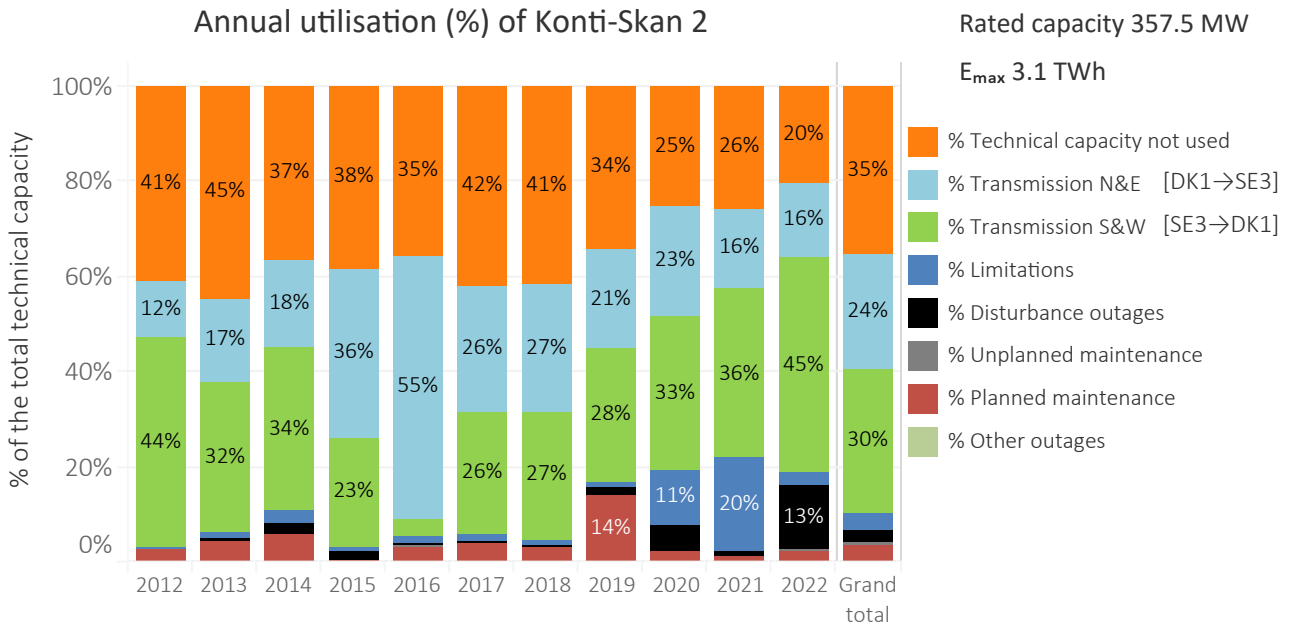

Figure 4.44: Annual utilisation of Konti-Skan 2 per the utilisation and unavailability categories for the years 2012–2022.

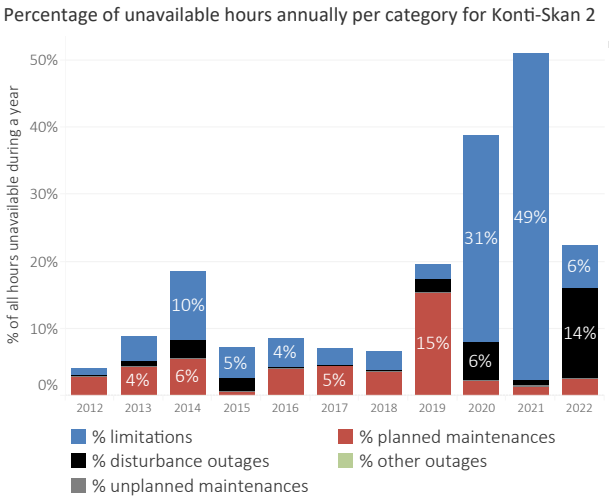

Figure 4.45: Percentage of hours Konti-Skan 2 has been affected by either a limitation or an outage annually since 2012. The percentage is calculated by counting the number of hours with a limitation or outage and dividing it by the total number of hours in a year. It should be noted that any single hour can be affected by both an outage and a limitation.

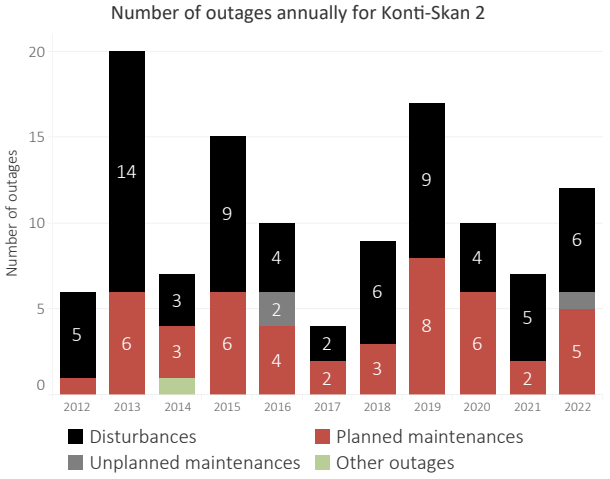

Figure 4.46: The annual number of disturbances, unplanned and planned maintenance outages and other outages for Konti-Skan 2 for the years 2012–2022.

4.4.10 LitPol Link

Figure 4.47 presents the availability and utilisation of LitPol Link for 2022 and Table 3.1 presents the numerical values behind it. LitPol Link has been in operation since the end of 2015. In Lithuania, it is connected to Alytus (bidding zone LT) and in Poland to Ełk (bidding zone PL). The transmission capacity of LitPol Link is 500 MW.

In 2022, LitPol Link had an available technical capacity of 96 %. The technical capacity not used was 35 %. Totally, 1.7 TWh (40 % of the technical capacity) as transmitted west (LT→PL) and 0.9 TWh (22 % of the technical capacity) was transmitted east (PL→LT).

The annual maintenance of LitPol Link and lasted 5 days in May. LitPol Link had in addition unplanned maintenance outage in December, and 5 disturbance outages with minimal impact in 2022.

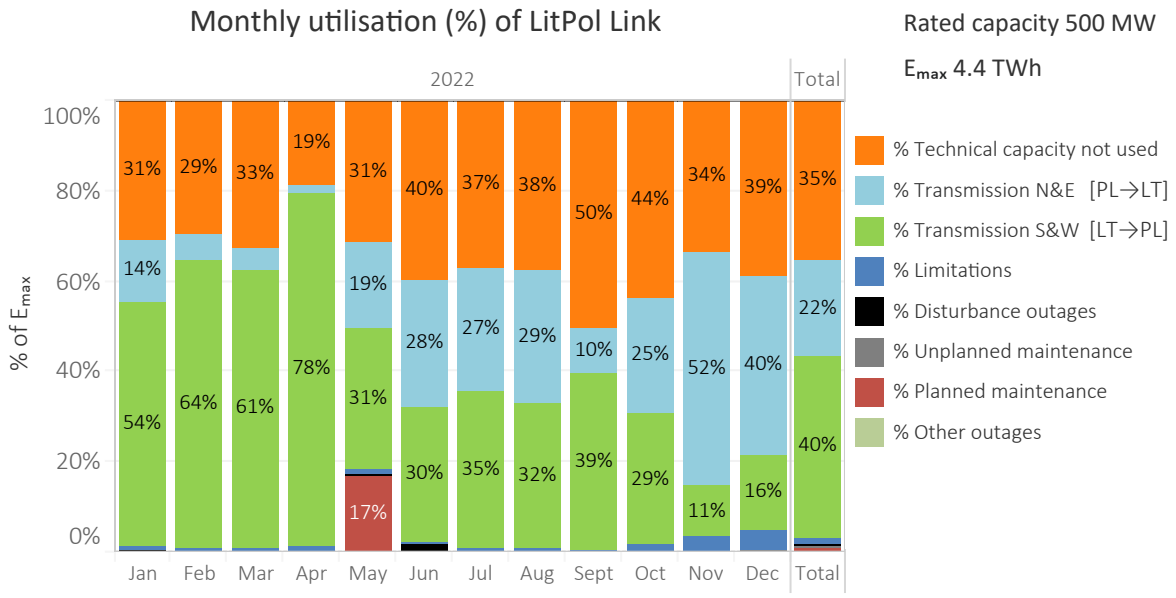

Figure 4.47: Monthly percentage allocation of utilisation by category for LitPol Link in 2022.

Table 4.13: Monthly allocation of technical capacity (E_{max}) for LitPol Link in 2022. Note that losses are not included in the technical capacity (E_{max}), as is shown in Figure 2.1.

Monthly utilisation of LitPol Link (South & West direction LT→PL)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	% total
Technical capacity not used, GWh	114.7	98.7	121.4	67.8	116.2	142.8	137.4	140.1	181.6	162.4	120.8	145.3	1549.4	35.4%
Transmission N&E, GWh	51.7	19.2	18.9	6.7	71.9	102.0	101.3	108.9	35.0	94.3	185.6	147.3	942.7	21.5%
Transmission S&W, GWh	201.1	214.7	228.1	280.5	115.9	106.5	130.6	119.1	141.9	109.1	41.0	60.7	1749.3	39.9%
Limitations, GWh	3.3	3.4	3.6	4.3	3.8	2.4	2.7	3.8	1.4	6.1	12.1	16.3	63.2	1.4%
Disturbance outages, GWh	1.2	-	-	0.6	1.8	6.3	-	-	-	-	-	-	10.0	0.2%
Unplanned maintenance., GWh	-	-	-	-	-	-	-	-	-	-	-	2.5	2.5	0.1%
Planned maintenance, GWh	-	-	-	-	62.4	-	-	-	-	-	-	-	62.4	1.4%
Other outages, GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total, GWh	372.0	336.0	372.0	360.0	372.0	360.0	372.0	372.0	360.0	372.0	359.5	372.0	4379.5	100.0%
Losses SW, GWh	3.0	3.2	3.4	4.0	1.8	1.7	2.1	1.9	2.4	1.9	0.8	1.2	27.4	0.6%
Losses NE, GWh	0.8	0.3	0.3	0.1	1.1	1.6	1.6	1.7	0.7	1.6	2.9	2.4	15.1	0.3%

Figure 4.48 presents the annual utilisation of LitPol Link per utilisation and unavailability category for the years 2016–2022.

Figure 4.49 presents the percentage of hours of a year LitPol Link has been affected by either a limitation, a disturbance outage, an unplanned or planned maintenance outage or other outage annually during the years 2016–2022. Figure 4.50 presents the annual number of disturbance outages, unplanned and planned maintenances and other outages during the years 2016–2022.

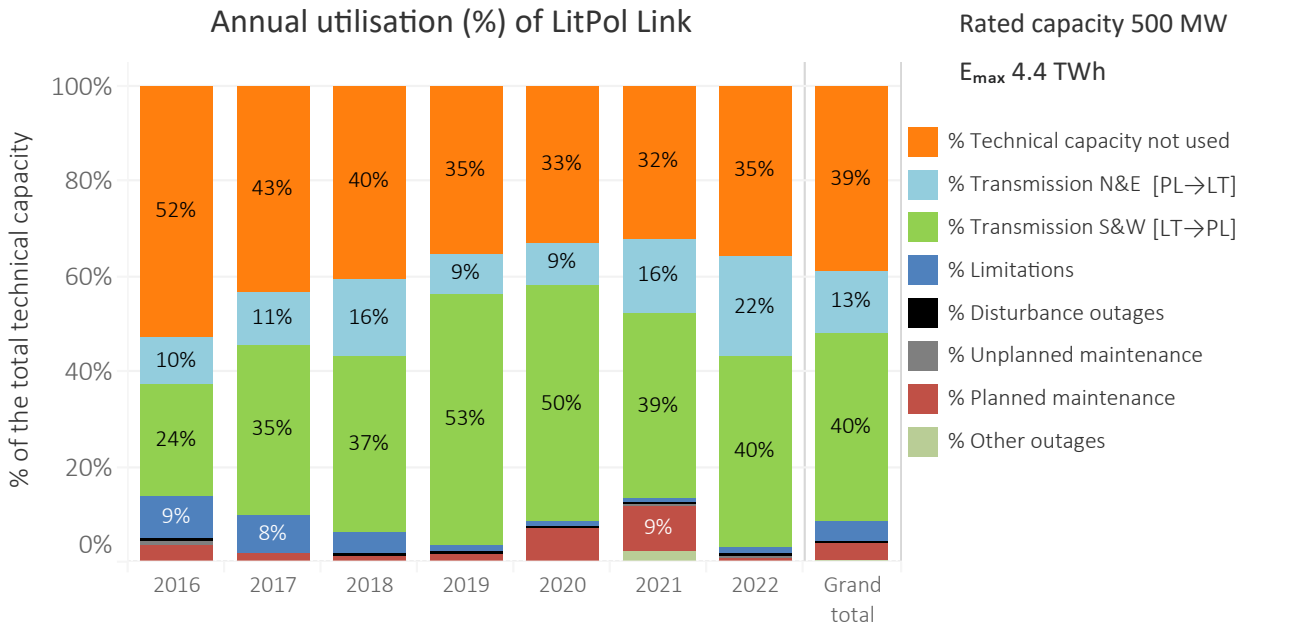

Figure 4.48: Annual utilisation of LitPol Link per the utilisation and unavailability categories for the years 2016–2022.

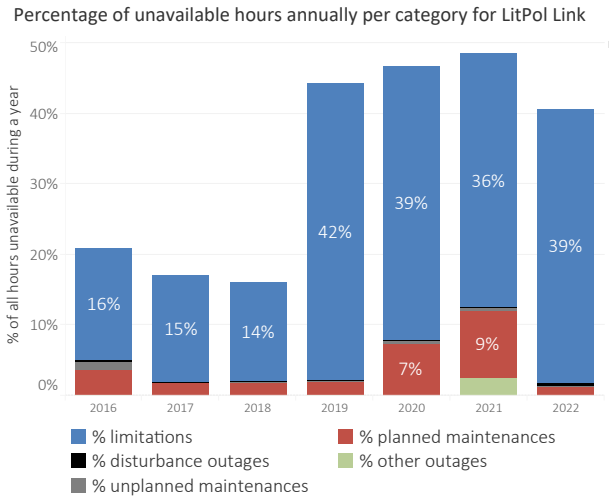

Figure 4.49: Percentage of hours LitPol Link has been affected by either a limitation or an outage annually since 2016. The percentage is calculated by counting the number of hours with a limitation or outage and dividing it by the total number of hours in a year. It should be noted that any single hour can be affected by both an outage and a limitation.

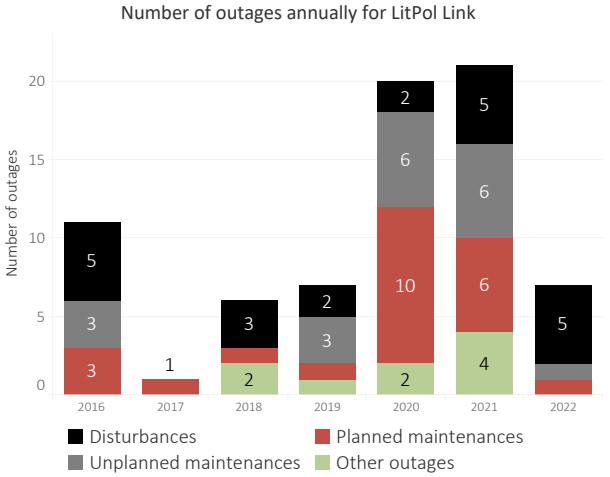

Figure 4.50: The annual number of disturbances, unplanned and planned maintenance outages and other outages for LitPol Link for the years 2016–2022.

4.4.11 NordBalt

Figure 4.51 presents the availability and utilisation of NordBalt for 2022 and Table 4.14 presents the numerical values behind it. NordBalt has been in operation since 2016. In Sweden, it is connected to Nybro (bidding zone SE4) and in Lithuania to Klaipeda (bidding zone LT). The transmission capacity of NordBalt is 700 MW at the receiving end.

In 2022, there was a single outage for the annual maintenance of Nordbalt, which spanned a duration of 7 days in November. During the rest of the year, the technical available capacity of the link remained consistent and comparable to the levels observed in the previous three years, hovering around 96 %.

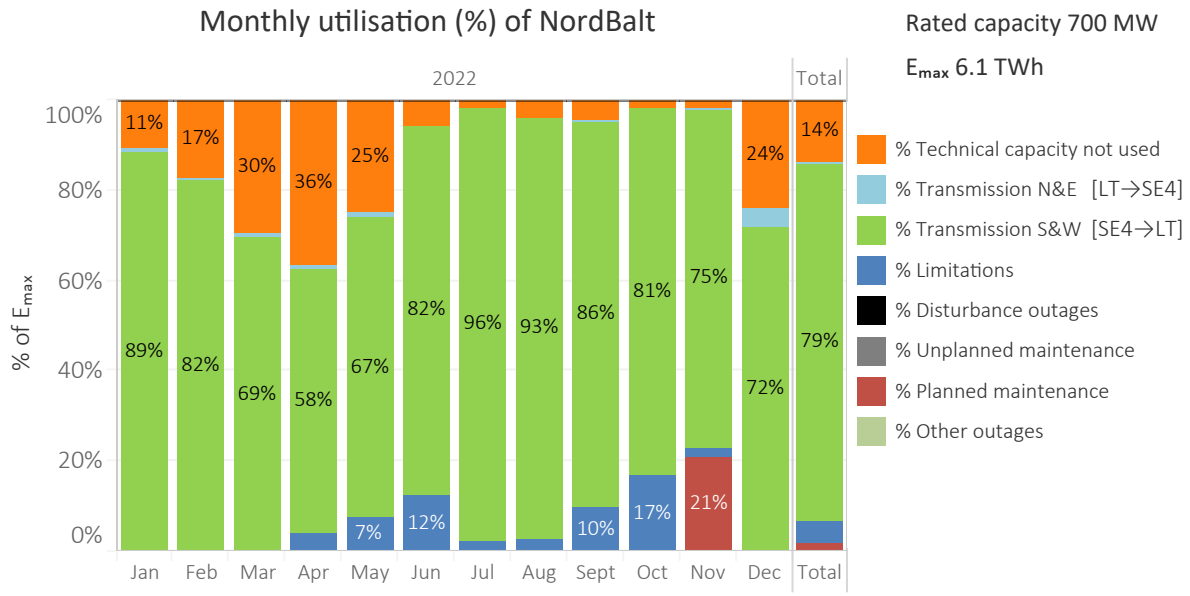

Figure 4.51: Monthly percentage allocation of utilisation by category for NordBalt in 2022.

Table 4.14: Monthly allocation of technical capacity (E_{max}) for NordBalt in 2022. Note that losses are not included in the technical capacity (E_{max}), as is shown in Figure 2.1.

Monthly utilisation of NordBalt (South & West direction SE4→LT)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	% total
Technical capacity not used, GWh	56.4	81.0	153.6	183.4	130.9	30.0	9.5	20.6	23.4	9.9	9.9	126.7	835.2	13.6%
Transmission N&E, GWh	3.5	3.3	5.1	5.9	3.1	-	-	-	0.1	-	-	19.2	40.0	0.7%
Transmission S&W, GWh	460.9	386.1	361.4	294.0	348.0	411.9	500.1	485.8	431.8	423.3	378.8	374.9	4857.1	79.2%
Limitations, GWh	-	-	-	20.7	38.8	62.2	11.1	14.5	48.7	88.3	10.3	-	294.7	4.8%
Disturbance outages, GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	
Unplanned maintenance., GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Planned maintenance, GWh	-	-	-	-	-	-	-	-	-	-	105.0	-	105.0	1.7%
Other outages, GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total, GWh	520.8	470.4	520.1	504.0	520.8	504.0	520.8	520.8	504.0	521.5	504.0	520.8	6132.0	100.0%
Losses SW, GWh	21.4	17.7	15.6	12.0	14.9	17.6	23.8	22.6	18.6	18.0	17.9	17.1	217.3	3.5%
Losses NE, GWh	0.1	0.1	0.2	0.2	0.1	-	-	-	-	-	-	0.7	1.4	0.0%

Figure 4.52 presents the annual utilisation of NordBalt per utilisation and unavailability category for the years 2016–2022.

Figure 4.53 presents the percentage of hours of a year NordBalt has been affected by either a limitation, a disturbance outage, an unplanned or planned maintenance outage or other outage annually during the years 2016–2022. Figure 4.54 presents the annual number of disturbance outages, unplanned and planned maintenances and other outages during the years 2016–2022.

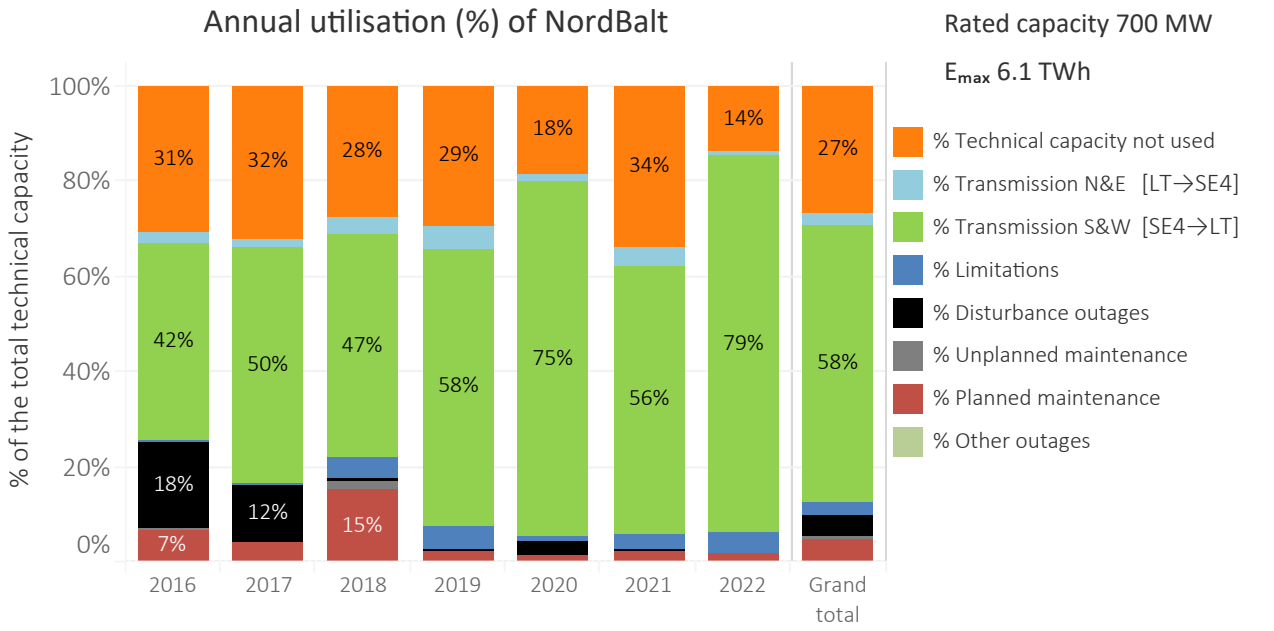

Figure 4.52: Annual utilisation of NordBalt per the utilisation and unavailability categories for the years 2016–2022.

