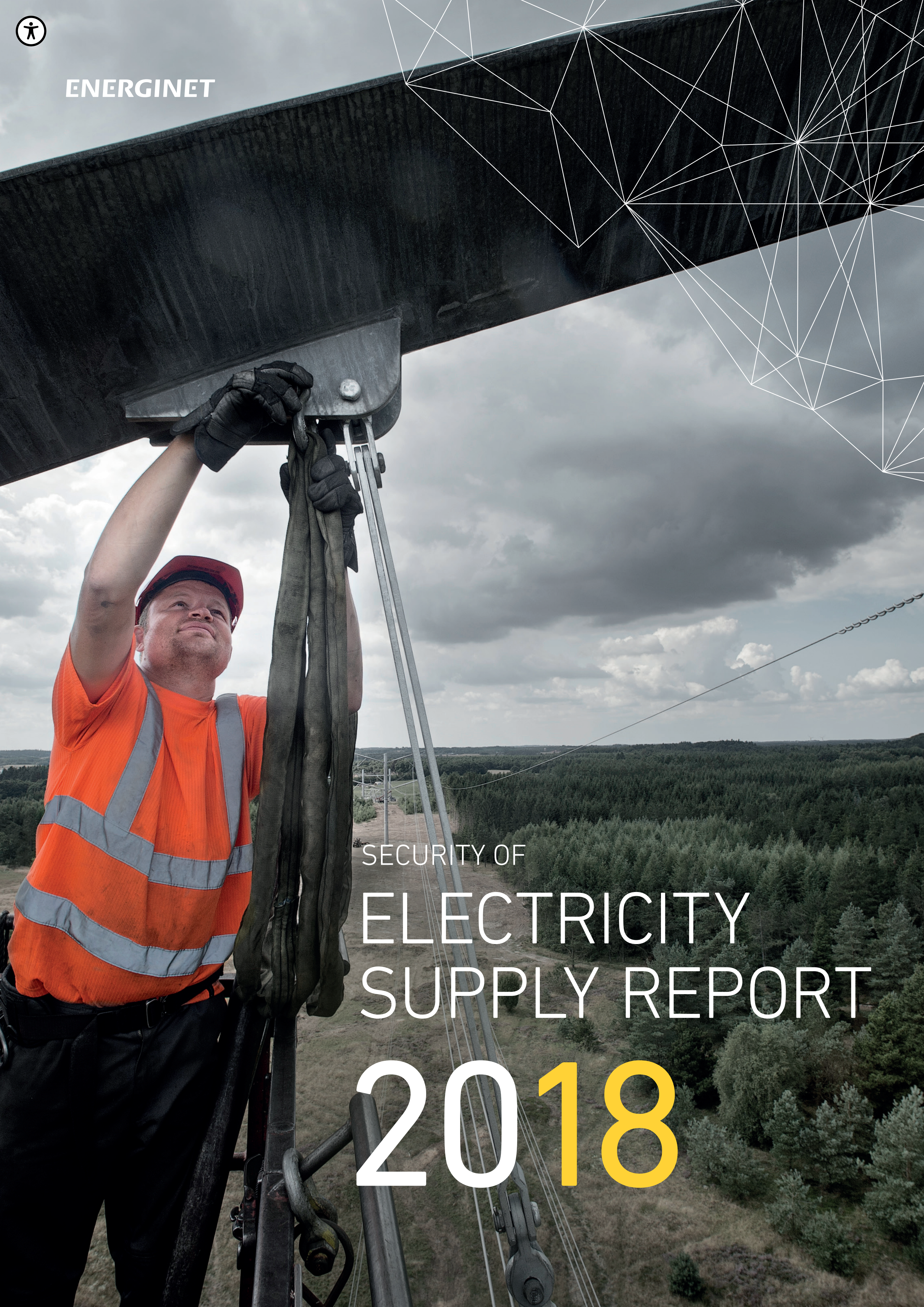

ENERGINET

SECURITY OF ELECTRICITY SUPPLY REPORT 2018

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Front page photo: Maintenance work on the electricity connection between Kassø by the Danish-German border and Tjele by Viborg.