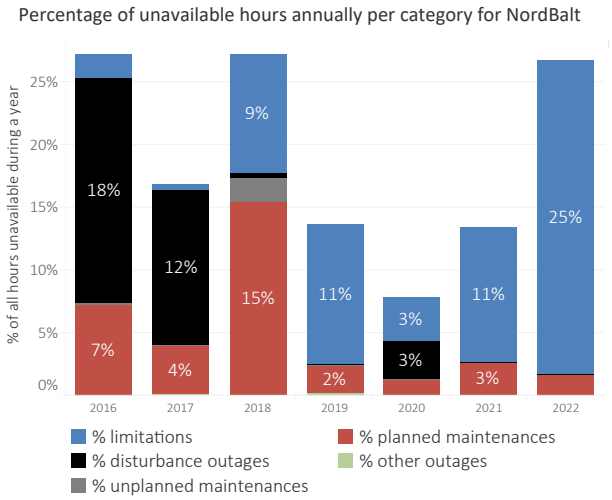

Figure 4.53: Percentage of hours NordBalt has been affected by either a limitation or an outage annually since 2016. The percentage is calculated by counting the number of hours with a limitation or outage and dividing it by the total number of hours in a year. It should be noted that any single hour can be affected by both an outage and a limitation.

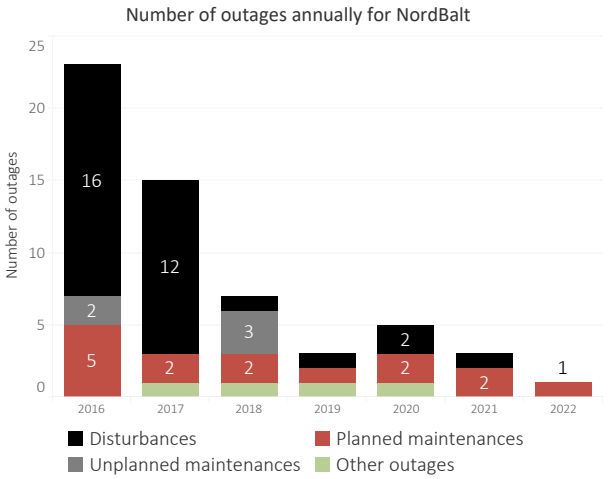

Figure 4.54: The annual number of disturbances, unplanned and planned maintenance outages and other outages for NordBalt for the years 2016–2022.

4.4.12 NordLink 1

Figure 4.55 presents the availability and utilisation of NordLink 1 for 2022 and Table 4.15 presents the numerical values behind it. NordLink 1 is the newly commissioned HVDC link located between Tonstad/Ertsmyra in Sirdal municipality in Norway (bidding zone NO2) and Wilster in Schleswig-Holstein in Germany (bidding zone DE). The parallel NordLink 1 and 2 links were commissioned on December 2020 and have each a transmission capacity of 700 MW (1400 MW in total).

In 2022, NordLink 1 had an available technical capacity of 97 %. The technical capacity not used was 39 %. Totally, 2.8 TWh (45 % of the technical capacity) was transmitted south to Germany (NO2→DE) and 0.8 TWh (13 % of the technical capacity) was transmitted north to Norway (DE→NO2).

HVDC links are normally utilised less during the first year due to testing and minor repairs.

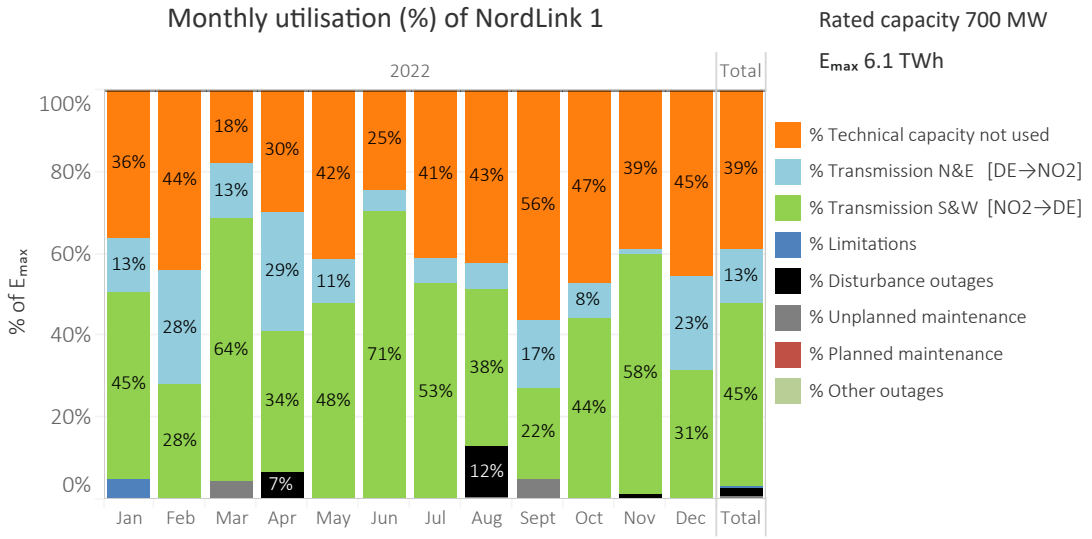

Figure 4.55: Percentage distribution of the availability and utilisation per category according to month for NordLink 1 in 2022.

Table 4.15: Monthly distribution of the technical capacity (E_{max}) for NordLink 1 in 2022. Note that losses are not included in the technical capacity (E_{max}), as is shown in Figure 2.1.

Monthly utilisation of NordLink 1 (South & West direction NO2→DE)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	% total
Technical capacity not used, GWh	189.3	207.3	93.5	151.6	216.7	124.6	213.5	221.8	283.0	247.9	195.7	236.2	2380.9	38.8%
Transmission N&E, GWh	70.1	131.4	70.1	146.7	55.3	24.0	32.0	32.5	84.6	43.3	8.0	120.8	818.8	13.3%
Transmission S&W, GWh	235.8	131.8	335.2	171.2	249.4	356.4	275.7	199.4	111.4	230.7	294.1	164.0	2755.2	44.9%
Limitations, GWh	26.1	-	-	-	-	-	-	-	-	-	-	-	26.1	0.4%
Disturbance outages, GWh	-	-	-	34.8	-	-	-	64.5	-	-	6.8	-	106.2	1.7%
Unplanned maintenance., GWh	-	-	22.4	-	-	-	-	2.9	25.1	-	-	-	50.3	0.8%
Planned maintenance, GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other outages, GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total, GWh	521.3	470.5	521.2	504.3	521.4	505.1	521.2	521.1	504.0	521.9	504.6	521.0	6137.5	100.0%
Losses SW, GWh	7.0	4.2	10.9	5.2	7.4	11.3	8.0	6.7	4.2	6.7	8.5	4.7	84.9	1.4%
Losses NE, GWh	2.1	4.0	2.0	4.7	1.6	0.7	0.9	1.0	2.5	1.3	0.2	3.4	24.4	0.4%

Figure 4.56 presents the annual utilisation of NordLink 1 per utilisation and unavailability category for the years 2021–2022.

Figure 4.57 presents the percentage of hours of a year NordLink 1 has been affected by either a limitation, a disturbance outage, an unplanned or planned maintenance outage or other outage annually during the years 2012–2022. Figure 4.58 presents the annual number of disturbance outages, unplanned and planned maintenances and other outages during the years 2012–2022.

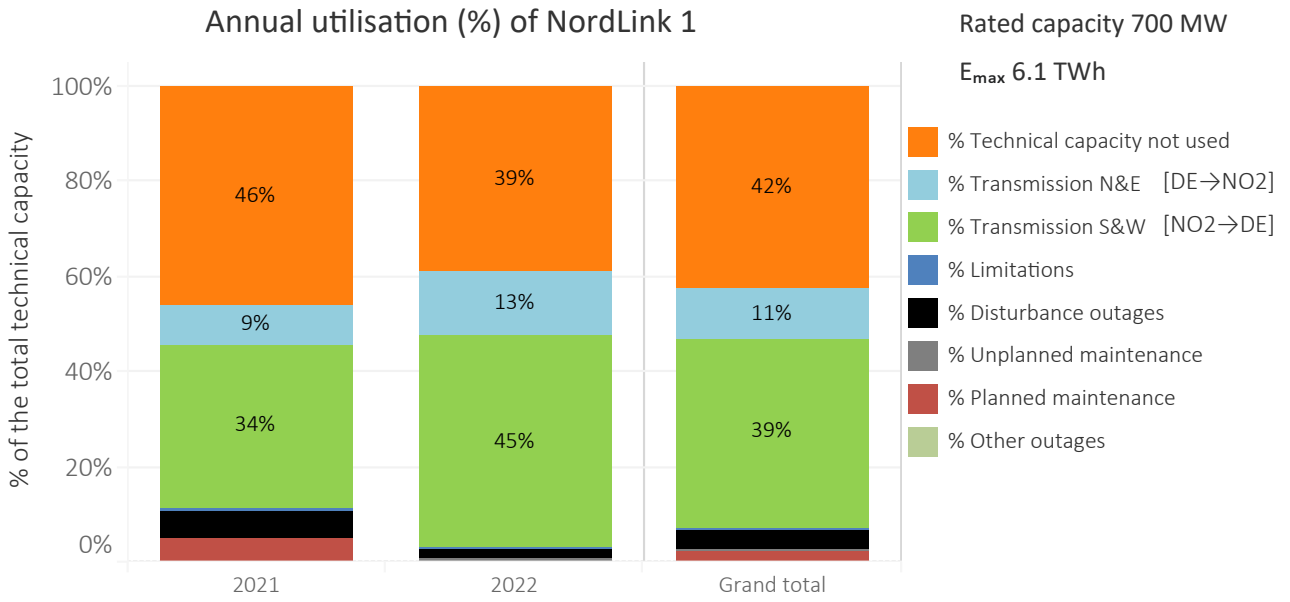

Figure 4.56: Annual utilisation of NordLink 1 per the utilisation and unavailability categories for the years 2021–2022.

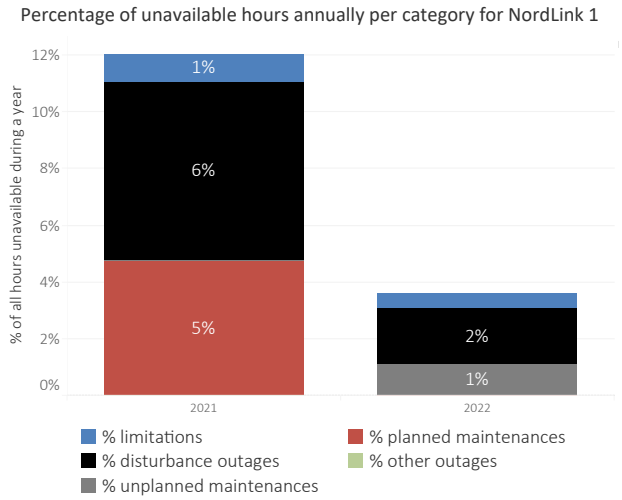

Figure 4.57: Percentage of hours NordLink 1 has been affected by either a limitation or an outage annually since 2021. The percentage is calculated by counting the number of hours with a limitation or outage and dividing it by the total number of hours in a year. It should be noted that any single hour can be affected by both an outage and a limitation.

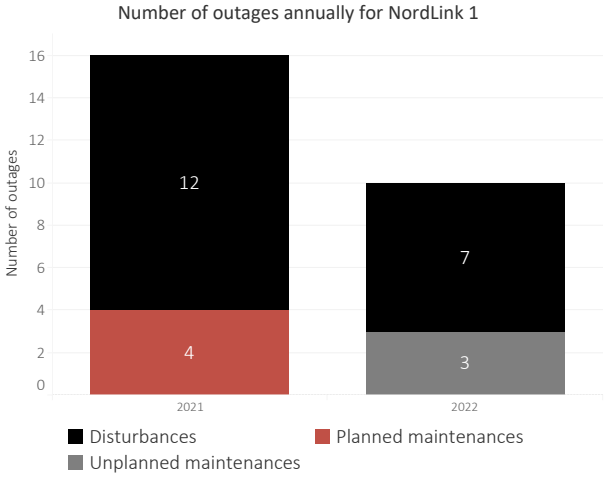

Figure 4.58: The annual number of disturbances, unplanned and planned maintenance outages and other outages for NordLink 1 for the years 2021–2022.

4.4.13 NordLink 2

Figure 4.59 presents the availability and utilisation of NordLink 2 for 2022 and Table 4.16 presents the numerical values behind it. NordLink 2 is the newly commissioned HVDC link located between Tonstad/Ertsmyra in Sirdal municipality in Norway (bidding zone NO2) and Wilster in Schleswig-Holstein in Germany (bidding zone DE). The parallel NordLink 2 and 2 links were commissioned on December 2020 and have each a transmission capacity of 700 MW (1400 MW in total).

In 2022, NordLink 2 had an available technical capacity of 94 %. The technical capacity not used was 37 %. Totally, 2.7 TWh (43 % of the technical capacity) was transmitted south to Germany (NO2→DE) and 0.8 TWh (13 % of the technical capacity) was transmitted north to Norway (DE→NO2).

HVDC links are normally utilised less during the first year due to testing and minor repairs.

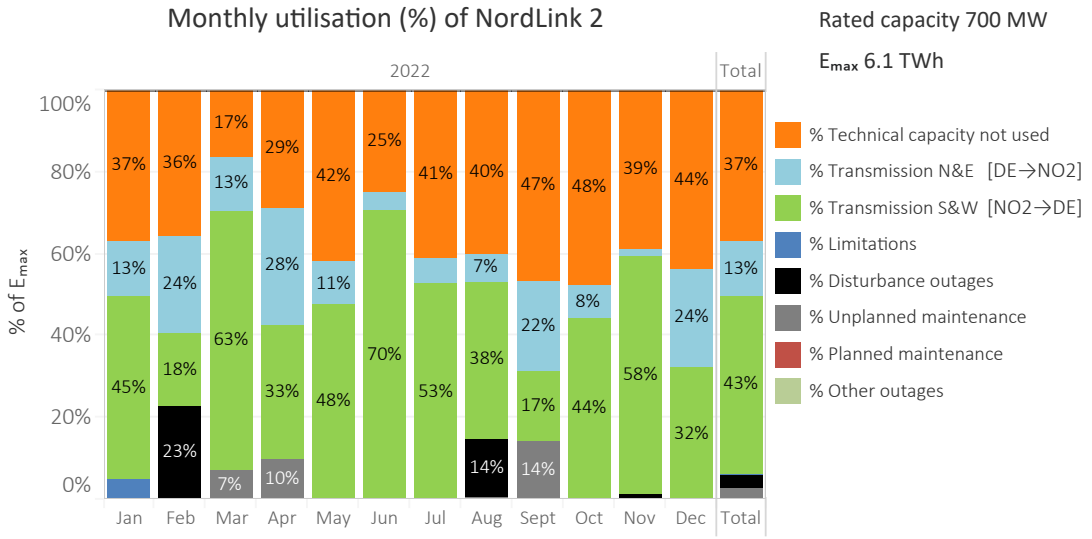

Figure 4.59: Percentage distribution of the availability and utilisation per category according to month for NordLink 2 in 2022.

Table 4.16: Monthly distribution of the technical capacity (E_{max}) for NordLink 2 in 2022. Note that losses are not included in the technical capacity (E_{max}), as is shown in Figure 2.1.

Monthly utilisation of NordLink 2 (South & West direction NO2→DE)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	% total
Technical capacity not used, GWh	192.2	168.8	86.6	146.8	217.5	125.3	214.2	210.2	237.2	248.6	196.5	228.5	2272.5	37.0%
Transmission N&E, GWh	70.0	110.9	67.1	142.6	55.1	23.9	31.9	35.0	108.6	43.2	7.9	124.3	820.7	13.4%
Transmission S&W, GWh	232.5	84.0	330.1	165.2	248.3	355.1	274.8	198.0	86.2	229.8	292.9	168.1	2665.1	43.4%
Limitations, GWh	26.1	-	-	-	-	-	-	-	-	-	-	-	26.1	0.4%
Disturbance outages, GWh	-	106.8	-	-	-	-	-	74.8	-	-	6.8	-	188.4	3.1%
Unplanned maintenance., GWh	-	-	36.6	49.5	-	-	-	2.9	72.0	-	-	-	161.0	2.6%
Planned maintenance, GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other outages, GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total, GWh	520.9	470.4	520.5	504.1	521.0	504.4	521.0	520.9	504.0	521.6	504.2	520.9	6133.8	100.0%
Losses SW, GWh	6.9	2.3	10.7	5.0	7.5	11.3	8.1	6.7	2.9	6.7	8.6	5.0	81.6	1.3%
Losses NE, GWh	7.7	2.3	10.7	5.0	7.5	11.3	8.1	6.7	2.9	6.7	8.6	5.0	82.4	1.3%

Figure 4.60 presents the annual utilisation of NordLink 2 per utilisation and unavailability category for the years 2021–2022.

Figure 4.61 presents the percentage of hours of a year NordLink 2 has been affected by either a limitation, a disturbance outage, an unplanned or planned maintenance outage or other outage annually during the years 2012–2022. Figure 4.62 presents the annual number of disturbance outages, unplanned and planned maintenances and other outages during the years 2012–2022.

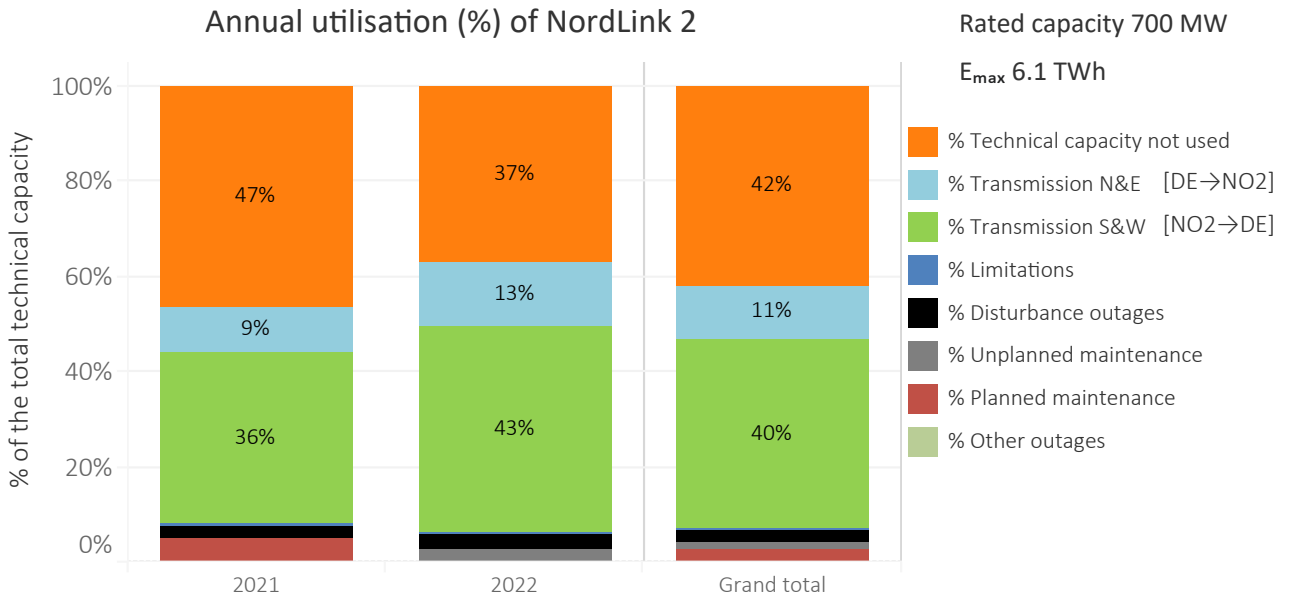

Figure 4.60: Annual utilisation of NordLink 2 per the utilisation and unavailability categories for the years 2021–2022.

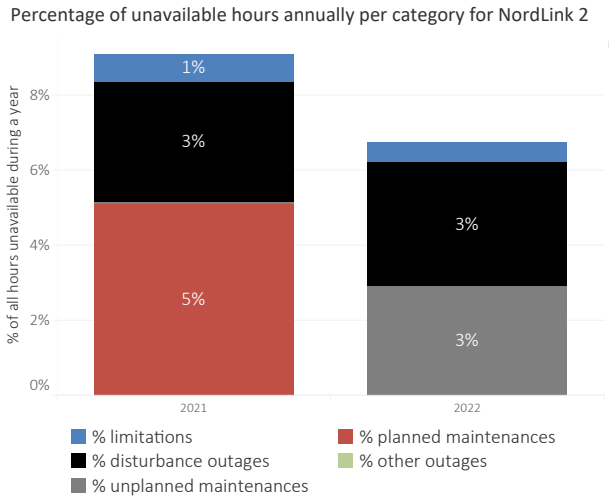

Figure 4.61: Percentage of hours NordLink 2 has been affected by either a limitation or an outage annually since 2021. The percentage is calculated by counting the number of hours with a limitation or outage and dividing it by the total number of hours in a year. It should be noted that any single hour can be affected by both an outage and a limitation.

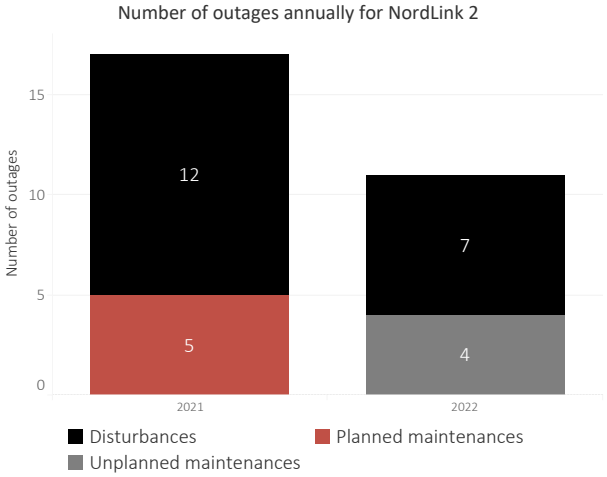

Figure 4.62: The annual number of disturbances, unplanned and planned maintenance outages and other outages for NordLink 2 for the years 2021–2022.