SUMMARY

In general, Denmark's security of electricity supply level ranks among the highest in Europe, and the 2017 level was no exception. Danes had power available 99.995 per cent of the time. This means that the average consumer experienced less than 25 minutes of outage. Though this is slightly more than in 2016, the figure is still very low. The high level of security of electricity supply is mainly due to conversion to cables in the distribution grids

The Security of electricity supply report 2018 uses selected highlights and analyses to sum up the security of electricity supply for 2017 and includes a related forward-looking risk assessment.

Energinet's goal is for Danes not to experience outages, resulting from faults in the power transmission grid, for more than 60 seconds in total during a normal year.

Of the 25 minutes outage in 2017, 92 seconds resulted from incidents in the transmission grid. The transmission grid fault that affected the most consumers occurred at Svanemøllen station in Copenhagen in October. It was a procedural error in connection with planned maintenance at the station.

Minimizing faults is essential to Energinet, as a single fault in the electricity transmission grid can escalate and lead to extensive outages for Danish electricity consumers. Energinet aims to avoid faults by continuously optimising work processes and component maintenance.

Key challenges for the high Danish security of electricity supply
The Danish and European electricity systems are undergoing significant changes. Extensive wind and solar power capacity is integrated in the electricity system, while many traditional thermal power stations are phased out. As more electricity interconnectors link different countries' electrical grids together, the security of electricity supply becomes an increasingly regional, instead of simply a national, issue. At the same time, electricity markets and operational collaboration across Europe are harmonised via new European regulations. This all greatly influences how Energinet will ensure the Danish security of electricity supply in the future.

In this 2018 report, Energinet describes the main challenges for the security of electricity supply. Examples are listed below.

Risk of no electricity east of the Great Belt
The Danish electricity grid has an eastern and a western section with the Great Belt as the dividing line. In Eastern Denmark, the risk of the electricity supply not meeting demand will increase in the coming years. Although Energinet's 10-year outlook shows an increased probability of brownouts - i.e. controlled disconnections of electricity consumers in limited areas - such situations are expected to be very rare events.

Energinet introduces concrete measures to address the Eastern Danish challenge. Among other things, Energinet is working to make better use of existing infrastructure, such as an upgrade of the domestic electricity grid close to the Øresund Link that will increase capacity in case of outages or revisions. Energinet is also looking into the possibility of obtaining approval for a temporary introduction of a strategic reserve. At the same time, Energinet is working determinedly to implement current electricity market reforms, which will combine with other new initiatives to ensure increased flexibility in both electricity generation and consumption, bringing new market solutions to ensure the security of electricity supply.

Renewal of the Copenhagen power grid
Operation of the power grid is changing in these years as a consequence of increased renewable electricity generation, a rise in electricity consumption, especially from data centres, and an ageing power grid. This requires expansion of and reinvestments in the domestic electricity grid, for example in Copenhagen.

In Copenhagen and the surrounding areas, the security of electricity supply is challenged by an ageing electricity grid with still longer outage times due to regular maintenance. In addition, electricity consumption is expecting to rise while electricity generation by Copenhagen thermal power stations is declining.

As a result, Energinet is in the process of laying new cables leading into Copenhagen, and these should be operational by the beginning of 2019. Energinet finds that the risk of load shedding is unacceptably high during the construction phase. Therefore, Energinet has ordered a thermal power station in operation to maintain the high security of electricity supply in Copenhagen until the cable is put into operation.

Changes in need for properties required to maintain power system stability
Properties required to maintain power system stability are important to ensure the robustness of the power system, as these properties help to ensure the stability of the electricity grid in case of faults or outages.

Energinet's most recent and most comprehensive analyses of the need for properties required to maintain power system stability show that the electricity system is more robust than previously assumed. This is due to, for example, the fact that today's modern wind turbines help to stabilise the system, and that Energinet can use automation to operate the grid closer to the limit.

Thus, Energinet can operate the electricity grid more stably, even without power stations running. Optimised utilisation of the electricity system's components facilitates the integration of renewable energy sources while maintaining a high level of security of electricity supply.

Greater focus on IT security
The electricity system's increasing dependence on IT requires high uptimes on crucial IT systems. It also triggers focus on external threats, as well as national and international preparedness cooperation. One measure implemented is a joint Nordic preparedness drill.

TOTAL OUTAGE MINUTES

2017, minutes: 25

2016, minutes: 19

Outage minutes for an average consumer in the Danish electricity system.

OUTAGE MINUTES DUE TO FAULTS IN THE TRANSMISSION GRID

2017, seconds: 92

2016, seconds: 48

Target, seconds: 60

Average outage minutes due to system disturbances in the transmission grid (above 100 kV).

ALERT STATE

2017, no. of times: 1

2016, no. of times: 1

The 2017 outage was caused by a fault in a cable into Copenhagen.

IT SECURITY

2017, no. of incidents: 0

2016, no. of incidents: 3

No incident with loss of critical IT tools in 2017.

PREPAREDNESS

2017, no. of incidents: 1

2016, no. of incidents: 0

The single 2017 incident was caused by a fire in a station.

ANCILLARY SERVICES

2017, DKK million: 626

2016 DKK million: 758

Costs of procuring ancillary services.

GENERATION ADEQUACY 2025

More data centres.
Fewer power stations.
More interconnectors.
More renewable energy.

Impact security of electricity supply in Denmark.

GENERATION ADEQUACY 2025

Eastern Denmark, minutes: 11

Western Denmark, minutes: : <1

Generation adequacy in Eastern Denmark is challenged.

GRID ADEQUACY

Ageing electricity grid and more reinvestments, e.g. in Copenhagen, may challenge security of electricity supply.

ROBUSTNESS

Units in the electricity grid required to maintain power system stability and greater extent of automation contribute to electricity system robustness.

IT SECURITY

Increasing dependence on IT in the electricity system requires high uptimes on critical IT systems.

OPERATIONAL AND MARKET DEVELOPMENT

Pan-European projects aim to ensure security of electricity supply efficiently.

1. SECURITY OF ELECTRICITY SUPPLY

Ensuring a high level of security of electricity supply is a complex interaction throughout the value chain between the physical electricity grid, electricity markets, electricity generators and electricity consumers. This is true not only in Denmark but for Europe as a whole. This requires harmonisation and cooperation across national borders.

1.1 What is security of electricity supply?
The level of security of electricity supply depends on the extent to which electricity consumption and electricity generation can be balanced and on the electricity grid's capacity to transfer the electrical energy and handle faults. Thus, risk assessments for the electricity system are divided into two categories – system adequacy and system security – which in reality are two partially overlapping elements.

Assessing system adequacy means assessing the electricity system's ability to meet the total electricity consumer demand, and can be subdivided into generation adequacy and grid adequacy.

Generation adequacy is defined as the electricity system's ability to ensure adequate electricity when the consumer needs it. Generation adequacy is closely linked to the electricity market, where inadequacy results in high electricity prices.

Grid adequacy is defined as the electricity transmission and distribution systems' ability to transport sufficient electricity from generation site to consumption site.

A lack of system adequacy will typically lead to announced disconnections of consumers in limited areas. These situations are referred to as planned disconnections or brownouts. A brownout is a precaution taken to protect against a blackout in a large area. Brownouts are serious incidents, yet less severe than blackouts.

An assessment of system security involves assessing the electricity system's robustness when faced with faults and IT incidents and is subdivided into robustness and IT security.

Robustness is defined as the electricity system's ability to handle sudden system disturbances caused by electrical short circuits, power station or transmission line outages etc. without these situations affecting the electricity supply or resulting in power outages.

IT security is defined as the electricity system's ability to maintain high uptimes on critical IT systems and to withstand cyberattacks, without the system and its participants being affected.

A lack of system security will, in a worst-case scenario, lead to blackouts in Western and/or Eastern Denmark. A blackout is a complete breakdown of the electricity system. The result may be substantial installation damage and long restoration times for the electricity supply. As such, system security is the main challenge faced by the Danish electricity system.