4.4.14 NorNed

Figure 4.63 presents the availability and utilisation of NorNed for 2022 and Table 4.17 presents the numerical values behind it. In Norway on the south-western coast (bidding zone NO2) it is connected to Feda substation and in Netherlands to Eemshaven (bidding zone APX NL). NorNed has been in operation since 2008 and its transmission capacity is 700 MW.

In 2022, NorNed had an available technical capacity of 51 %. The technical capacity not used was 16 %. Totally, 1,8 TWh (29 % of the technical capacity) was transmitted south to Netherlands (NO2→NL) and 0.4 TWh (6 % of the technical capacity) was transmitted north to Norway (NL→NO2).

NorNed had a major cable fault on the Dutch side so the cable was out between May and October.

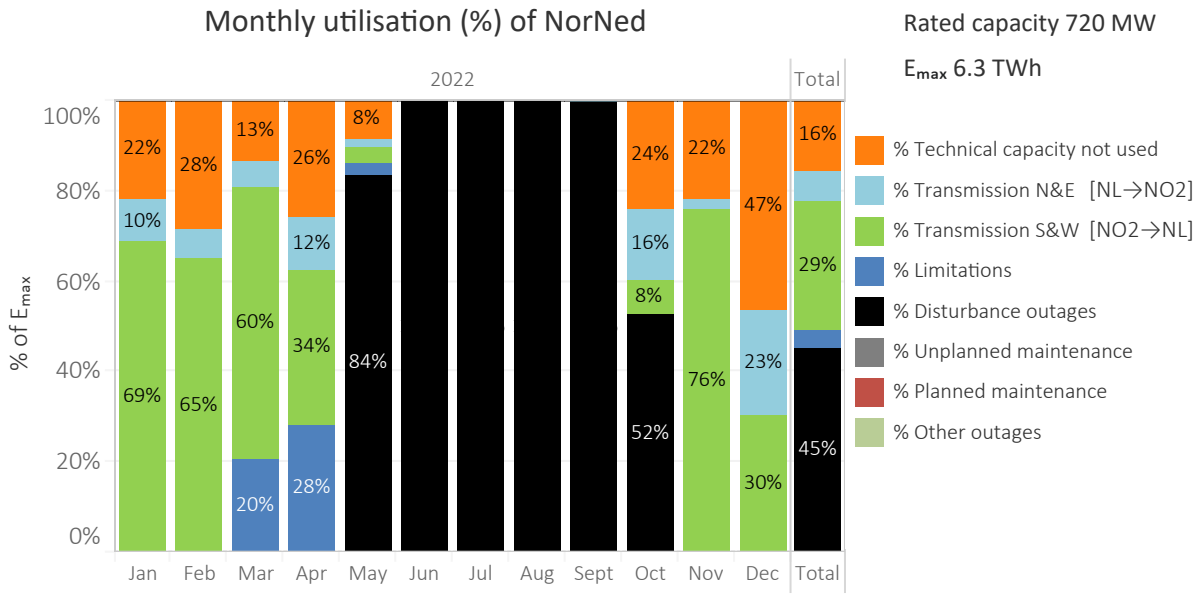

Figure 4.63: Monthly percentage allocation of utilisation by category for NorNed in 2022.

Table 4.17: Monthly allocation of technical capacity (E_{max}) for NorNed in 2022. Note that losses are not included in the technical capacity (E_{max}), as is shown in Figure 2.1.

Monthly utilisation of NorNed (South & West direction NO2→NL)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	% total
Technical capacity not used, GWh	116.2	137.3	70.9	135.1	44.5	-	-	-	-	129.7	114.5	249.3	997.5	15.8%
Transmission N&E, GWh	51.5	31.6	32.0	59.9	9.6	-	-	-	-	83.4	10.8	123.8	402.6	6.4%
Transmission S&W, GWh	367.5	314.9	323.2	177.9	18.9	-	-	-	2.5	41.8	393.1	162.6	1802.6	28.6%
Limitations, GWh	0.5	-	108.8	145.4	14.3	-	-	-	-	-	-	-	269.1	4.3%
Disturbance outages, GWh	-	-	-	-	448.3	518.4	535.7	535.7	515.8	281.6	-	-	2835.5	45.0%
Unplanned maintenance., GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Planned maintenance, GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other outages, GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total, GWh	535.7	483.8	535.0	518.4	535.7	518.4	535.7	535.7	518.4	536.4	518.4	535.7	6307.2	100.0%
Losses SW, GWh	13.0	11.8	10.8	4.8	0.5	-	-	-	0.1	1.6	16.5	6.4	65.4	1.0%
Losses NE, GWh	2.0	1.2	1.0	1.8	0.3	-	-	-	-	3.6	0.4	5.3	15.7	0.2%

Figure 4.64 presents the annual utilisation of NorNed per utilisation and unavailability category for the years 2012–2022.

Figure 4.65 presents the percentage of hours of a year NorNed has been affected by either a limitation, a disturbance outage, an unplanned or planned maintenance outage or other outage annually during the years 2012–2022. Figure 4.66 presents the annual number of disturbance outages, unplanned and planned maintenances and other outages during the years 2012–2022.

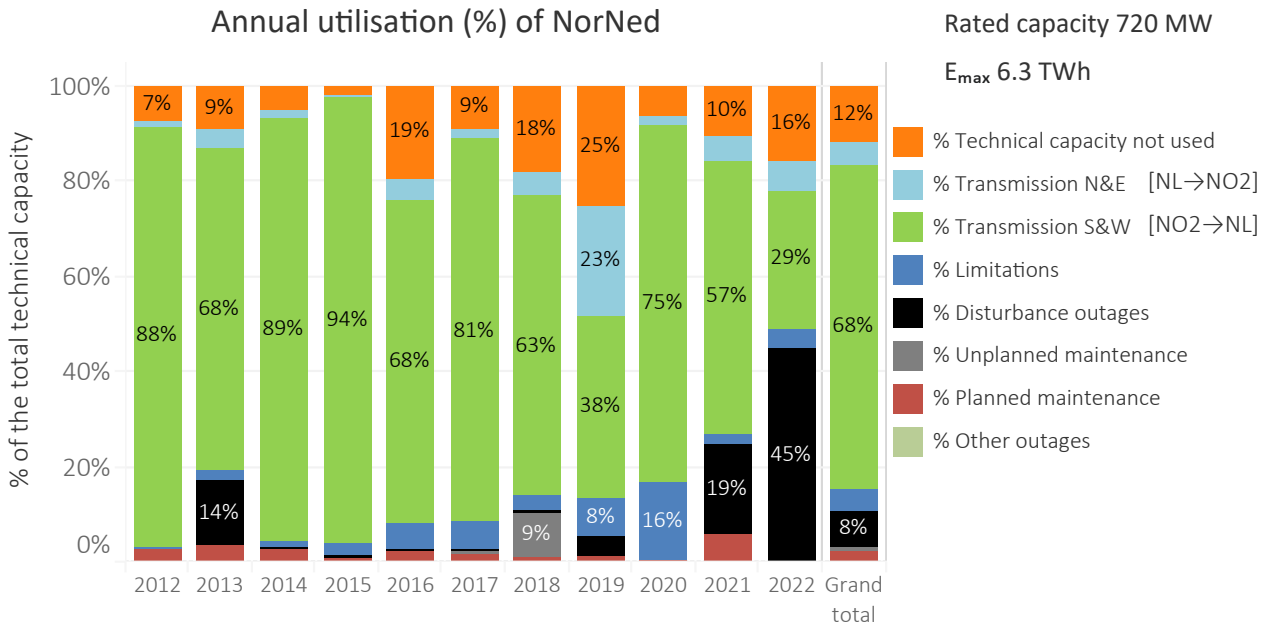

Figure 4.64: Annual utilisation of NorNed per the utilisation and unavailability categories for the years 2012–2022.

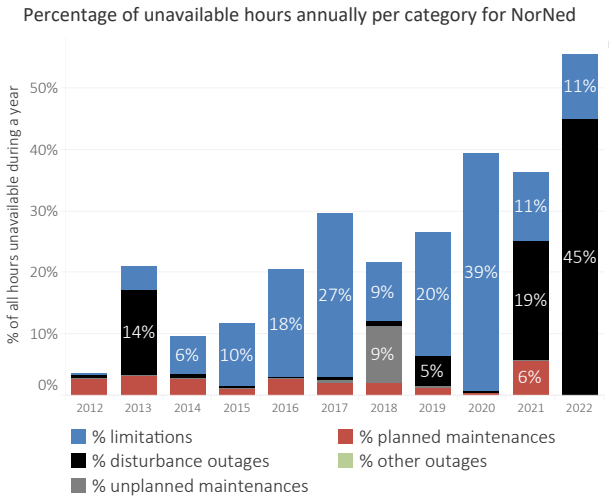

Figure 4.65: Percentage of hours NorNed has been affected by either a limitation or an outage annually since 2012. The percentage is calculated by counting the number of hours with a limitation or outage and dividing it by the total number of hours in a year. It should be noted that any single hour can be affected by both an outage and a limitation.

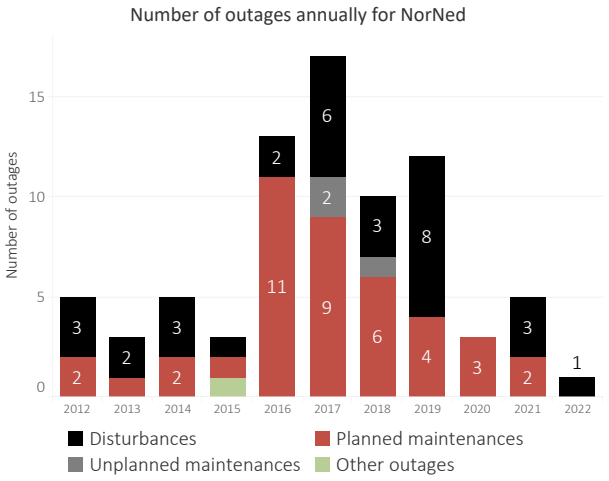

Figure 4.66: The annual number of disturbances, unplanned and planned maintenance outages and other outages for NorNed for the years 2012–2022.

4.4.15 North Sea Link 1

Figure 4.67 presents the availability and utilisation of North Sea Link 1 for 2022 and Table 4.18 presents the numerical values behind it.

North Sea Link 1 where put into operation 1. October 2021 so 2022 was the first complete year in operation. With a cable length of 720 km the cable is the longest in this publication. During the year there have been to longer outages for North Sea Link 1. North Sea Link 1 went into the 2022 with operation on just North Sea Link 2 due to a fault in the yard in Blyth that where fixed in February. Then a new fault occurred in Blyth the 22. March with a three month repair time. In May and June this window was utilized to do the annual maintenance on both poles. Apart from that there have been only shorter outages. The technical capacity has been reduced periodically due to AC network limitations, mainly in the United Kingdom.

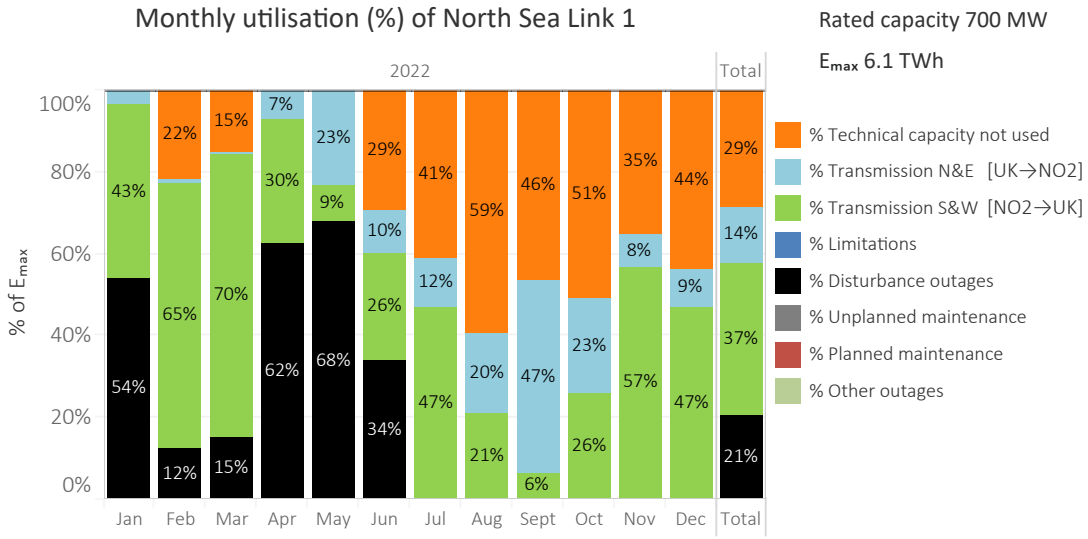

Figure 4.67: Monthly percentage allocation of utilisation by category for North Sea Link 1 in 2022.

Table 4.18: Monthly allocation of technical capacity (E_{max}) for North Sea Link 1 in 2022. Note that losses are not included in the technical capacity (E_{max}), as is shown in Figure 2.1.

Monthly utilisation of North Sea Link 1 (South & West direction NO2→UK)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	% total
Technical capacity not used, GWh	-	101.9	78.6	-	-	148.4	214.3	308.6	234.2	265.1	178.8	228.7	1758.8	28.7%
Transmission N&E, GWh	17.9	4.7	1.3	36.3	120.9	52.1	63.3	102.7	238.3	121.5	39.4	47.4	845.8	13.8%
Transmission S&W, GWh	222.3	305.1	361.5	153.2	45.9	131.4	243.3	109.4	31.5	134.9	285.8	244.7	2269.0	37.0%
Limitations, GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Disturbance outages, GWh	280.5	58.6	78.6	314.5	354.0	172.1	-	-	-	-	-	-	1258.4	20.5%
Unplanned maintenance., GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Planned maintenance, GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other outages, GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total, GWh	520.8	470.4	520.1	504.0	520.8	504.0	520.8	520.8	504.0	521.5	504.0	520.8	6132.0	100.0%
Losses SW, GWh	14.6	11.3	14.5	9.8	2.9	4.8	8.6	4.5	1.0	4.3	9.6	8.0	93.7	1.5%
Losses NE, GWh	1.1	0.2	-	2.1	7.4	2.2	1.9	4.0	7.4	3.9	1.2	1.5	33.0	0.5%

4.4.16 North Sea Link 2

Figure 4.68 presents the availability and utilisation of North Sea Link 2 for 2022 and Table 4.19 presents the numerical values behind it.

North Sea Link 2 where put into operation 1. October 2021 so 2022 was the first complete year in operation. With a cable length of 720 km the cable is the longest in this publication. During the year there have been to longer outages for North Sea Link 2. North Sea Link 2 went into the 2022 with operation on just North Sea Link 1 due to a fault in the yard in Blyth that where fixed in February. Then a new fault occurred in Blyth the 22. March with a three month repair time. In May and June this window was utilized to do the annual maintenance on both poles. Apart from that there have been only shorter outages. The technical capacity has been reduced periodically due to AC network limitations, mainly in the United Kingdom.

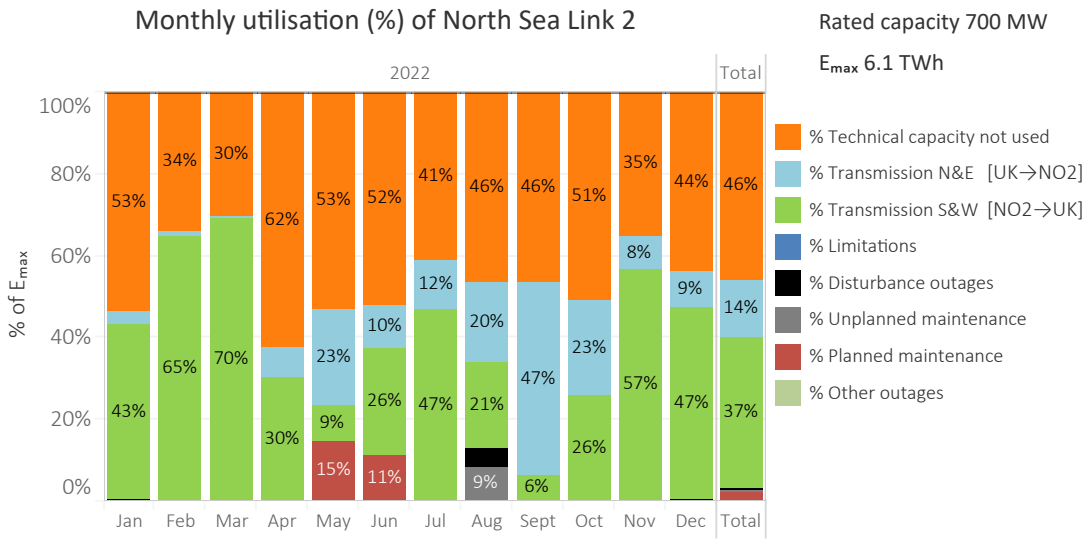

Figure 4.68: Monthly percentage allocation of utilisation by category for North Sea Link 2 in 2022.

Table 4.19: Monthly allocation of technical capacity (E_{max}) for North Sea Link 2 in 2022. Note that losses are not included in the technical capacity (E_{max}), as is shown in Figure 2.1.

Monthly utilisation of North Sea Link 2 (South & West direction NO2→UK)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	% total
Technical capacity not used, GWh	278.0	160.6	157.3	314.5	277.2	263.4	214.3	241.7	234.2	265.1	178.8	226.9	2812.0	45.9%
Transmission N&E, GWh	17.9	4.7	1.3	36.3	120.9	52.1	63.3	102.7	238.3	121.5	39.4	47.4	845.8	13.8%
Transmission S&W, GWh	222.3	305.1	361.5	153.2	45.9	131.4	243.3	109.4	31.5	134.9	285.8	244.7	2269.0	37.0%
Limitations, GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Disturbance outages, GWh	2.5	-	-	-	-	-	-	22.0	-	-	-	1.8	26.4	0.4%
Unplanned maintenance., GWh	-	-	-	-	-	-	-	44.9	-	-	-	-	44.9	0.7%
Planned maintenance, GWh	-	-	-	-	76.8	57.1	-	-	-	-	-	-	133.9	2.2%
Other outages, GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total, GWh	520.8	470.4	520.1	504.0	520.8	504.0	520.8	520.8	504.0	521.5	504.0	520.8	6132.0	100.0%
Losses SW, GWh	14.6	11.3	14.5	9.8	2.9	4.8	8.6	4.5	1.0	4.3	9.6	8.0	93.7	1.5%
Losses NE, GWh	1.1	0.2	-	2.1	7.4	2.2	1.9	4.0	7.4	3.9	1.2	1.5	33.0	0.5%

4.4.17 Skagerrak 1

Figure 4.69 presents the availability and utilisation of Skagerrak 1 for 2022 and Table 4.20 presents the numerical values behind it. Skagerrak 1 and Skagerrak 2 have been in operation since 1976 and are the oldest HVDC links in operation in the Nordic countries. In Norway, the links are connected to Kristiansand on the southern coast (bidding zone NO2) and in Denmark to Tjele (bidding zone DK1), 15 km east of the town of Viborg in the northern part of Jutland. The transmission capacity is 236 MW at the receiving end.

In 2022, Skagerrak 1 had an available technical capacity of 98 %. The technical capacity not used was 44 %. Totally, 0.7 TWh (36 % of the technical capacity) was transmitted south to Denmark (NO2→DK1) and 0.4 TWh (19 % of the technical capacity) was transmitted north to Norway (DK1→NO2).

Annual maintenance for Skagerrak 1 lasted 6 days. There were one minor disturbance outage and two minor corrective maintenance outages. Skagerrak 1, 2, 3 and 4 have been limited due to "careful operation" since the Skagerrak 4 cable faults in December 2019. In 2022, the north and the south direction were approximately equally prioritized. The careful operation of the Skagerrak links has impacted each of the links differently based on the transmission direction and which links are in operation. For example, if all links are available and the transmission goes from Denmark to Norway (i.e., north), Skagerrak 2 is limited to 0 MW and Skagerrak 3 is limited to 200 MW to maintain acceptable electrode current levels.

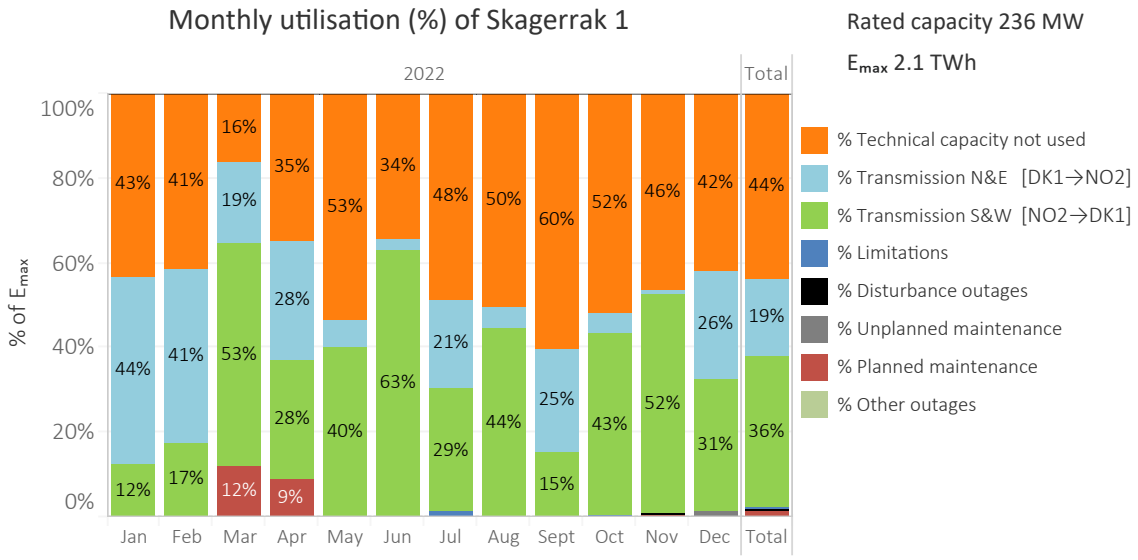

Figure 4.69: Monthly percentage allocation of utilisation by category for Skagerrak 1 in 2022.

Table 4.20: Monthly allocation of technical capacity (E_{max}) for Skagerrak 1 in 2022. Note that losses are not included in the technical capacity (E_{max}), as is shown in Figure 2.1.

Monthly utilisation of Skagerrak 1 (South & West direction NO2→DK1)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	% total
Technical capacity not used, GWh	75.8	65.8	28.4	59.7	93.9	58.1	85.1	88.3	102.3	91.5	78.8	73.5	901.1	43.5%
Transmission N&E, GWh	77.8	65.1	33.7	47.8	11.3	4.8	36.8	9.2	42.0	8.2	1.7	44.9	383.2	18.5%
Transmission S&W, GWh	21.8	27.7	92.4	48.0	70.6	107.0	51.6	78.0	25.8	75.8	88.1	54.9	741.8	35.8%
Limitations, GWh	0.2	-	-	-	-	-	2.1	-	-	0.5	-	-	2.8	0.1%
Disturbance outages, GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0%
Unplanned maintenance., GWh	-	-	-	-	-	-	-	-	-	-	-	2.5	2.5	0.1%
Planned maintenance, GWh	-	-	21.2	14.8	-	-	-	-	-	-	1.7	-	37.8	1.8%
Other outages, GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total, GWh	175.6	158.6	175.7	170.3	175.8	170.0	175.6	175.6	170.0	175.9	170.3	175.8	2069.2	100.0%
Losses SW, GWh	0.9	1.1	4.2	2.1	3.1	5.2	2.6	4.0	1.2	3.4	3.9	2.3	33.9	1.6%
Losses NE, GWh	3.5	3.2	1.4	2.1	0.5	0.2	1.5	0.4	1.7	0.4	0.1	2.2	17.1	0.8%

Figure 4.70 presents the annual utilisation of Skagerrak 1 per utilisation and unavailability category for the years 2012–2022.

Figure 4.71 presents the percentage of hours of a year Skagerrak 1 has been affected by either a limitation, a disturbance outage, an unplanned or planned maintenance outage or other outage annually during the years 2012–2022. Figure 4.72 presents the annual number of disturbance outages, unplanned and planned maintenances and other outages during the years 2012–2022.

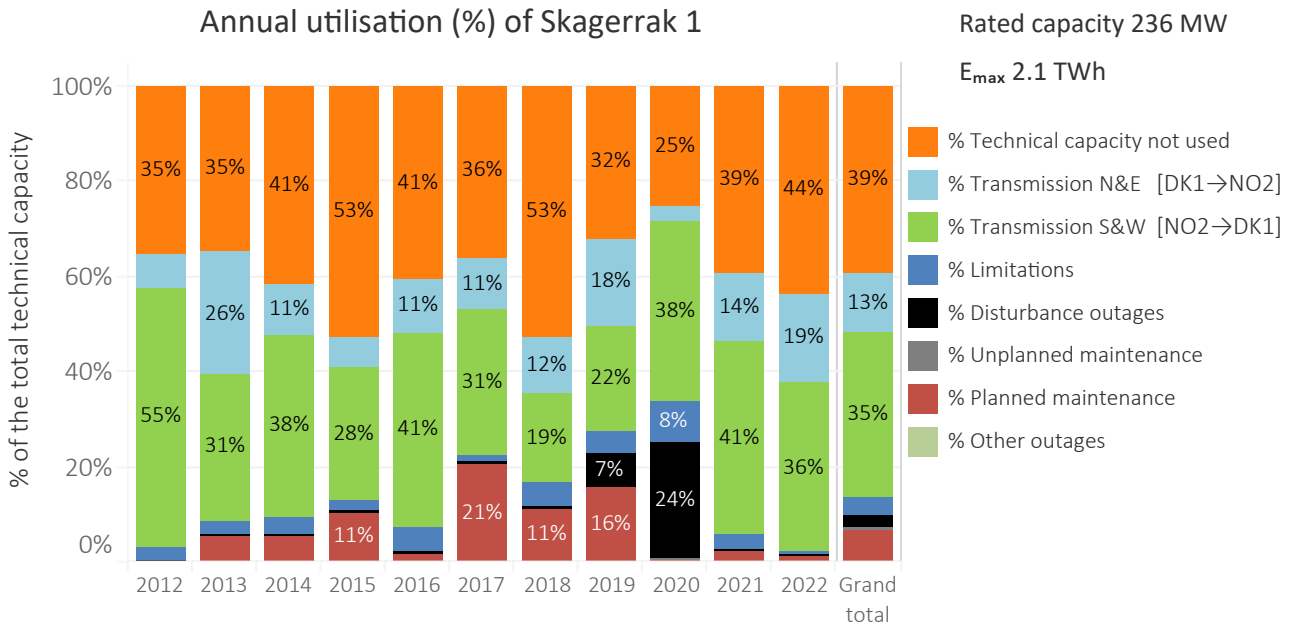

Figure 4.70: Annual utilisation of Skagerrak 1 per the utilisation and unavailability categories for the years 2012–2022.

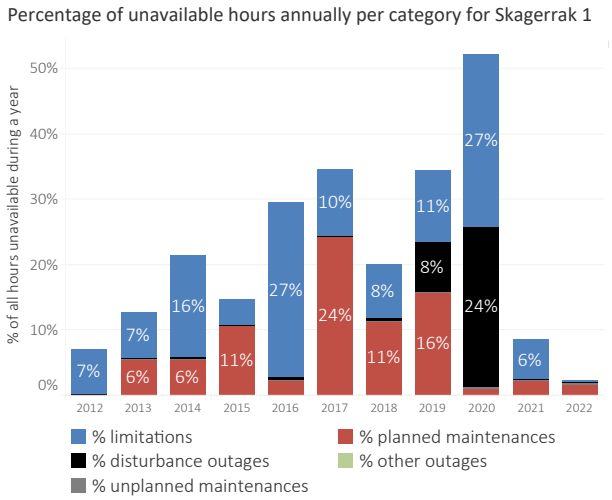

Figure 4.71: Percentage of hours Skagerrak 1 has been affected by either a limitation or an outage annually since 2012. The percentage is calculated by counting the number of hours with a limitation or outage and dividing it by the total number of hours in a year. It should be noted that any single hour can be affected by both an outage and a limitation.

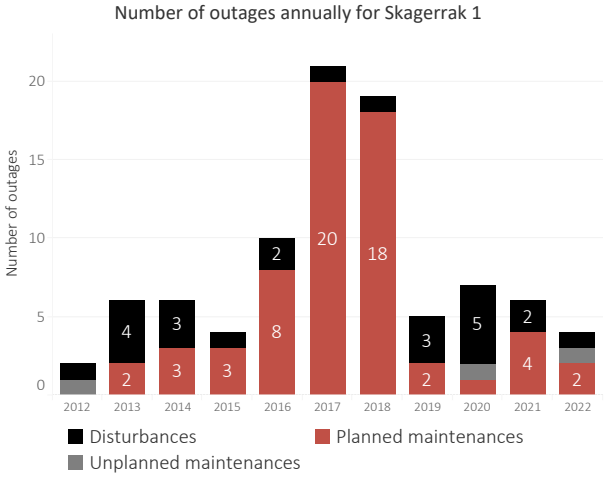

Figure 4.72: The annual number of disturbances, unplanned and planned maintenance outages and other outages for Skagerrak 1 for the years 2012–2022. Skagerrak 1 had no other outages during the years 2012–2022.

4.4.18 Skagerrak 2

Figure 4.73 presents the availability and utilisation of Skagerrak 2 for 2022 and Table 4.21 presents the numerical values behind it. Skagerrak 1 and Skagerrak 2 have been in operation since 1976 and are the oldest HVDC links in operation in the Nordic countries. In Norway, the links are connected to Kristiansand on the southern coast (bidding zone NO2) and in Denmark to Tjele (bidding zone DK1), 15 km east of the town of Viborg in the northern part of Jutland. The transmission capacity of Skagerrak 2 is 236 MW at the receiving end.

In 2022, Skagerrak 2 had an available technical capacity of 60 %. The technical capacity not used was 34 %. Totally, 0.4 TWh (17 % of the technical capacity) was transmitted south to Denmark (NO2→DK1) and 0.2 TWh (9 % of the technical capacity) was transmitted north to Norway (DK1→NO2).

Annual maintenance for Skagerrak 2 lasted 7 days in April. There were one minor disturbance outage. Skagerrak 1, 2, 3 and 4 have been limited due to "careful operation" since the Skagerrak 4 cable faults in December 2019. In 2022, the north and the south direction were approximately equally prioritized. The careful operation of the Skagerrak links has impacted each of the links differently based on the transmission direction and which links are in operation. For example, if all links are available and the transmission goes from Denmark to Norway (i.e., north), Skagerrak 2 is limited to 0 MW and Skagerrak 3 is limited to 200 MW to maintain acceptable electrode current levels.

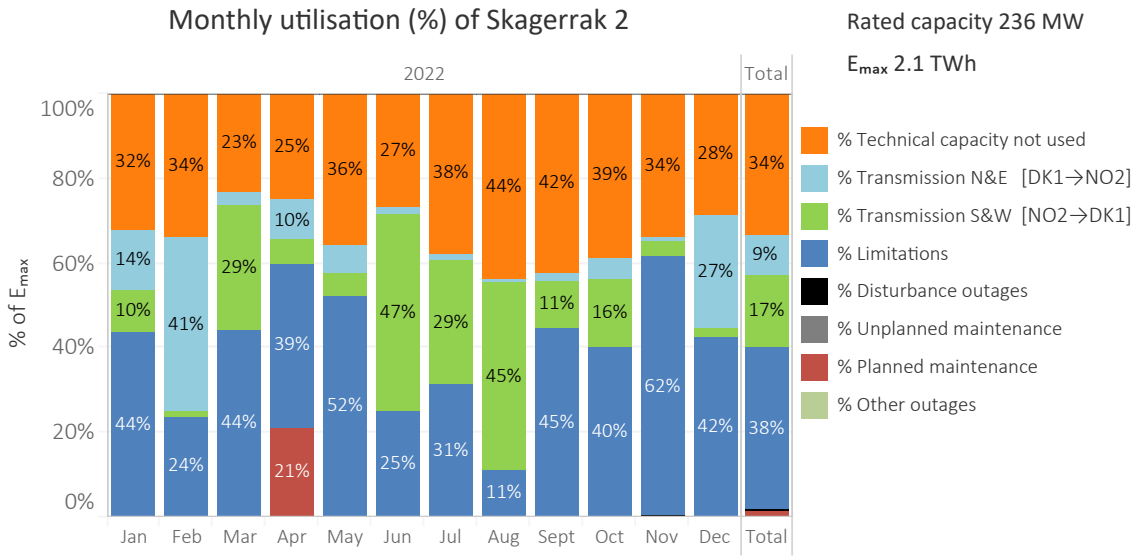

Figure 4.73: Monthly percentage allocation of utilisation by category for Skagerrak 2 in 2022.

Table 4.21: Monthly allocation of technical capacity (E_{max}) for Skagerrak 2 in 2022. Note that losses are not included in the technical capacity (E_{max}), as is shown in Figure 2.1.

Monthly utilisation of Skagerrak 2 (South & West direction NO2→DK1)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	% total
Technical capacity not used, GWh	56.5	53.9	40.6	42.4	62.8	45.3	66.7	77.2	72.1	68.5	57.5	49.8	693.5	33.5%
Transmission N&E, GWh	24.8	65.0	5.4	16.3	11.3	3.0	2.6	0.9	3.2	8.2	1.3	47.5	189.5	9.2%
Transmission S&W, GWh	17.2	1.8	51.5	9.4	9.4	79.4	51.6	78.1	19.0	28.4	6.2	3.7	355.8	17.2%
Limitations, GWh	77.0	37.8	77.8	66.3	92.0	42.2	54.8	19.4	75.6	70.7	104.5	74.5	792.8	38.3%
Disturbance outages, GWh	-	-	-	-	-	-	-	-	-	-	0.4	-	0.4	0.0%
Unplanned maintenance., GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Planned maintenance, GWh	-	-	-	35.4	-	-	-	-	-	-	-	-	35.4	1.7%
Other outages, GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total, GWh	175.6	158.6	175.4	169.9	175.6	169.9	175.6	175.6	169.9	175.8	169.9	175.6	2067.4	100.0%
Losses SW, GWh	0.8	0.2	2.7	0.6	0.7	4.1	2.5	3.9	1.0	1.7	0.5	0.3	19.1	0.9%
Losses NE, GWh	1.5	3.3	0.4	0.8	0.6	0.2	0.2	0.1	0.3	0.4	0.1	2.4	10.1	0.5%

Figure 4.74 presents the annual utilisation of Skagerrak 2 per utilisation and unavailability category for the years 2012–2022.

Figure 4.75 presents the percentage of hours of a year Skagerrak 2 has been affected by either a limitation, a disturbance outage, an unplanned or planned maintenance outage or other outage annually during the years 2012–2022. Figure 4.76 presents the annual number of disturbance outages, unplanned and planned maintenances and other outages during the years 2012–2022.

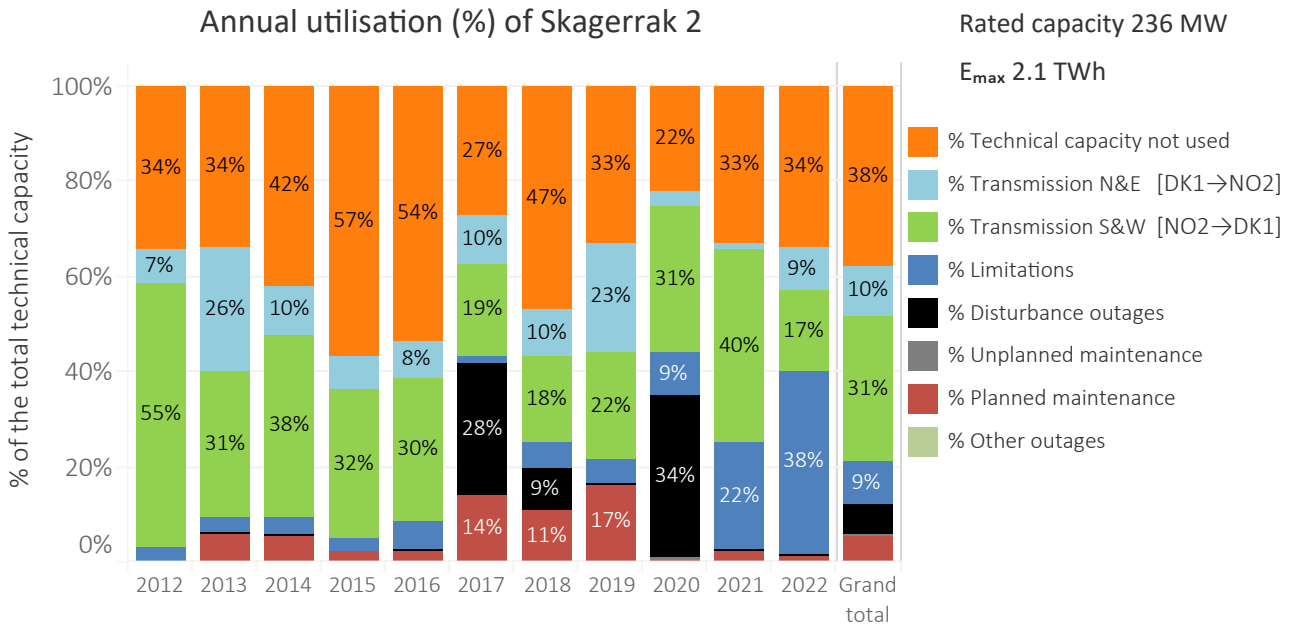

Figure 4.74: Annual utilisation of Skagerrak 2 per the utilisation and unavailability categories for the years 2012–2022.

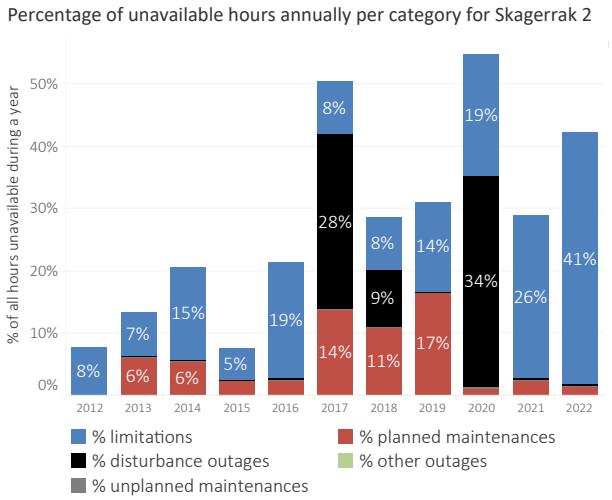

Figure 4.75: Percentage of hours Skagerrak 2 has been affected by either a limitation or an outage annually since 2012. The percentage is calculated by counting the number of hours with a limitation or outage and dividing it by the total number of hours in a year. It should be noted that any single hour can be affected by both an outage and a limitation.

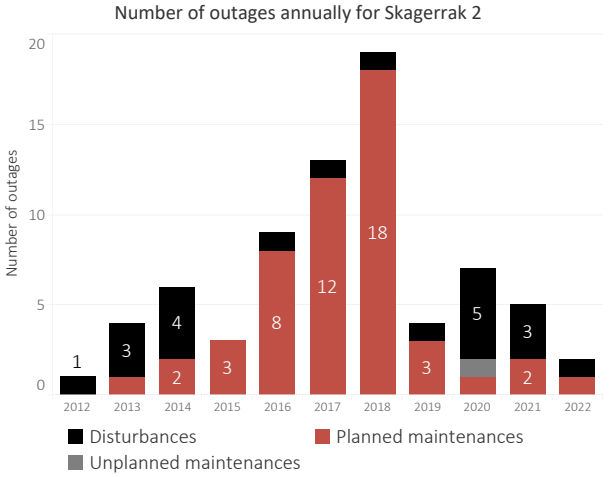

Figure 4.76: The annual number of disturbances, unplanned and planned maintenance outages and other outages for Skagerrak 2 for the years 2012–2022. Skagerrak 2 had no other outages during the years 2012–2022.

4.4.19 Skagerrak 3

Figure 4.77 presents the availability and utilisation of Skagerrak 3 for 2022 and Table 4.22 presents the numerical values behind it. Skagerrak 3 has been in operation since 1993. In Norway, it is connected to Kristiansand (bidding zone NO2) and in Denmark to Tjele (bidding zone DK1). The transmission capacity of Skagerrak 3 is 478 MW at the receiving end.

In 2022, Skagerrak 3 had an available technical capacity of 75 %. The technical capacity not used was 23 %. Totally, 1.4 TWh (33 % of the technical capacity) was transmitted south to Denmark (NO2→DK1) and 0.8 TWh (20 % of the technical capacity) was transmitted north to Norway (DK1→NO2).

There was no annual maintenance for Skagerrak 3 in 2022. There were two minor disturbance outages and three minor corrective maintenance. Skagerrak 1, 2, 3 and 4 have been limited due to "careful operation" since the Skagerrak 4 cable faults in December 2019. In 2022, the north and the south direction were approximately equally prioritized. The careful operation of the Skagerrak links has impacted each of the links differently based on the transmission direction and which links are in operation. For example, if all links are available and the transmission goes from Denmark to Norway (i.e., north), Skagerrak 2 is limited to 0 MW and Skagerrak 3 is limited to 200 MW to maintain acceptable electrode current levels.

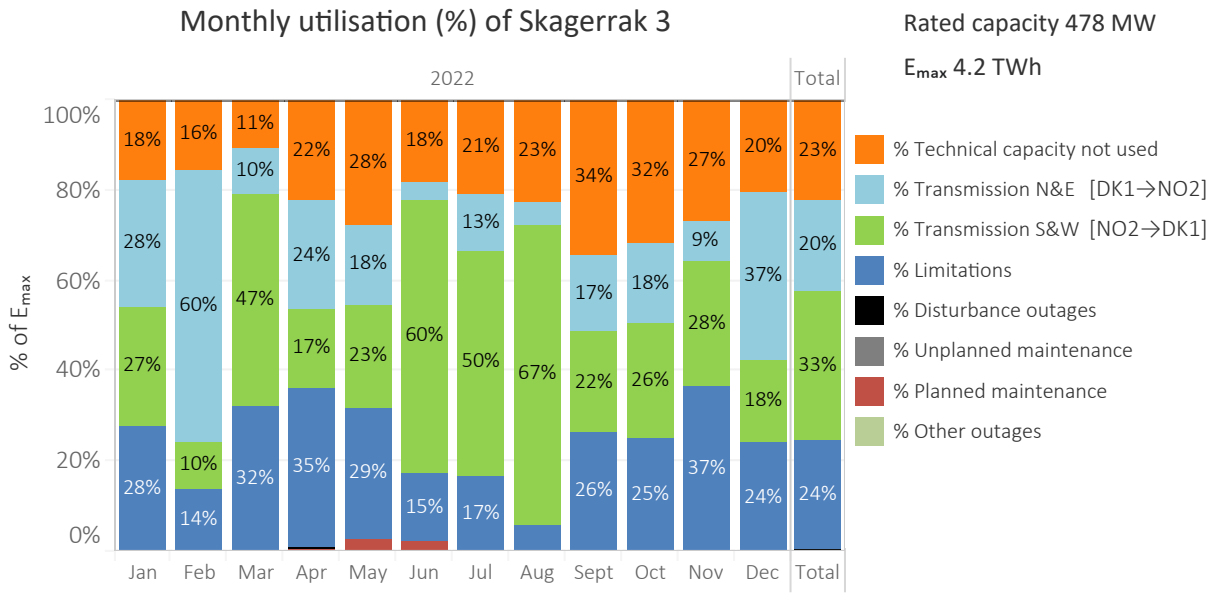

Figure 4.77: Monthly percentage allocation of utilisation by category for Skagerrak 3 in 2022.

Table 4.22: Monthly allocation of technical capacity (E_{max}) for Skagerrak 3 in 2022. Note that losses are not included in the technical capacity (E_{max}), as is shown in Figure 2.1.