1.2 The security of electricity supply framework is becoming more international
Generation adequacy is becoming an increasingly regional and international issue with the expansion of renewable energy and the change in the electricity generation mix across national borders.

In order to solve future challenges of security of electricity supply, a large

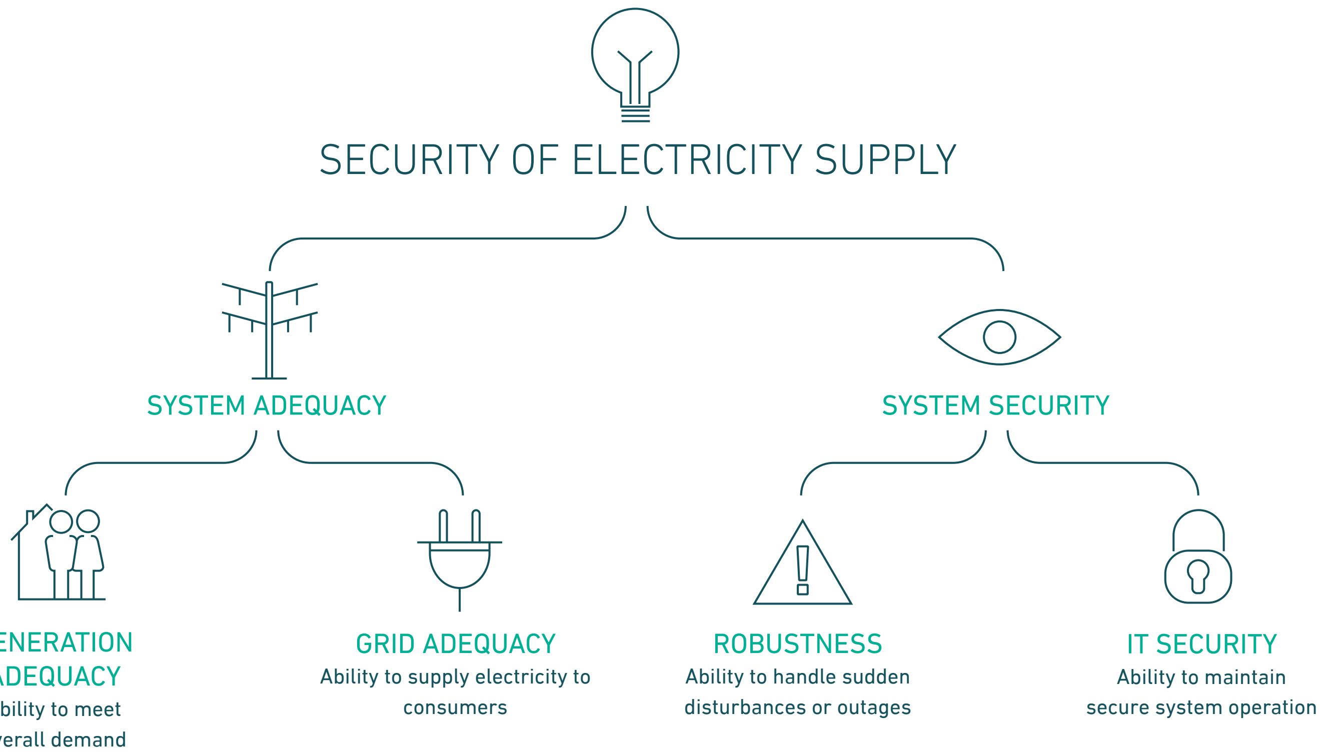


Figure 1: Illustration of security of electricity supply consisting of system adequacy and system security.

number of initiatives have been launched across Europe. Energinet is also faced with more local challenges of grid adequacy and system security as a result of the increasing electricity generation from renewable energy sources and reduction in the number of thermal power stations in operation.

These initiatives include both the implementation of new EU regulation in the form of European legislation and network codes aimed at promoting European and regional cooperation on security of electricity supply in order to ensure optimal use of capacity across national borders.