Monthly utilisation of Skagerrak 3 (South & West direction NO2→DK1)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	% total
Technical capacity not used, GWh	64.2	50.1	38.8	76.8	99.2	63.2	74.3	81.1	118.7	112.3	91.7	72.4	943.0	22.5%
Transmission N&E, GWh	98.7	193.5	36.3	82.6	62.5	13.1	45.5	17.4	58.6	64.3	30.8	132.2	835.4	19.9%
Transmission S&W, GWh	94.4	32.8	165.8	60.1	80.9	208.3	176.9	237.2	76.5	91.2	95.5	64.6	1384.3	33.0%
Limitations, GWh	98.3	44.9	114.5	121.1	103.7	51.8	59.2	20.0	90.4	88.3	126.1	86.5	1004.8	24.0%
Disturbance outages, GWh	-	-	-	0.2	-	-	-	0.3	-	-	-	-	0.6	0.0%
Unplanned maintenance., GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Planned maintenance, GWh	-	-	-	3.3	9.5	8.1	-	-	-	-	-	-	20.8	0.5%
Other outages, GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total, GWh	355.7	321.2	355.4	344.2	355.7	344.5	355.9	356.1	344.2	356.1	344.2	355.7	4188.9	100.0%
Losses SW, GWh	2.3	0.7	3.9	1.3	1.8	5.2	4.4	6.0	1.8	2.0	2.1	1.4	32.8	0.8%
Losses NE, GWh	2.6	5.6	1.0	2.3	1.8	0.4	1.2	0.5	1.5	1.8	0.8	3.8	23.2	0.6%

Figure 4.78 presents the annual utilisation of Skagerrak 3 per utilisation and unavailability category for the years 2012–2022.

Figure 4.79 presents the percentage of hours of a year Skagerrak 3 has been affected by either a limitation, a disturbance outage, an unplanned or planned maintenance outage or other outage annually during the years 2012–2022. Figure 4.80 presents the annual number of disturbance outages, unplanned and planned maintenances and other outages during the years 2012–2022.

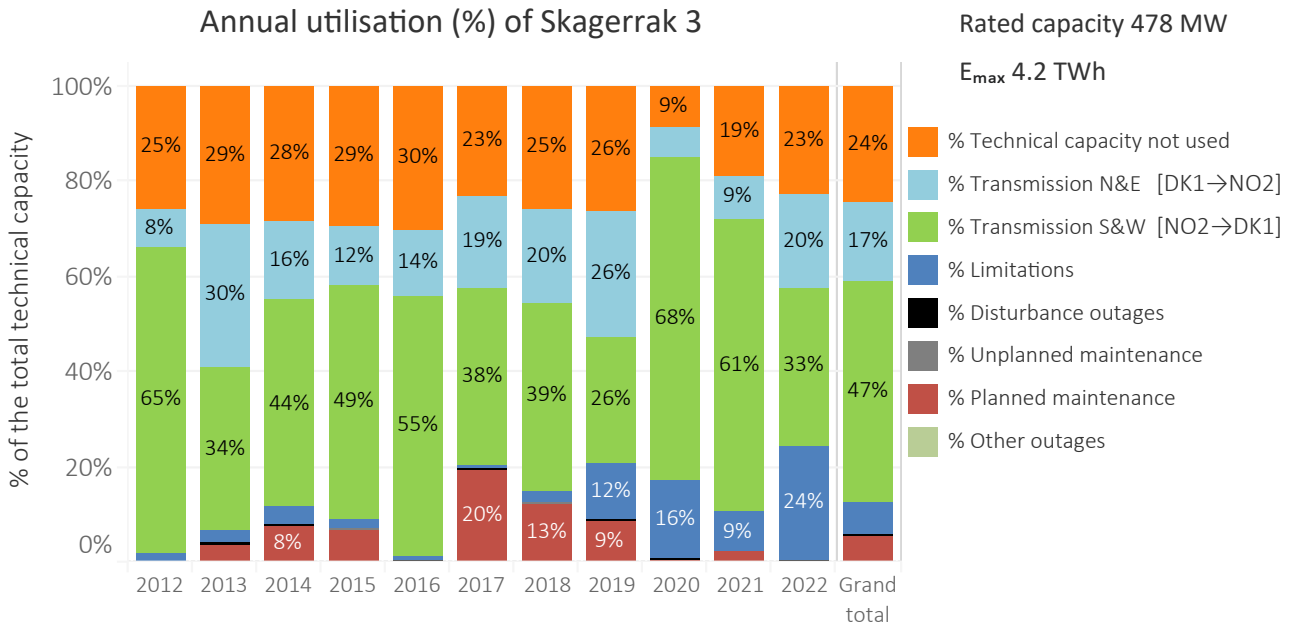

Figure 4.78: Annual utilisation of Skagerrak 3 per the utilisation and unavailability categories for the years 2012–2022.

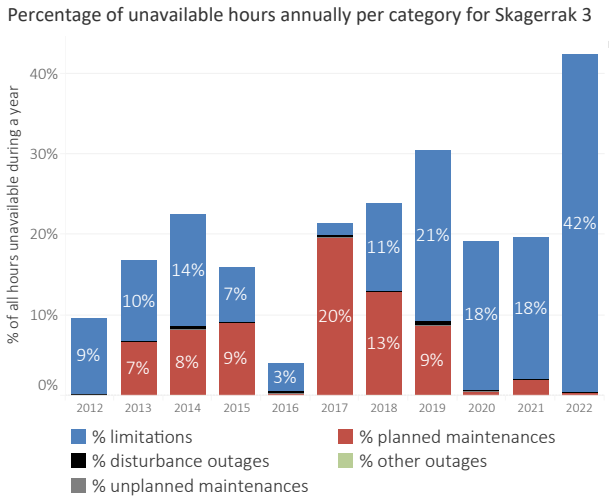

Figure 4.79: Percentage of hours Skagerrak 3 has been affected by either a limitation or an outage annually since 2012. The percentage is calculated by counting the number of hours with a limitation or outage and dividing it by the total number of hours in a year. It should be noted that any single hour can be affected by both an outage and a limitation.

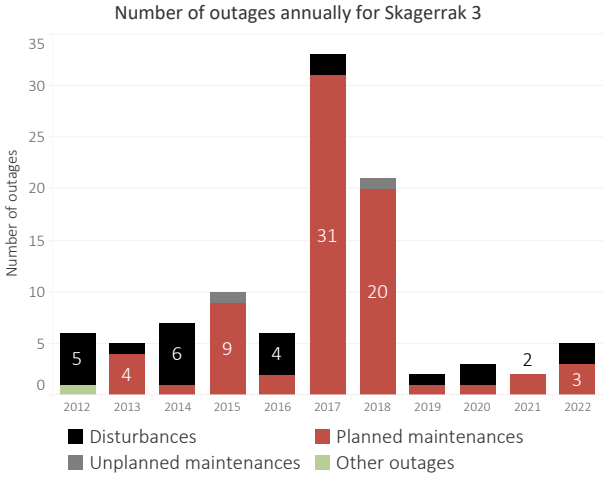

Figure 4.80: The annual number of disturbances, unplanned and planned maintenance outages and other outages for Skagerrak 3 for the years 2012–2022.

4.4.20 Skagerrak 4

Figure 4.81 presents the availability and utilisation of Skagerrak 4 for 2022 and Table 4.23 presents the numerical values behind it. Skagerrak 4 has been in commercial operation since 29 December 2014. In Norway, it is connected to Kristiansand (bidding zone NO2) and in Denmark to Tjele (bidding zone DK1). The transmission capacity is 682 MW at the receiving end.

In 2022, Skagerrak 4 had an available technical capacity of 98 %. The technical capacity not used was 31 %. Totally, 2.5 TWh (42 % of the technical capacity) was transmitted south to Denmark (NO2→DK1) and 1.5 TWh (25 % of the technical capacity) was transmitted north to Norway (DK1→NO2).

Annual maintenance for Skagerrak 4 lasted 5 days in October. There were four minor disturbance outages.

Skagerrak 1, 2, 3 and 4 have been limited due to "careful operation" since the Skagerrak 4 cable faults in December 2019. In 2022, the north and the south direction were approximately equally prioritized. The careful operation of the Skagerrak links has impacted each of the links differently based on the transmission direction and which links are in operation. For example, if all links are available and the transmission goes from Denmark to Norway (i.e., north), Skagerrak 2 is limited to 0 MW and Skagerrak 3 is limited to 200 MW to maintain acceptable electrode current levels.

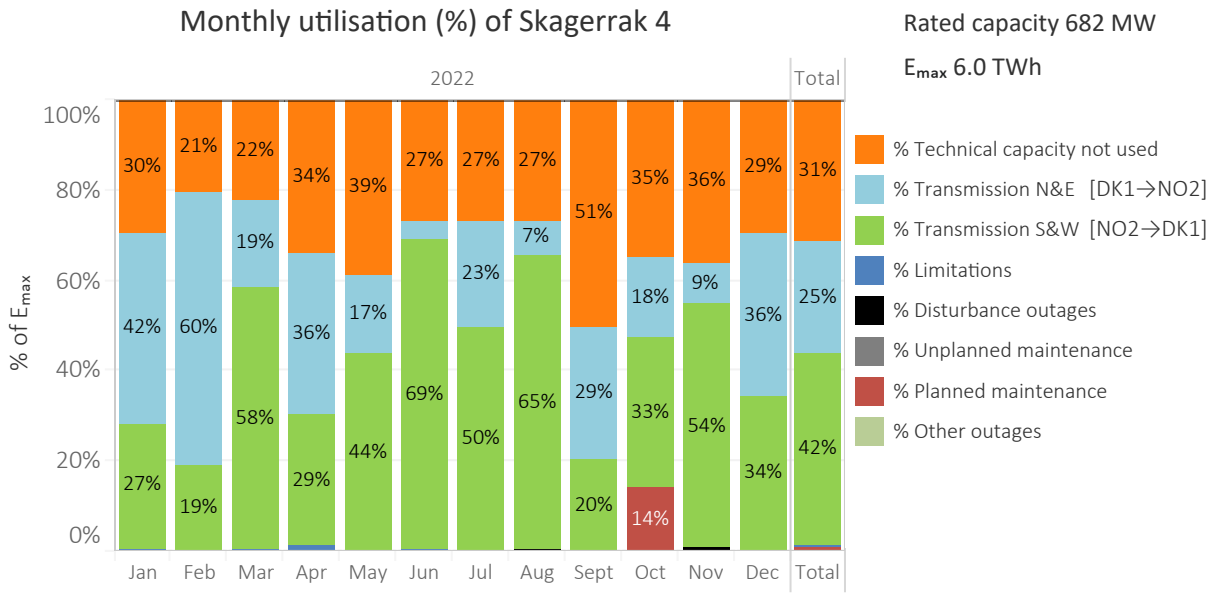

Figure 4.81: Monthly percentage allocation of utilisation by category for Skagerrak 4 in 2022.

Table 4.23: Monthly allocation of technical capacity (E_{max}) for Skagerrak 4 in 2022. Note that losses are not included in the technical capacity (E_{max}), as is shown in Figure 2.1.

Monthly utilisation of Skagerrak 4 (South & West direction NO2→DK1)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	% total
Technical capacity not used, GWh	150.1	95.0	112.7	165.9	197.4	132.2	136.4	136.6	248.4	177.6	177.5	148.7	1878.5	31.4%
Transmission N&E, GWh	215.5	275.5	98.1	175.7	87.4	20.4	119.0	37.3	142.1	90.5	43.5	185.0	1489.8	24.9%
Transmission S&W, GWh	138.7	87.9	293.5	143.6	222.6	337.9	252.8	330.3	99.9	167.8	266.6	173.7	2515.2	42.1%
Limitations, GWh	1.3	-	2.4	5.9	-	1.3	-	-	0.6	-	-	-	11.5	0.2%
Disturbance outages, GWh	1.8	-	-	-	-	-	-	3.3	-	-	3.5	-	8.7	0.1%
Unplanned maintenance., GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Planned maintenance, GWh	-	-	-	-	-	-	-	-	-	72.2	-	-	72.2	1.2%
Other outages, GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total, GWh	507.4	458.3	506.7	491.0	507.4	491.7	508.1	507.5	491.0	508.1	491.0	507.4	5975.8	100.0%
Losses SW, GWh	2.7	2.0	6.2	3.2	5.0	7.0	5.0	6.6	2.0	3.7	6.0	3.9	53.3	0.9%
Losses NE, GWh	6.0	6.9	2.7	4.7	2.2	0.5	3.3	1.0	3.9	2.3	1.1	4.7	39.4	0.7%

Figure 4.82 presents the annual utilisation of Skagerrak 4 per utilisation and unavailability category for the years 2015–2022.

Figure 4.83 presents the percentage of hours of a year Skagerrak 4 has been affected by either a limitation, a disturbance outage, an unplanned or planned maintenance outage or other outage annually during the years 2015–2022. Figure 4.84 presents the annual number of disturbance outages, unplanned and planned maintenances and other outages during the years 2015–2022.

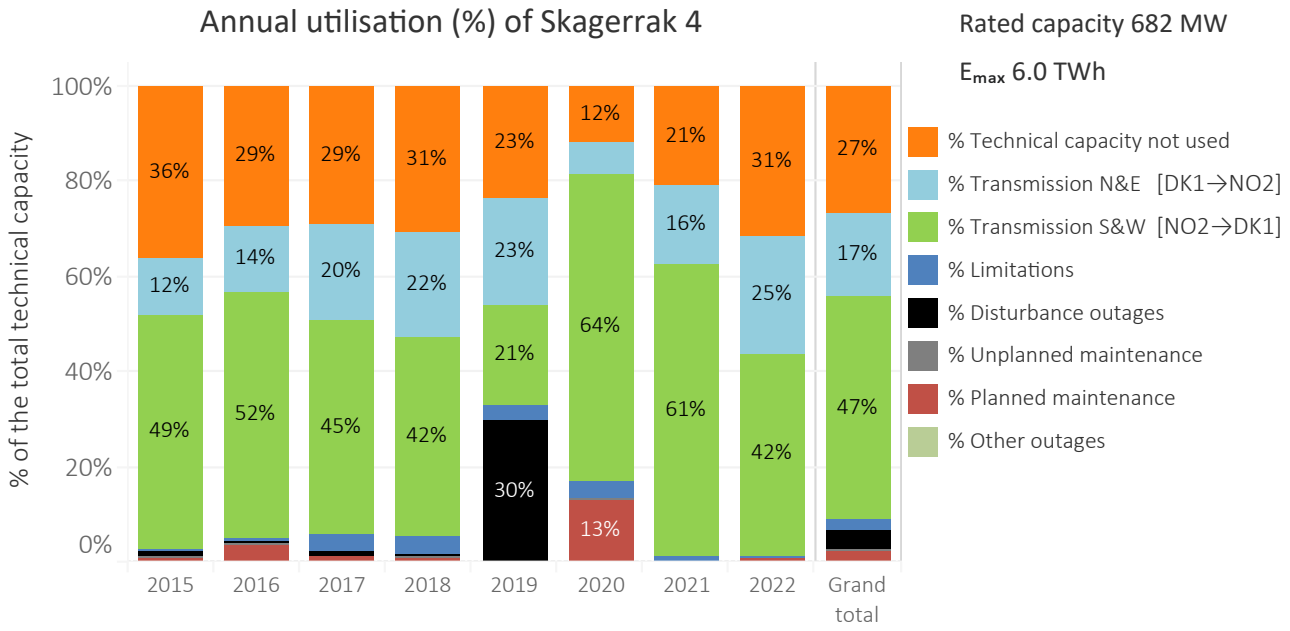

Figure 4.82: Annual utilisation of Skagerrak 4 per the utilisation and unavailability categories for the years 2015–2022.

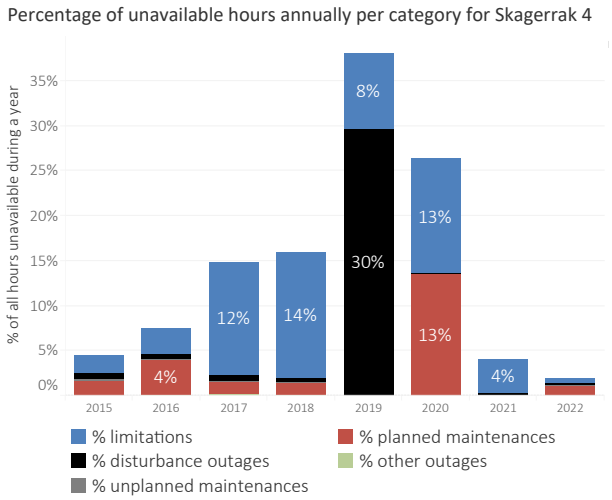

Figure 4.83: Percentage of hours Skagerrak 4 has been affected by either a limitation or an outage annually since 2015. The percentage is calculated by counting the number of hours with a limitation or outage and dividing it by the total number of hours in a year. It should be noted that any single hour can be affected by both an outage and a limitation.

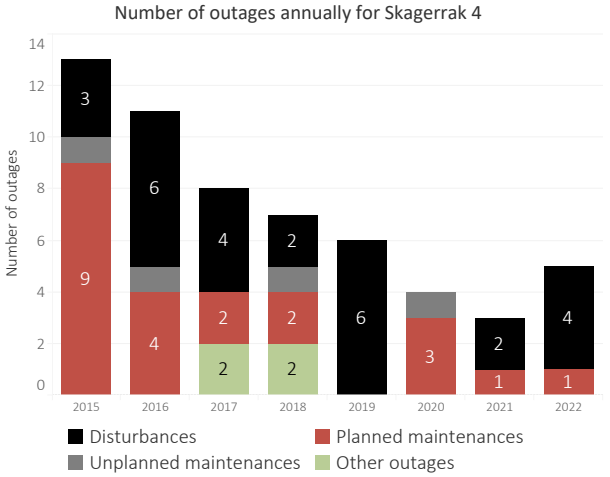

Figure 4.84: The annual number of disturbances, unplanned and planned maintenance outages and other outages for Skagerrak 4 for the years 2015–2022.

4.4.21 Storebaelt

Figure 4.85 presents the availability and utilisation of Storebaelt for 2022 and Table 4.24 presents the numerical values behind it. Storebaelt has been in operation since 2010. It connects the western part of the Danish system, which belongs to the Continental European synchronous system (Jutland and the island of Fynen), with the eastern part, belonging to the Nordic synchronous system (Zealand). The link is connected to Fraugde on Fynen (bidding zone DK1) and to Herslev on Zealand (bidding zone DK2). The transmission capacity is 600 MW.

In 2022, Storebaelt had an available technical capacity of 96 %. The technical capacity not used was 45 %. Totally, 1.5 TWh (29 % of the technical capacity) was transmitted east to Zealand (DK1→DK2) and 1.1 TWh (21 % of the technical capacity) was transmitted west to Jutland (DK2→DK1).

Annual maintenance for Storebaelt lasted 5 days in May. There were one minor planned maintenance outage, where a local controller were replaced.

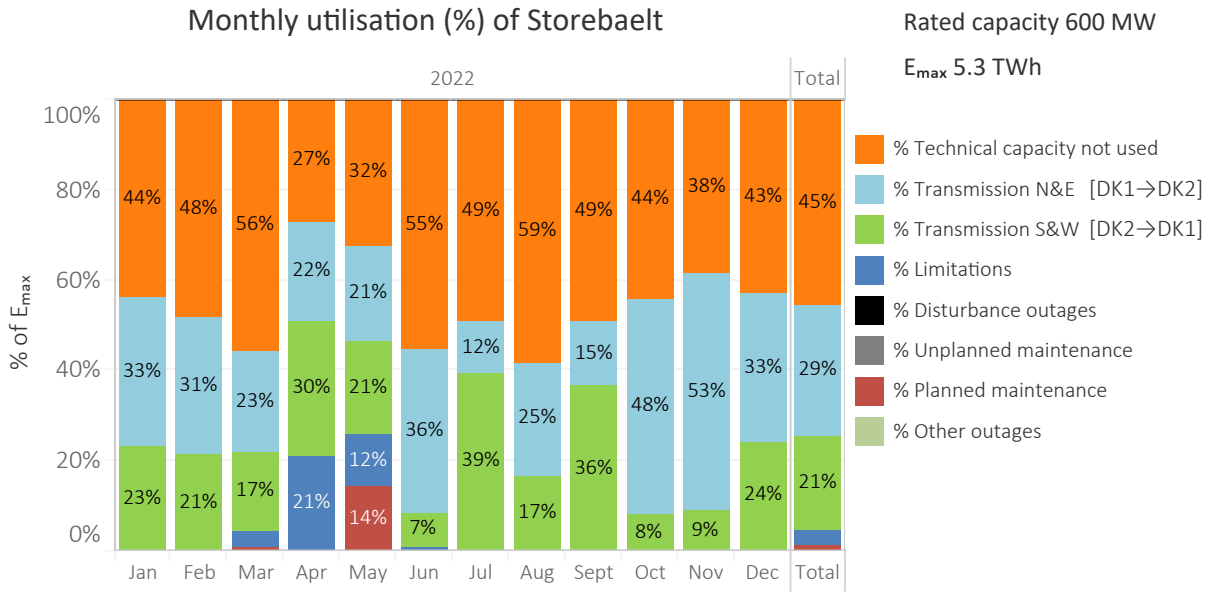

Figure 4.85: Monthly percentage allocation of utilisation by category for Storebaelt in 2022.

Table 4.24: Monthly allocation of technical capacity (E_{max}) for Storebaelt in 2022. Note that losses are not included in the technical capacity (E_{max}), as is shown in Figure 2.1.

Monthly utilisation of Storebaelt (South & West direction DK2→DK1)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	% total
Technical capacity not used, GWh	195.4	194.3	248.7	117.7	144.6	239.8	220.2	262.0	211.7	197.7	165.0	191.8	2388.8	45.4%
Transmission N&E, GWh	147.6	123.3	100.5	94.6	94.2	156.5	51.4	109.7	62.9	212.9	228.7	148.0	1530.4	29.1%
Transmission S&W, GWh	103.4	85.6	77.2	129.9	92.0	31.5	173.9	73.9	157.3	36.3	38.3	106.3	1105.6	21.0%
Limitations, GWh	-	-	15.8	89.8	52.0	4.2	0.9	0.8	-	-	-	0.4	163.9	3.1%
Disturbance outages, GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	
Unplanned maintenance., GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Planned maintenance, GWh	-	-	3.6	-	63.6	-	-	-	-	-	-	-	67.2	1.3%
Other outages, GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total, GWh	446.4	403.2	445.8	432.0	446.4	432.0	446.4	446.4	432.0	447.0	432.0	446.4	5256.0	100.0%
Losses SW, GWh	1.6	1.3	1.2	2.0	1.4	0.5	2.7	1.2	2.5	0.6	0.6	1.7	17.4	0.3%
Losses NE, GWh	2.4	2.0	1.7	1.5	1.5	2.5	0.8	1.9	1.1	3.5	3.9	2.5	25.3	0.5%

Figure 4.86 presents the annual utilisation of Storebaelt per utilisation and unavailability category for the years 2012–2022.

Figure 4.87 presents the percentage of hours of a year Storebaelt has been affected by either a limitation, a disturbance outage, an unplanned or planned maintenance outage or other outage annually during the years 2012–2022. Figure 4.88 presents the annual number of disturbance outages, unplanned and planned maintenances and other outages during the years 2012–2022.

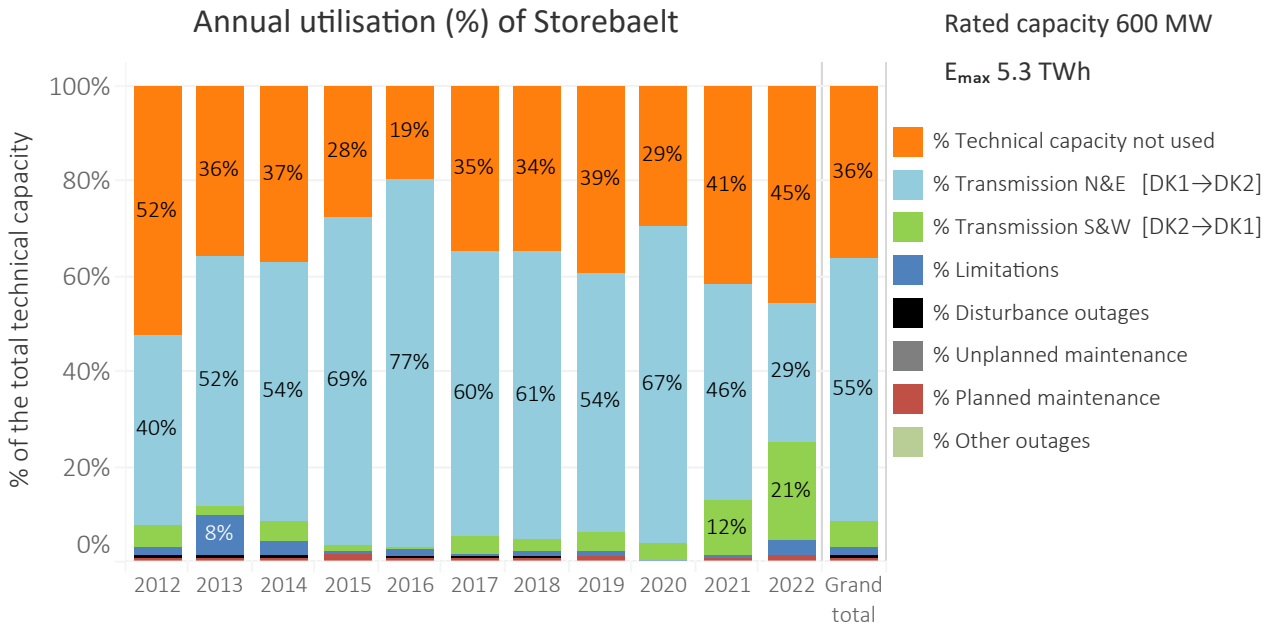

Figure 4.86: Annual utilisation of Storebaelt per the utilisation and unavailability categories for the years 2012–2022.

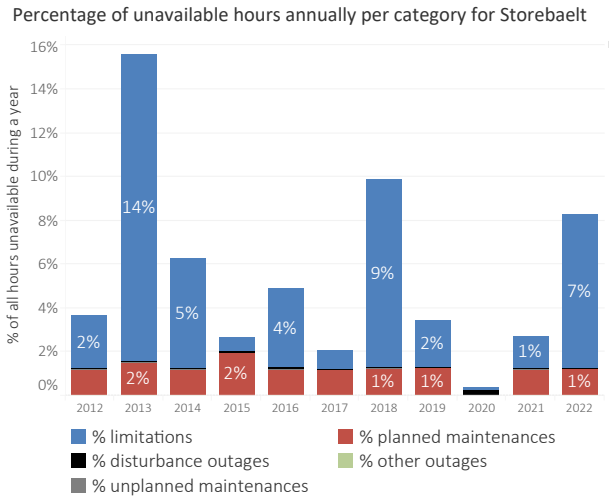

Figure 4.87: Percentage of hours Storebaelt has been affected by either a limitation or an outage annually since 2012. The percentage is calculated by counting the number of hours with a limitation or outage and dividing it by the total number of hours in a year. It should be noted that any single hour can be affected by both an outage and a limitation.

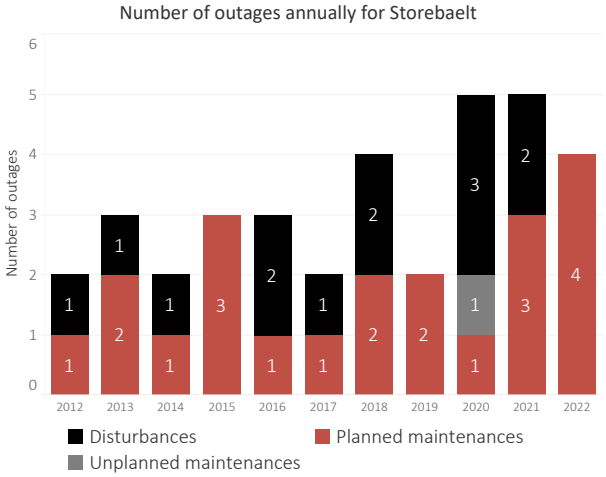

Figure 4.88: The annual number of disturbances, unplanned and planned maintenance outages and other outages for Storebaelt for the years 2012–2022. Storebaelt had no other outages during the years 2012–2022.

4.4.22 SwePol

Figure 4.89 presents the availability and utilisation of SwePol for 2022 and Table 4.25 presents the numerical values behind it. SwePol Link has been in operation since 2000 and it connects the Swedish and Polish transmission grids. In south-eastern Sweden (bidding zone SE4) it is connected to Stärnö and in Poland (bidding zone PL) to Slupsk. The transmission capacity is 600 MW.

In 2022, Swepol experienced a total of 23 outages, comprising 17 maintenance outages and 6 disturbances. Among the maintenance outages, a majority of them were brief and conducted for corrective maintenance purposes, even though the specific reasons behind these maintenance requirements remained unclear. The annual maintenance period for SwePol occurred over a duration of 29 days, spanning September and October. Unfortunately, this extended maintenance period led to a decrease in the available technical capacity, which dropped to 87,3 %.

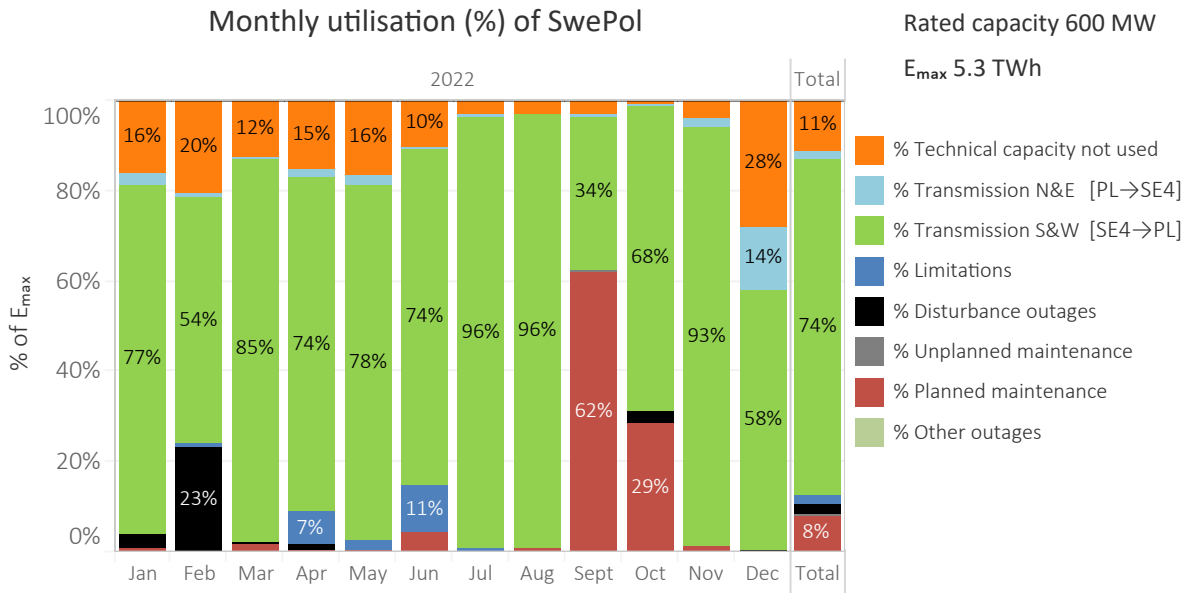

Figure 4.89: Monthly percentage allocation of utilisation by category for SwePol in 2022.

Table 4.25: Monthly allocation of technical capacity (E_{max}) for SwePol in 2022. Note that losses are not included in the technical capacity (E_{max}), as is shown in Figure 2.1.

Monthly utilisation of SwePol (South & West direction SE4→PL)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	% total
Technical capacity not used, GWh	72.5	81.9	55.2	65.8	73.0	43.6	14.4	14.0	13.5	3.2	18.2	125.3	580.6	11.0%
Transmission N&E, GWh	11.4	5.2	3.2	8.5	11.7	2.3	0.7	-	0.2	0.1	6.2	61.8	111.1	2.1%
Transmission S&W, GWh	344.8	219.0	376.8	319.4	350.4	321.5	428.1	428.8	147.7	304.3	402.4	257.1	3900.3	74.2%
Limitations, GWh	-	2.9	-	31.5	9.0	45.5	3.2	-	-	-	-	-	92.1	1.8%
Disturbance outages, GWh	14.4	94.2	2.9	4.6	-	-	-	-	-	11.9	-	1.7	129.7	2.5%
Unplanned maintenance., GWh	-	-	-	-	-	-	-	-	1.2	-	-	-	1.2	0.0%
Planned maintenance, GWh	3.3	-	7.7	2.3	2.3	19.1	-	3.6	269.4	127.5	5.3	0.6	441.1	8.4%
Other outages, GWh	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total, GWh	446.4	403.2	445.8	432.0	446.4	432.0	446.4	446.4	432.0	447.0	432.0	446.4	5256.0	100.0%
Losses SW, GWh	9.9	6.3	11.0	8.6	9.7	8.5	12.5	12.6	4.3	9.0	11.9	7.1	111.4	2.1%
Losses NE, GWh	0.3	0.1	0.1	0.2	0.3	0.1	-	-	-	-	0.2	1.8	3.2	0.1%

Figure 4.90 presents the annual utilisation of SwePol per utilisation and unavailability category for the years 2012–2022.

Figure 4.91 presents the percentage of hours of a year SwePol has been affected by either a limitation, a disturbance outage, an unplanned or planned maintenance outage or other outage annually during the years 2012–2022. Figure 4.92 presents the annual number of disturbance outages, unplanned and planned maintenances and other outages during the years 2012–2022.

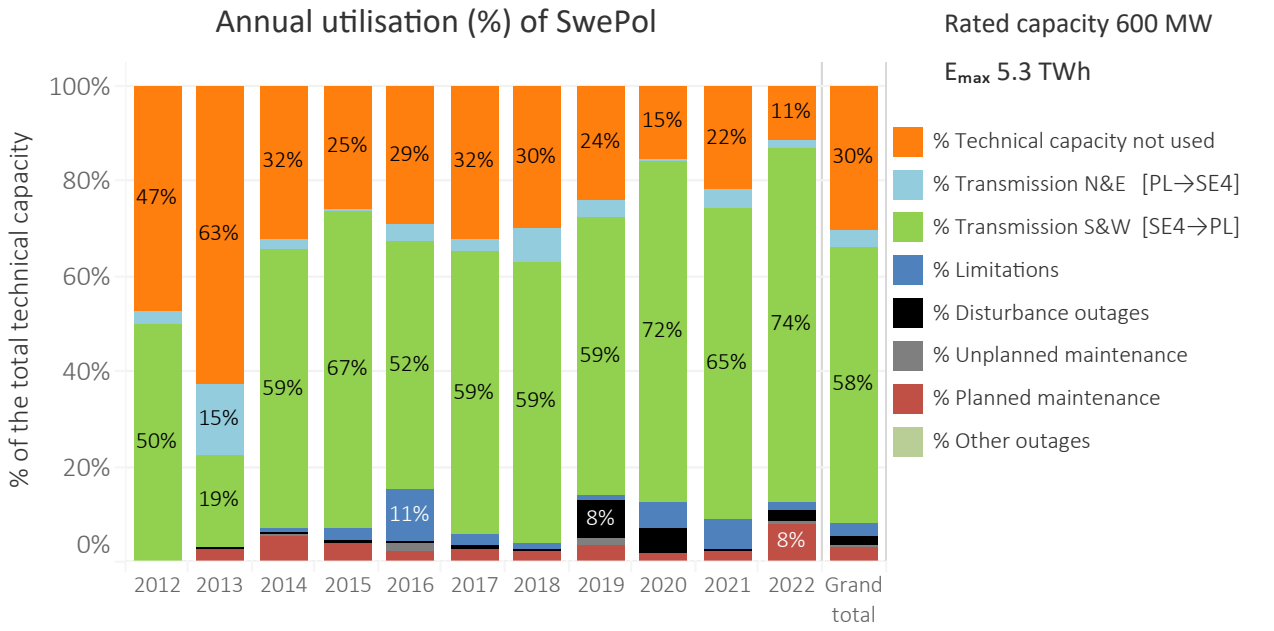

Figure 4.90: Annual utilisation of SwePol per the utilisation and unavailability categories for the years 2012–2022.

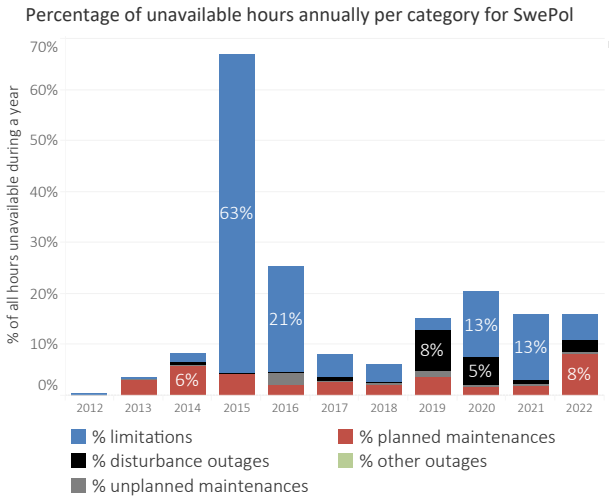

Figure 4.91: Percentage of hours SwePol has been affected by either a limitation or an outage annually since 2012. The percentage is calculated by counting the number of hours with a limitation or outage and dividing it by the total number of hours in a year. It should be noted that any single hour can be affected by both an outage and a limitation.

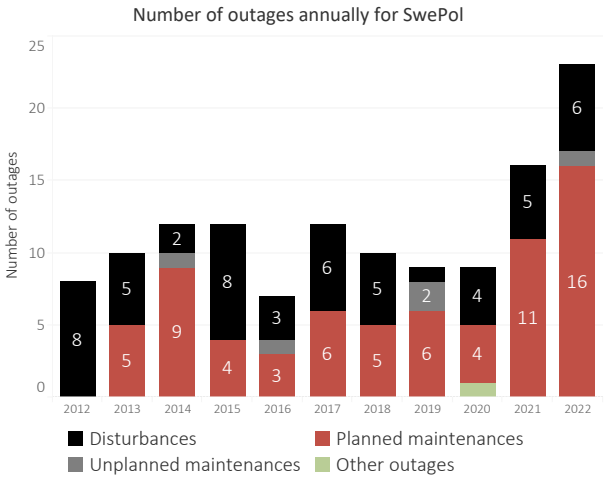

Figure 4.92: The annual number of disturbances, unplanned and planned maintenance outages and other outages for SwePol for the years 2012–2022. SwePol had no other outages during the years 2012–2022.

References

[1] DISTAC, "NORDIC AND BALTIC GUIDELINES FOR HVDC STATISTICS." https://eepublicdownloads.entsoe.eu/clean-documents/SOC%20documents/Nordic/Nordic_and_Baltic_Guidelines_for_HVDC_Statistics_17.11.2020.pdf, November 2020.

[2] DISTAC, "Nordic Grid Disturbance Statistics 2010." https://eepublicdownloads.entsoe.eu/clean-documents/pre2015/publications/entsoe/RG_SOC_Nordic/110831_NORDIC_GRID_DISTURBANCE_AND_FAULT_STATISTICS_2010.pdf, August 2010.

[3] CIGRE Technical Brochure, "Protocol for reporting the operational performance of HVDC Transmission Systems," technical brochure, CIGRE, 2014.

Glossary

DISTAC Disturbance Statistics Group. Reports to Regional Group Nordic (RGN) in ENTSO-E.
ENTSO-E European Network of Transmission System Operators for Electricity.
HVAC High-voltage alternating current.
HVDC High-voltage direct current.
LCC Line-commutated converters.
NordAM Nordic Asset Management Forum.
PEX Cross-linked polyethylene.
RGN Regional Group Nordic.
TSO Transmission System Operator.
VSC Voltage-source converters.

Appendices

A Schematic presentation of HVDC links

Figure A.1 and Figure A.2 show the schematic presentations of a HVDC converter station having line-commutated converters (LCC) and voltage-source converters (VSC), respectively. All the figures also show definitions for the origin of an event. The origin of each event is used for categorizing a disturbance or a limitation for statistical purposes. The figures also show the locations of the circuit breakers and measurement points for transferred energy on a link.

It should be noted that these figures are only show an example of a possible LCC or VSC converter station as there are multiple different ways to construct one.

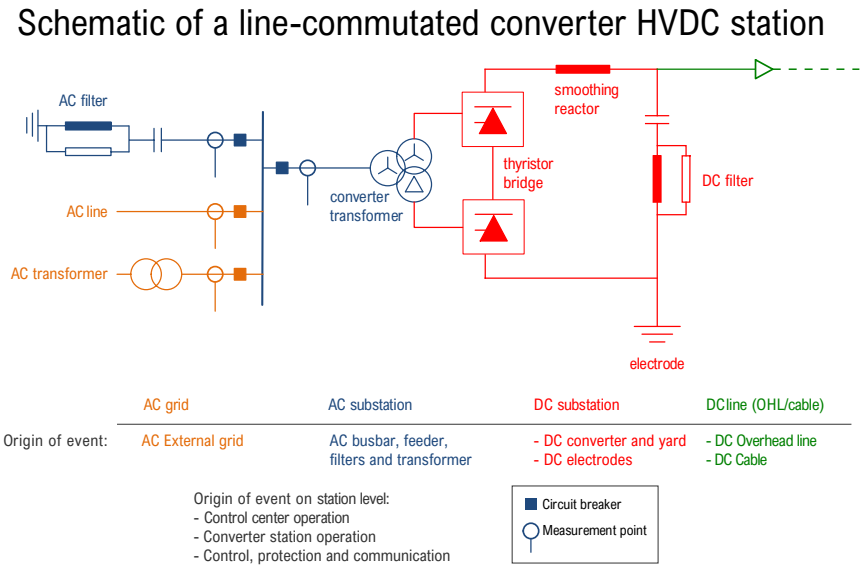

Figure A.1: An example of a line-commutated converter (LCC) station schematic with the connection to the AC grid. The other remote side of the HVDC link has a similar albeit mirrored version of the converter station.

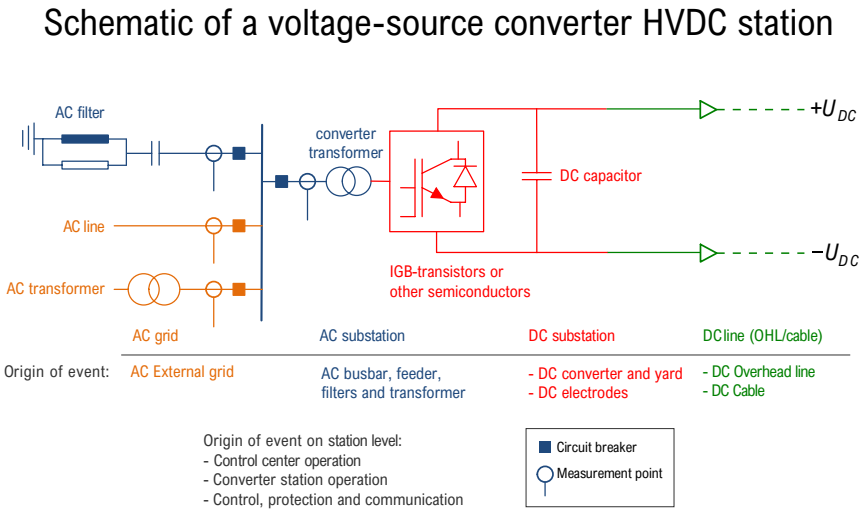

Figure A.2: An example of a voltage-source converter (VSC) station schematic with the connection to the AC grid. The other remote side of the HVDC link has a similar albeit mirrored version of the converter station.

B DISTAC/CIGRE origin of event classification

Table B.1 show the DISTAC origins and their subcategories and the corresponding CIGRE outage codes [3]. It should be noted that full compatibility is not achieved in control and protection areas. The schematics in Appendix A can be helpful in visualizing the different categories.

Table B.1: The DISTAC origin of event categories and subcategories and the corresponding CIGRE outage codes.