The implementation of the System Operation Guideline network code is particularly important. This provides a framework for Energinet's options when it comes to maintaining the desired level of security of electricity supply. This includes:

- Requirements for the content of the outage plan and for enhanced regional coordination.
- Requirements for data exchange between Energinet, balance responsible parties, electricity distribution companies and installations.
- Principles for activating measures to safeguard the security of electricity supply.

With the adoption of the System Operation Guideline, the Danish Electricity Supply Act must be updated to avoid double regulation. Moreover, the Act will incorporate the recommendations of the Danish committee on electricity regulation on security of electricity supply, and the objectives in the government report Supply for the future of increased marketization of the services that Energinet demands to safeguard the security of electricity supply.

The act also proposes that the Minister for Energy, Utilities and Climate will have the overall responsibility for the

CLEAN ENERGY FOR ALL EUROPEANS

On 30 November 2016, the European Commission issued the draft of a major legislative package called 'Clean Energy For All Europeans'. This is expected to be implemented in 2018. The package aims to promote European and regional cooperation on the security of electricity supply in order to ensure optimal use of capacity across national borders. In addition, the package is expected to require that the level of security of electricity supply be assessed on the basis of Value of Lost Load.

Value of Lost Load, abbreviated VoLL, is an economic indicator that states the cost of interrupted supply. VoLL is usually determined in DKK/kWh.

security of electricity supply and the level thereof going forward. Energinet will continue to be responsible for maintaining and monitoring the established level of security of electricity supply.

In addition, the annual security of electricity supply report is expected to become mandatory.

POSSIBLE REMOVAL OF THE COMBINED HEAT AND POWER (CHP) REQUIREMENT

There has been a political debate on whether to remove the CHP requirement for thermal power stations.

Removing the CHP requirement may impact the security of the electricity supply differently in the short and long term, respectively. However, Energinet does not expect the level of security of electricity supply to be noticeably reduced.

In the short term, the electricity system depends on central thermal power stations to provide several different services. Especially in situations where, for instance, a vital grid component is out of service due to audit or breakdown.

In addition, it may be necessary to expand the grid locally to compensate for the decommissioning of certain power stations, since these have been part of electricity grid planning historically. This will lead to increased costs of investments in the electricity grid.

A removal of the CHP requirement may also prove the least expensive solution socio-economically, if the socio-economic savings for the stations are greater than the increased socio-economic costs for the electricity system.

In the long term, the need for technical characteristics will change as the electricity system develops. At some point, the services delivered by central power stations today may be replaced by different technologies.

1.3 Level of security of electricity supply

Energinet's strategy 2018-2020 does not state an explicit target for security of electricity supply. However, Energinet is working to keep the Danish level of security of electricity supply at the European top. With the update of the Danish Electricity Supply Act, the Minister for Energy, Utilities and Climate may change the security of electricity supply objective.

Historically, Denmark's level of security of electricity supply has been very high, and it is expected to remain so in the coming years, albeit not necessarily at exactly the same level.

The level of security of electricity supply is influenced by a number of things. In some cases, an increasing dependence on foreign supply, a rise in the number of wind turbines and declining thermal electricity generation capacity pose challenges to generation adequacy.

ELECTRICITY SUPPLY ACT

§ The Danish Electricity Supply Act contains various provisions regarding the framework for a high level of security of electricity supply, and various authorities are assigned tasks and competences in relation to this. Energinet has the overall responsibility for security of electricity supply in Denmark. This obligation creates the foundation for Energinet's core tasks in connection with the support of a high level of security of electricity supply. The Danish Electricity Supply Act is expected to be revised in 2018.

Energinet monitors the development and continuously evaluates whether to take action to maintain the level of security of electricity supply.

Energinet works on the implementation of new market reforms on an ongoing basis, including incentives for consumption flexibility combined with more transparency and marketization of services to maintain security of electricity supply.

At the same time, new grid components make it possible to safeguard system robustness, even on days with no central electricity generation capacity.