DISTAC Origin of event	DISTAC / CIGRE Subcategory / Outage Code	Comment
Multiple places	-	Used primarily for annual maintenance in DISTAC.
Control centre operation[1]	C-P.L – Local HVDC Control & Protection[1]	Control, protection or monitoring equipment of the local HVDC station, for example, converter firing control, current and voltage regulators, converter and dc yard protections, valve control and protection, and local control sequences.
	C-P.M – Master HVDC Control & Protection[1]	Equipment used for inter-station coordination of current and voltage orders, inter-station sequences, auxiliary controls such as damping controls or higher level controls such as run-back/run-up power control or frequency control.
	C-P.T – Control & Protection and Telecommunication[1]	Equipment for coding of control and indication information to be sent over a telecommunication circuit including the telecommunication circuit itself (microwave, PLC or optical).
Converter station operation[1]	Same as for “Control centre operation” above	
Control, protection and communication[1]	Same as for “Control centre operation” above	
AC External grid	EXT – External AC System	
AC and auxiliary equipment	AC-E.F – AC Filter and Shunt Bank	Including AC filter CTs, arresters as well as PLC/RI, SVC, STATCOM, series capacitor at HVDC station.
	AC-E.SW – Other AC Switchyard Equipment	For example, switches, surge arresters, busbars, insulators.
	AC-E.CP – AC Control and Protection	AC C&P including CTs, VTs, also for auxiliary power and valve cooling.
	AC-E.TX – Converter Transformer	Including interface transformers.
	AC-E.SC – Synchronous Compensator	Including SC cooling system and exciter.
	AC-E.AX – Auxiliary Equipment and Auxiliary Power	For example, auxiliary transformers, pumps, battery chargers, heat exchangers, cooling system instrumentation, LV switchgear, motor control centres, fire protection, civil works.
DC converter and yard	V.E – Valve Electrical	
	V.VC – Valve Cooling	Valve Cooling pipes and parts in valve hall.
	V.C – Valve Capacitor	
	DC-E.F – DC Filters	
	DC-E.SR – DC Smoothing Reactor	
	DC-E.SW – DC Switching Equipment	
	DC-E.ME – DC Measuring Equipment	
	DC-E.O – Other DC Yard and Valve Hall Equipment	
DC Electrodes	DC-E.GE – DC Ground Electrode	
	DC-E.EL – DC Ground Electrode Line	
DC Overhead line	TL-OH – DC Overhead Transmission Line	
DC Cable	TL-C – DC Underground / submarine Cable	
Other or unknown	O – Other	

[1] There is no direct one-to-one compatibility between DISTAC and CIGRE for these definitions.

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D Sorted overview of utilisation and unavailability for all HVDC links

This chapter presents sorted versions of Figure 4.1 Utilisation (%) by category for each HVDC link in 2022.

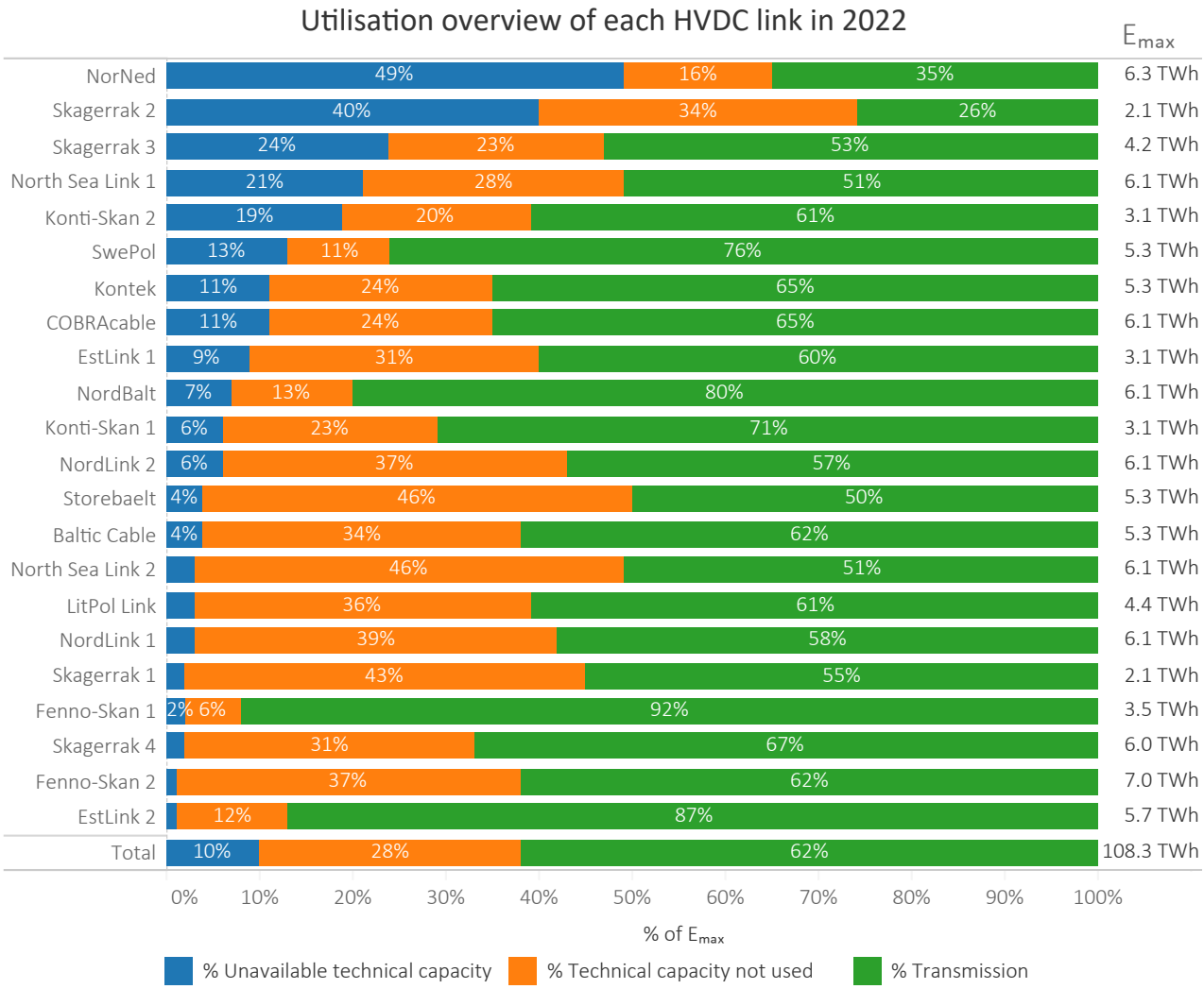

Figure D.1: Overview of each HVDC link sorted by descending unavailable technical capacity (E_U) in 2022.

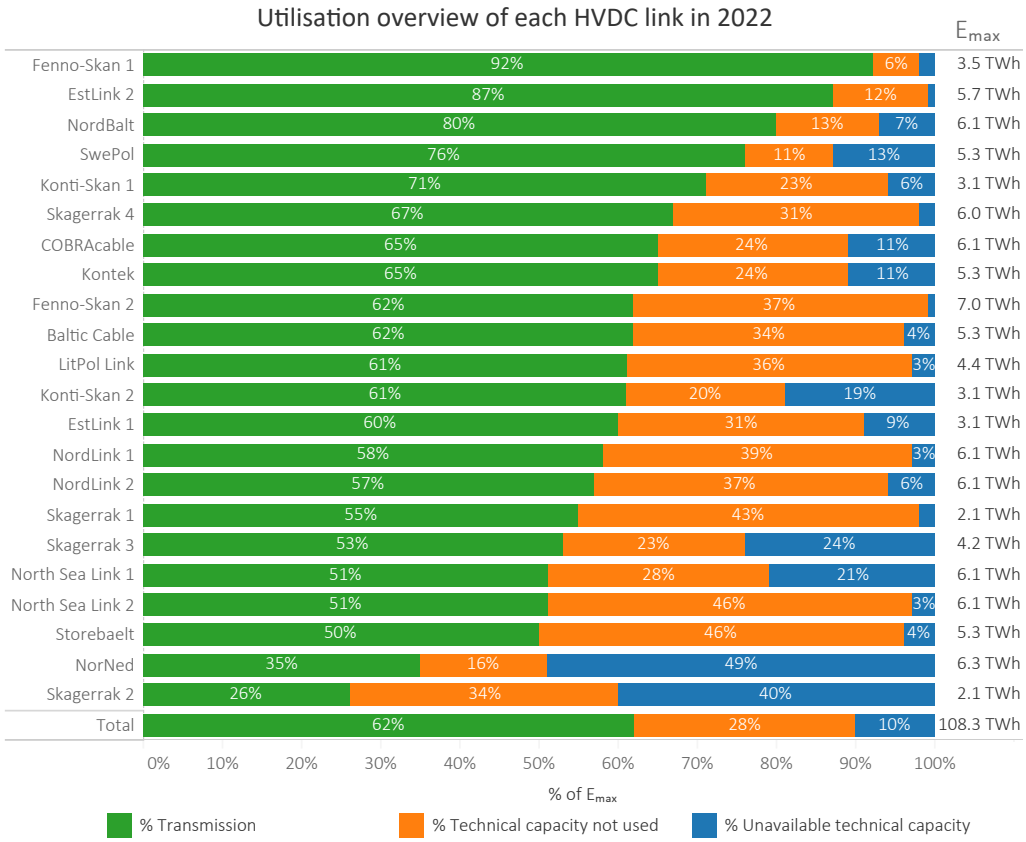

Figure D.2: Overview of each HVDC link sorted by descending transmission (E_T) in 2022.

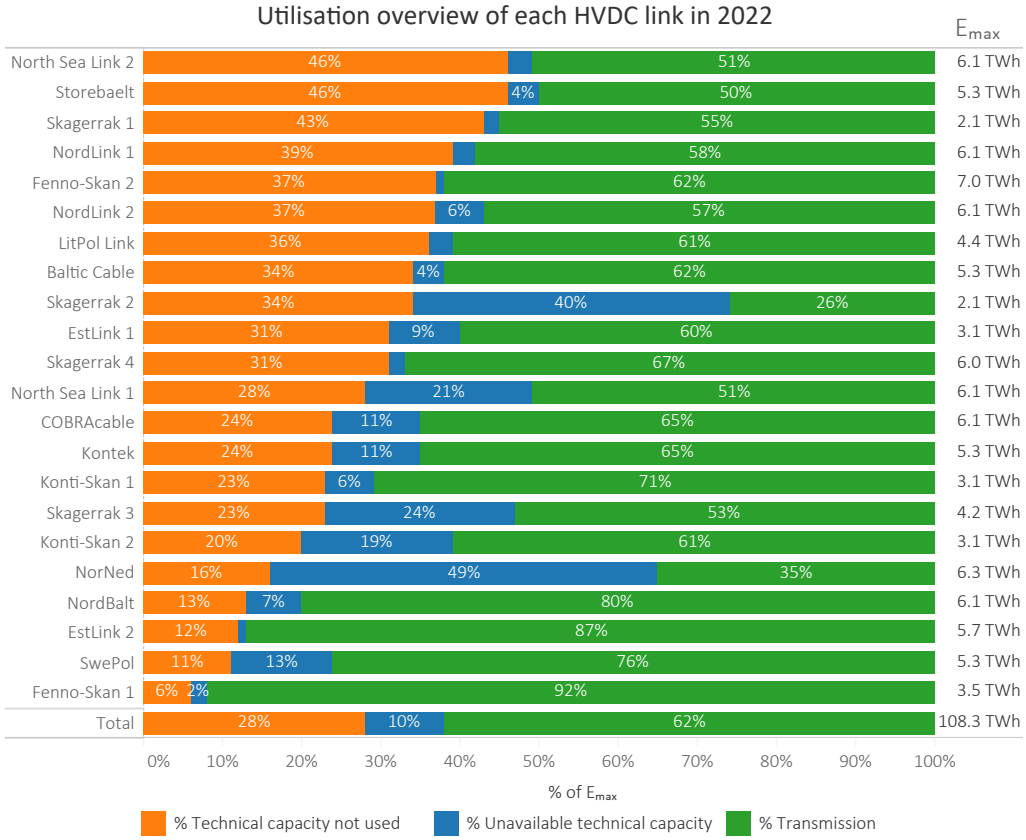

Figure D.3: Overview of each HVDC link sorted by descending technical capacity not used (E_{TCNU}) in 2022.

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.

E.1 Annual utilisation per type of HVDC converter

Figure E.1 presents the annual utilisation of all HVDC links using line-commutated converters (LCC) and Figure E.2 all HVDC links using voltage-source converters (VSC).

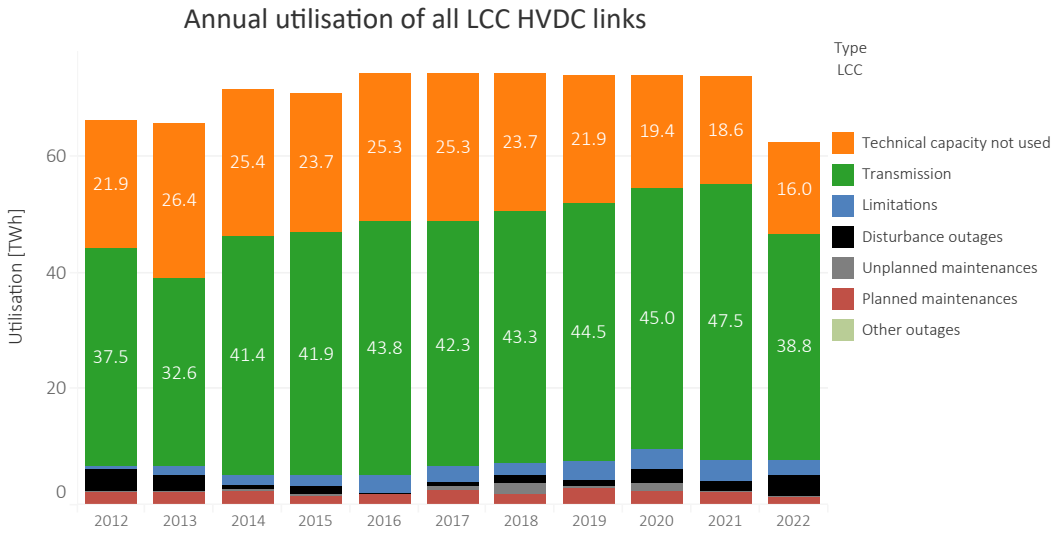

Figure E.1: Annual utilisation of all HVDC links using line-commutated converters (LCC) together presented in megawatt hours (MWh). Vyborg link is not included in the report year 2022.

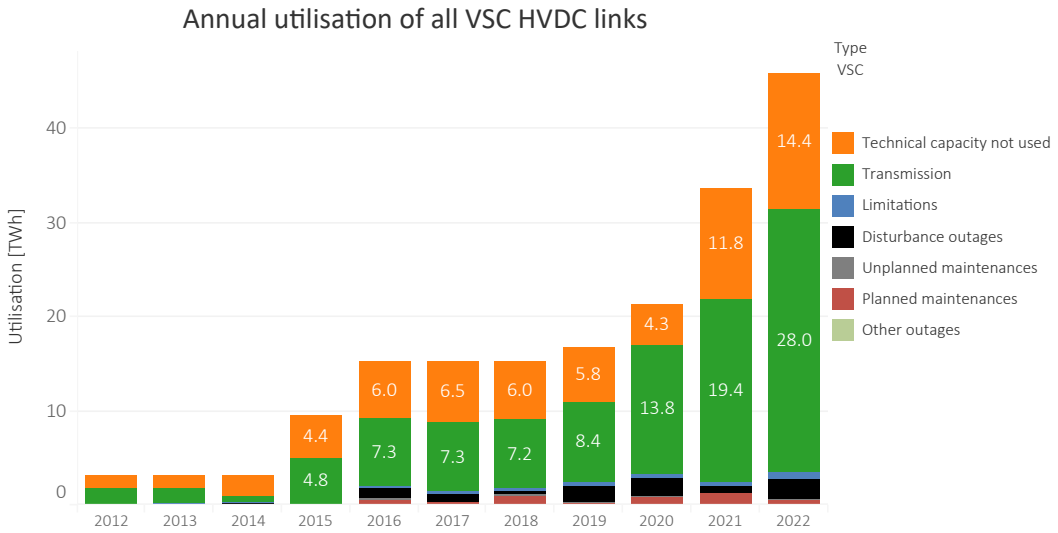

Figure E.2: Annual utilisation of all HVDC links using voltage-source converters (VSC) together presented in megawatt hours (MWh).

E.2 Additional figures with percentages of hours unavailable

This section presents additional figures with a more detailed categorisation of unavailability. Figure E.3 presents the hours (%) limited due to seasonal causes annually for all HVDC links. Figure E.4 presents the hours (%) limited by limitation origin and type annually for all HVDC links. The limitation origins are AC and DC limiting conditions, and the types are planned or unplanned.

Figure E.5 presents the hours (%) limited by limitation origin and type in 2022 for each HVDC link. Figure E.6 presents the same but for each market connection.

Figure E.7 presents hours (%) unavailable due to planned maintenance by primary cause in 2022 for each HVDC link and the corresponding annual values for all HVDC links combined.

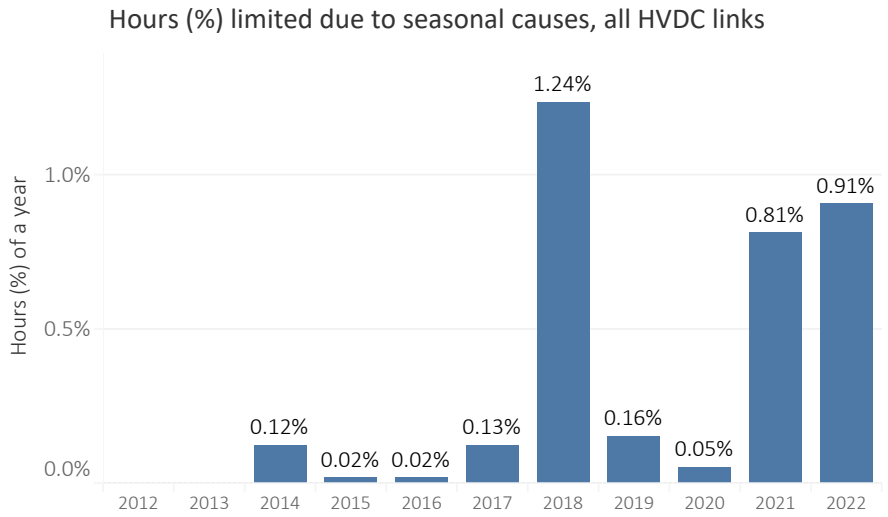

Figure E.3: Hours (%) limited due seasonal causes for all HVDC links. The percentage is calculated by counting the number of hours with a limitation due to seasonal causes and dividing it by the total number of hours in a year.

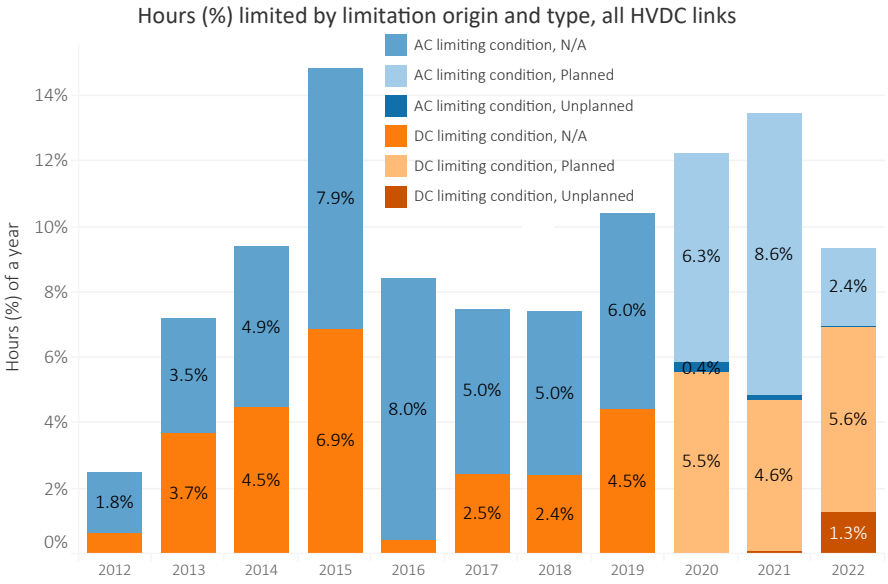

Figure E.4: Hours (%) by limitation origin and type annually for all HVDC links. The limitation origins are AC limiting and DC limiting and the types are planned and unplanned. The percentage is calculated by counting the number of hours with the specific limitation origin and type and dividing it by the total number of hours in a year. Limitation type was not recorded prior to 2020.

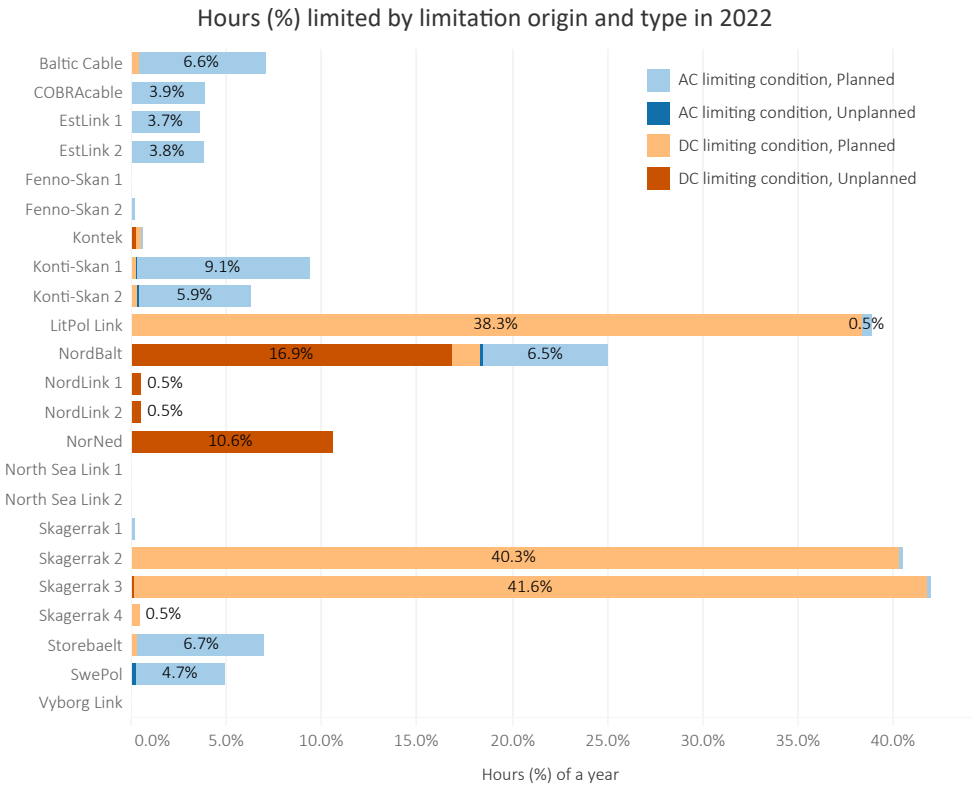

Figure E.5: Hours (%) limited by limitation origin and type in 2022 for each HVDC link. The percentage is calculated by counting the number of hours with the specific limitation origin and type and dividing it by the total number of hours in a year.

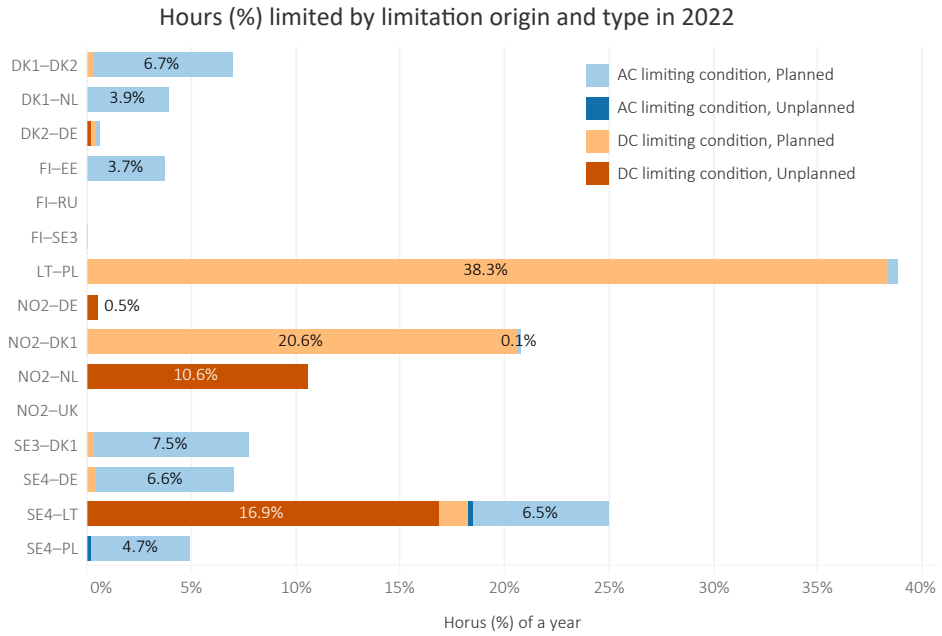

Figure E.6: Hours (%) limited by limitation origin and type for each market connection in 2022. The percentage is calculated by counting the number of hours with the specific limitation origin and type and dividing it by the total number of hours in a year.

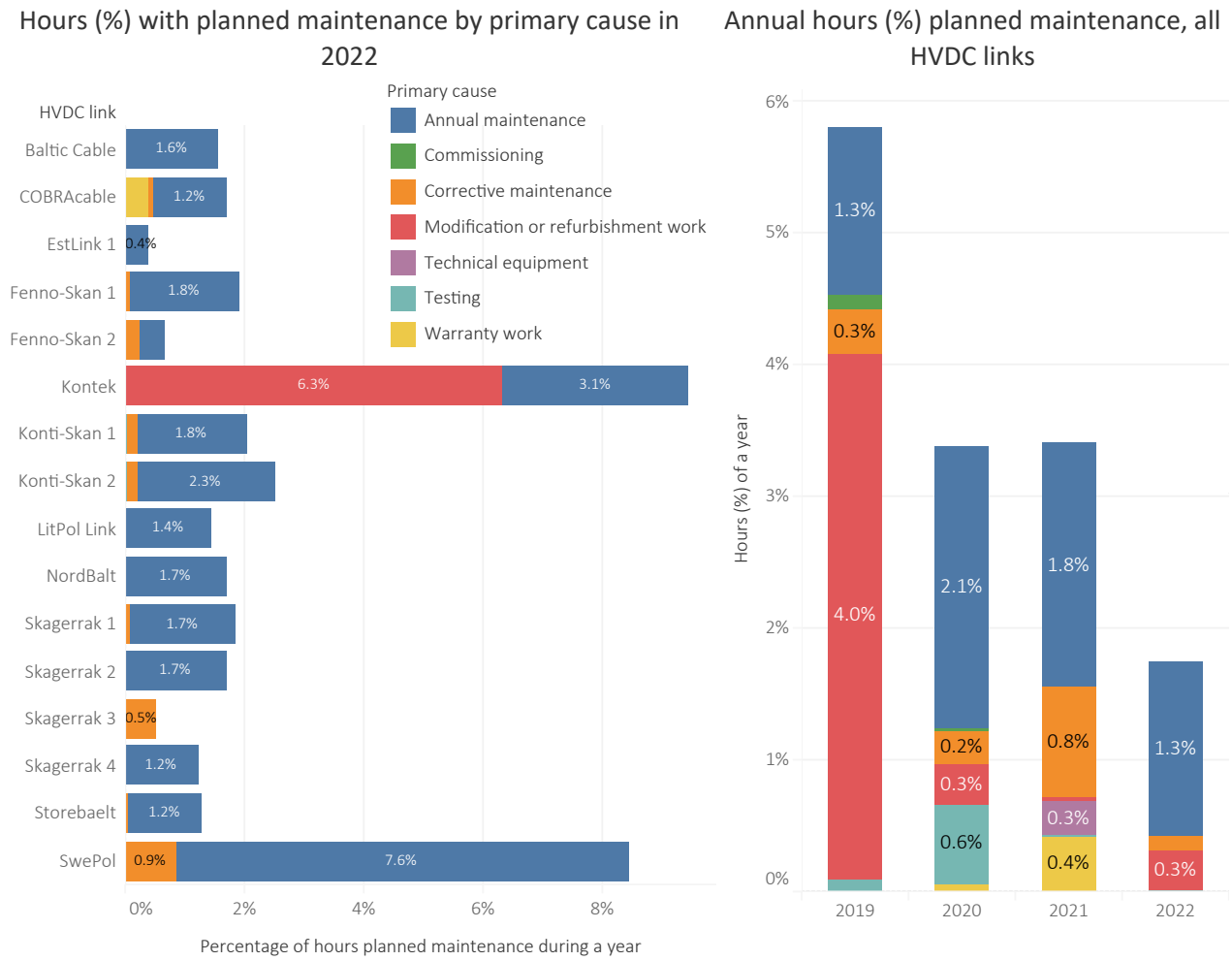

Figure E.7: On the left: hours (%) with planned maintenance by primary cause for each HVDC link in 2022. On the right: hours (%) with planned maintenance by primary cause annually for all HVDC links combined. The percentage is calculated by counting the number of hours with a planned maintenance and dividing it by the total number of hours in a year.

E.3 Additional figures with origin of event

This section presents additional figures about disturbance and maintenance outages, with a focus on their origin of the event. Origin of event corresponds to the location on the HVDC link that the event originated from. The origin of event categories and subcategories are presented in Appendix B. The HVDC link schematics in Appendix A can be helpful in visualising the categories.

Figure E.8 presents the number of disturbance outages divided by the number of HVDC links annually grouped by origin. Figure E.9 presents the annual unavailable capacity due to disturbance outages by origin of event for all HVDC links combined. Last, Table E.1 presents the numerical values behind Figure E.9 with further subcategorisation of the origin.

Figure E.10 presents the annual unavailable capacity due to maintenance outages by primary cause. Figure E.11 presents the annual unavailable capacity due to corrective maintenances by origin of event for all HVDC links, and the number of corrective maintenances divided by the number of HVDC links annually grouped by origin of event. Primary cause of outages has not been recorder prior to the year 2019.

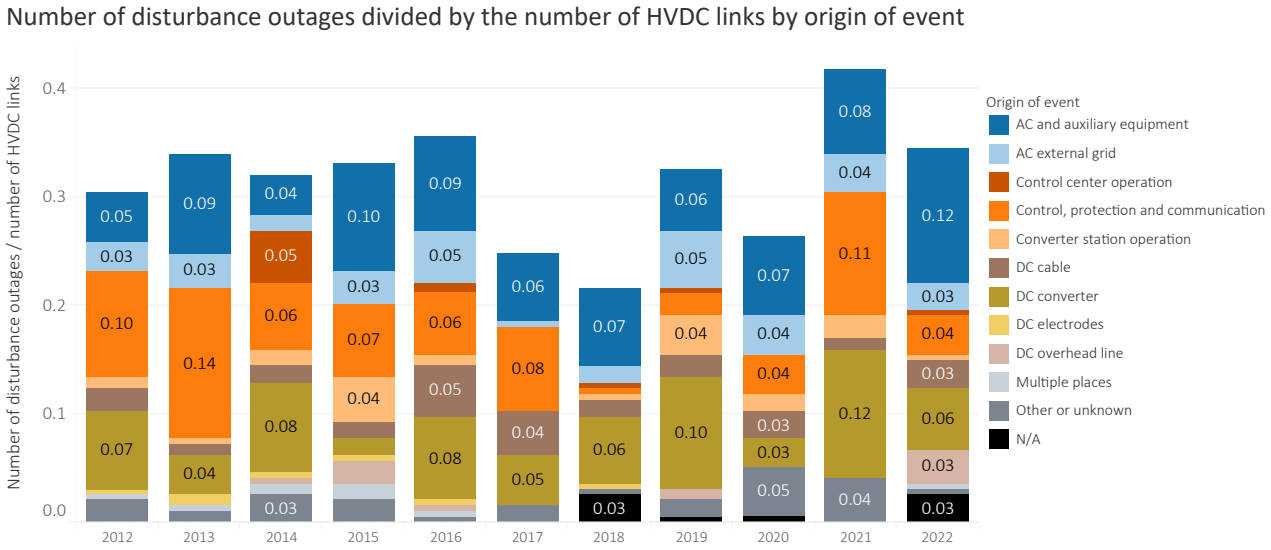

Figure E.8: Number of disturbance outages divided by the number of HVDC links, grouped by origin of event.

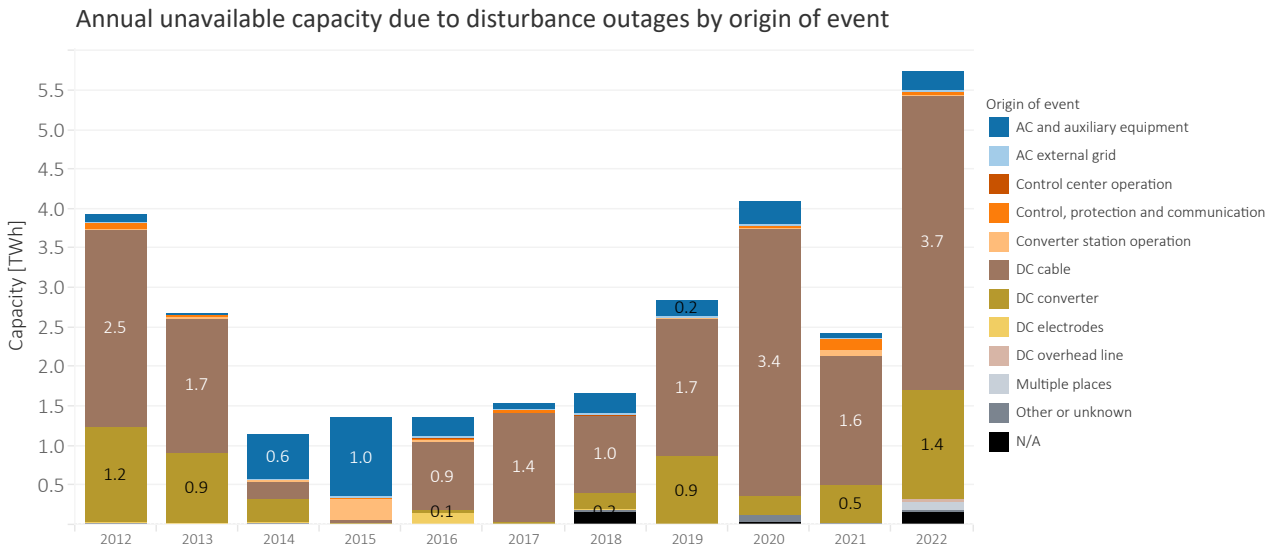

Figure E.9: Annual unavailable capacity due to disturbances outages by origin of event for all HVDC links.

Table E.1: Annual unavailable capacity due to disturbances outages by origin of event and subcategory for all . N/A means not available. Note that the level of detail in the data collection has increased since 2019.

Annual utilisation of all HVDC links

		GWh										
Origin	Subcategory	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
AC and auxiliary equipment	AC-E.AX - Auxiliary Equipment and Auxiliary Power	-	-	-	-	-	-	-	1.5	280.1	12.9	97.2
	AC-E.CP - AC Control and Protection	-	-	-	-	-	-	-	15.0	3.6	6.7	1.7
	AC-E.F - AC Filter and Shunt Bank	-	-	-	-	-	-	-	0.1	0.6	0.1	112.5
	AC-E.SW - Other AC Switchyard Equipment	-	-	-	-	-	-	-	0.2	1.1	18.6	-
	AC-E.TX - Convertor Transformer	-	-	-	-	-	-	-	168.7	0.2	3.3	13.2
	N/A	93.9	13.5	556.5	1005.9	228.9	65.2	260.5	0.8	1.3	1.1	9.8
AC external grid	EXT - External AC System	-	-	-	-	-	-	-	8.0	9.2	4.9	5.3
	N/A	11.4	10.4	1.9	6.2	13.6	0.5	2.2	-	-	9.1	-
Control center operation	C-P.M - Master HVDC Control & Protection	-	-	-	-	-	-	-	-	-	-	0.0
	N/A	-	-	5.1	-	9.6	-	0.2	0.0	-	-	-
Control, protection and communication	C-P.L - Local HVDC Control & Protection	-	-	-	-	-	-	-	6.8	10.3	106.2	7.8
	C-P.M - Master HVDC Control & Protection	-	-	-	-	-	-	-	-	6.6	37.3	-
	C-P.T - Control & Protection and Telecommunicati..	-	-	-	-	-	-	-	-	0.7	-	-
	N/A	79.8	38.3	23.1	12.6	26.3	63.5	0.6	2.7	-	1.3	0.2
	C-P.L - Local HVDC Control & Protection	-	-	-	-	-	-	-	-	-	-	46.1
Converter station operation	C-P.L - Local HVDC Control & Protection	-	-	-	-	-	-	-	21.1	0.8	84.2	-
	C-P.M - Master HVDC Control & Protection	-	-	-	-	-	-	-	8.2	0.6	-	-
	N/A	0.4	5.9	2.3	290.4	20.1	-	1.5	-	-	-	-
	C-P.L - Local HVDC Control & Protection	-	-	-	-	-	-	-	-	-	-	1.8
DC cable	TL-C - DC Underground / submarine Cable	-	-	-	-	-	-	-	1729.1	3410.9	1623.7	3748.9
	N/A	2505.5	1704.1	226.9	32.2	876.0	1361.8	996.5	-	-	-	-
DC converter	DC-E.F - DC Filters	-	-	-	-	-	-	-	-	-	0.1	-
	DC-E.ME - DC Measuring Equipment	-	-	-	-	-	-	-	65.2	3.6	148.3	-
	DC-E.O - Other DC Yard and Valve Hall Equipment	-	-	-	-	-	-	-	2.8	-	18.6	30.2
	DC-E.SR - DC Smoothing Reactor	-	-	-	-	-	-	-	245.3	174.5	-	-
	V.C - valve capacitor	-	-	-	-	-	-	-	36.5	-	-	-
	V.E - Valve Electrical	-	-	-	-	-	-	-	36.9	33.6	217.0	7.1
	V.VC - Valve Cooling	-	-	-	-	-	-	-	52.8	13.5	91.4	3.6
	N/A	1192.2	888.1	283.0	3.3	37.2	33.8	210.6	424.4	-	12.4	-
	DC filter	-	-	-	-	-	-	-	-	-	-	339.1
	V.C - Valve Capacitor	-	-	-	-	-	-	-	-	-	-	994.1
DC electrodes	N/A	3.2	18.4	6.8	9.0	136.3	-	4.6	-	-	-	-
DC overhead line	TL-OH - DC Overhead Transmission Line	-	-	-	-	-	-	-	3.1	-	-	28.5
	N/A	-	-	0.6	3.0	2.3	-	-	-	-	-	-
Multiple places	N/A	24.3	2.1	0.2	0.2	0.7	-	-	-	-	-	106.8
N/A	TL-C - DC Underground / submarine Cable	-	-	-	-	-	-	-	-	-	-	34.8
	N/A	-	-	-	-	-	-	186.5	0.7	42.8	-	147.0
Other or unknown	O - Other	-	-	-	-	-	-	-	0.0	4.5	1.2	0.2
	N/A	13.2	0.9	34.5	1.4	0.7	8.4	0.7	3.1	83.1	17.1	-

Table dist.out. GWh lookup without zeros broken down by GWh (Parameters)andDatetime Year vs. OriginandSubcategory.The data is filtered on HVDC link, which excludes Vyborg Link FI→RUandVyborg Link RU→FI.

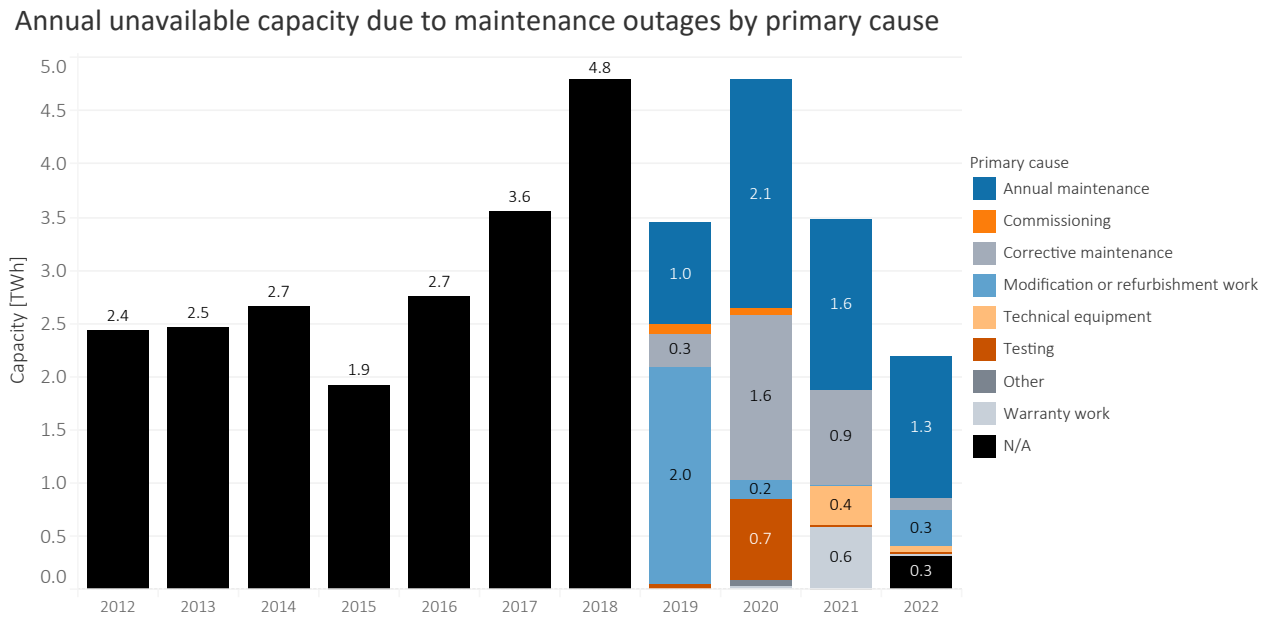

Figure E.10: Annual unavailable capacity due to maintenance outages by primary cause for all HVDC links. Primary cause of outages has not been recorded prior to 2019.

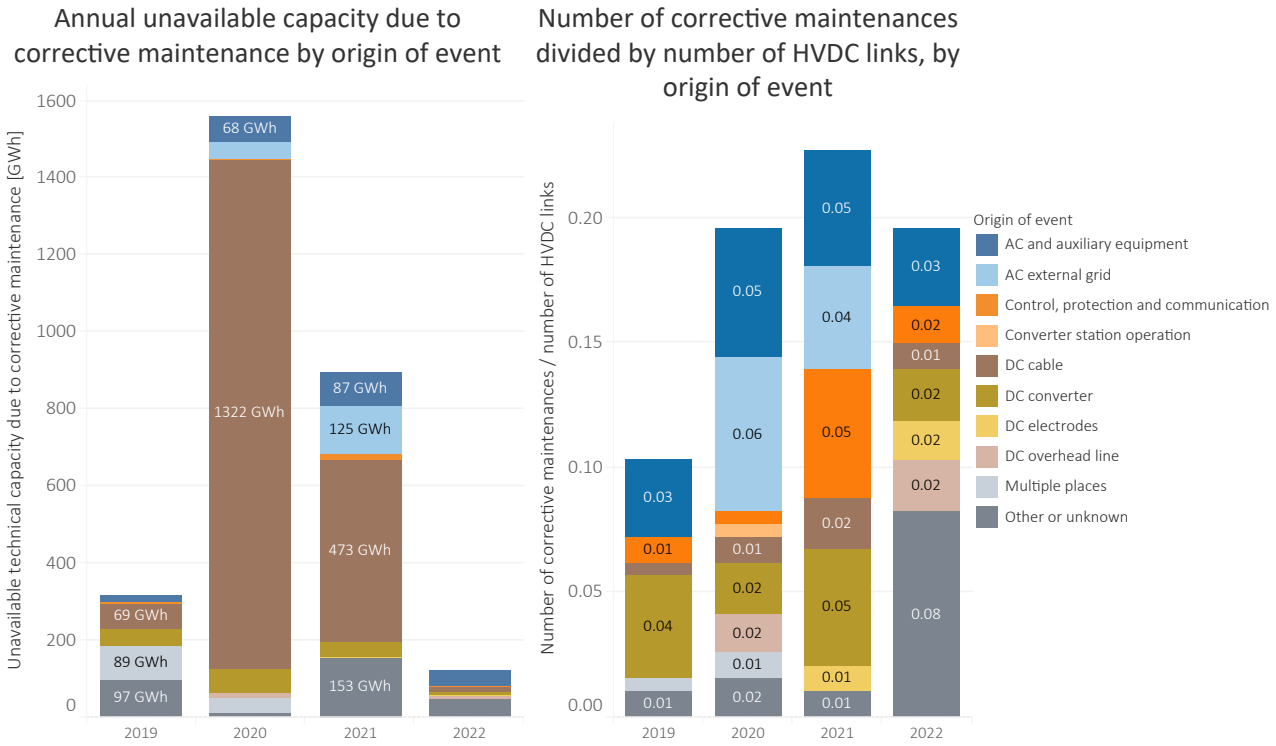

Figure E.11: On the left: annual unavailable capacity due to corrective maintenance outages by origin of event for all HVDC links. On the right: number of corrective maintenance outages divided by the number of HVDC links annually grouped by origin of event. Primary cause of outages has not been recorder prior to the year 2019.