Cost-effective security of electricity supply is about ensuring that the electricity system works, so the participants throughout the value chain can supply energy to customers when needed.

A high level of security of electricity supply is of great socio-economic value, and the Danish electricity system is designed accordingly. Whether to invest more in strengthening the security of electricity supply depends on the availability of cost-effective tools to minimise the risk of outages. Therefore, this entails an assessment of whether additional measures are to be taken to prevent a loss of electricity supply. This means that cost becomes a question of looking into different measures and comparing these in respect of the risk reductions that they will provide.

Generation adequacy analyses in Denmark towards 2025 show that Eastern Denmark still faces the greatest risk of power shortage. Although results are somewhat uncertain, they show that there is an increased probability of a limited number of brownout situations over the next 10 years. Brownouts are most likely to occur in situations involving several simultaneous cases of outage in the grid, interconnectors and/or thermal power station outages, and low levels of wind power generation. Thus, power shortage situations will be very rare events.

Achieving a higher level of generation adequacy will require the launch of initiatives that underpin the energy-only market by means of e.g. incentive-promoting electricity market reforms, new interconnectors or a capacity mechanism in the form of a strategic reserve.

This explains Energinet's wish to open up talks with the European Commission and the Danish authorities on the possibility of obtaining approval for a time-limited strategic reserve in order to uphold generation adequacy in Eastern Denmark. Energinet will use these talks to ask for an approval for the period 2025-2029 with an option to extend this period by five years.

At the same time, Energinet is working determinedly to actualise ongoing electricity market reforms, and new initiatives aimed at ensuring greater flexibility both from electricity generation and electricity consumption and from new storage technologies will be launched in the coming years.

STRATEGIC RESERVE

From 2014-2017, the European Commission approved a number of capacity mechanisms in e.g. England, France and Germany based on new regulation, and in February 2018, strategic reserves were approved for the first time in Germany and Belgium.

In case of the latter two countries, these are temporary strategic reserves. The purpose of strategic reserves is to ensure national generation adequacy in the event of a series of unexpected changes in the electricity system with potentially significant impact on the security of electricity supply. In other words, the reserves in these two cases should be seen as measures to ensure the security of electricity supply during the ongoing transition of the two countries' power systems.

2. HISTORICAL SECURITY OF ELECTRICITY SUPPLY

For many years, Danish electricity consumers have experienced very high levels of security of electricity supply. This was also the case in 2017 with a very low number of outage minutes per consumer and a low number of incidents that impacted the security of supply in the electricity system.

2.1 Outage statistics
Danish electricity transmission grid and distribution grid faults and outages are recorded in the Elselskabernes Fejl- og Afbrudsstatistik (ELFAS) statistics.

Outage statistics show the extent to which an average electricity consumer experienced outages. This means that some electricity consumers experienced several outages, while others experienced none.

In 2017, the number of outage minutes was still very low. There were just less than 25 minutes of outage, which is higher than in 2016. Thus, Danes had power 99.995 per cent of the time on average. This makes 2017 yet another year where Danish electricity consumers had a security of electricity supply level that was among the highest in Europe.

Until 2011, the outage statistic was divided into the voltage levels 1-24 kV and 25-99 kV, with the electricity transmission grid included in the 25-99 kV statistics. After 2011, the electricity transmission grid is shown independently using the category > 100 kV.

FIGURE 2: OUTAGE STATISTICS FOR DENMARK, 1998-2017.

Source: Elselskabernes Fejl- og Afbrudsstatistik (ELFAS), Danish Energy Association.

The figure shows the average duration of electricity supply outages in minutes per consumer per year (calculated per delivery point) in Denmark. Historically, power shortages have not led to the disconnection of consumers in Denmark and are therefore not included in the figure.

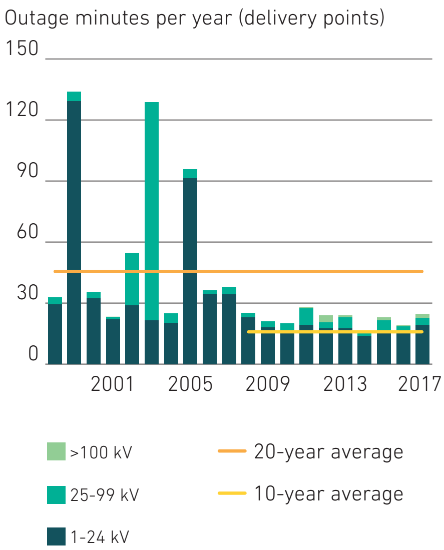


TABLE 1: AVERAGE NUMBER OF OUTAGE MINUTES OVER THE LAST 5, 10, 15 AND 20 YEARS.

Source: Elselskabernes Fejl- og Afbrudsstatistik (ELFAS), Danish Energy Association.

(Minutes/ year)	5 years	10 years	15 years	20 years
1-24 kV	16	18	25	31
25-99 kV	4	5	11	10
>100 kV	1	-	-	-
Total	21	23	36	41

Apart from one-time incidents, such as a fault in Western Denmark's transmission grid in 2002 and a fault in the Swedish grid in 2003, the general picture is that the vast majority of outage minutes are due to faults in the distribution grid.

There are approximately 20-30 outage minutes per average consumer per year caused by outages at the distribution level. As more overhead lines are converted to cables, the number of outage minutes in the distribution grid is gradually declining.

The underlying reasons for the high outage minute numbers in 1999 and 2005 were a hurricane and a storm, respectively.

Therefore, average outage levels should be viewed over a number of years.

TABLE 2: DISTURBANCES IN THE TRANSMISSION GRID INVOLVING DISCONNECTION OF ELECTRICITY CONSUMERS IN THE DANISH ELECTRICITY SYSTEM IN 2017.

Source: Elselskabernes Fejl- og Afbrudsstatistik (ELFAS), Danish Energy Association.

Date	Error type	Unserved energy (MWh)	Outage minutes (seconds)
6/2	Procedural error in Energinet's control centre	14	15
4/10	Procedural error at station	35	34
11/10	Procedural error at station	8	8
29/10	Component error	36	35
Total		93	1 minute and 32 seconds

FAULT AT SVANEMØLLEN STATION

The fault that affected the most electricity consumers occurred at Svanemøllen station on 4 October 2017. The fault was caused by a procedural error in connection with switching during planned maintenance at the station.

A manual switching procedure of an operational busbar went wrong, resulting in the tripping of the entire station. This then led to an automatic unintentional tripping of the line between Amager Power Station and Bellahøj station.

Close to 92,000 electricity consumers were disconnected, and it took around 25 minutes before the electricity supply was restored by rerouting the underlying distribution grid.

DISTURBANCES, OUTAGES, INCIDENTS AND FAULTS

Typical incidents include disturbances, near-miss incidents, IT incidents and N-1 exceeding.

The term disturbance is defined as faults in the grid that make at least one component disconnect, thus affecting operation of the electricity system. Disturbances do not necessarily lead to disconnection of electricity consumers.

Outages, on the other hand, are defined as situations where electricity consumers are not supplied with the electricity demanded.

Outages caused by the transmission grid
On average, a total of 92 seconds (1 minute and 32 seconds) of the 25 minutes of outage that electricity consumers experienced in 2017, were caused by four disturbances in the transmission grid.

These faults mainly owed to procedural errors that Energinet is working to avoid by implementing new workflows in the control centre and establishing better cooperation with contractors, among other things.

Outage seconds at transmission level were distributed as follows: 15 seconds were caused by a procedural error in the electricity system control centre, 42 seconds by procedural errors at stations and 35 seconds by component faults.

2.2 Electricity system incidents in 2017
Incidents of significance to security of electricity supply occur at the electricity market, system, IT and component levels.

Generation adequacy
There were no incidents related to generation shortages in the Danish electricity system in 2017. As has been the trend historically, there were thus no market-related shortages in 2017 which led to failure to reach a market price.

COPENHAGEN

In the Copenhagen area, security of electricity supply is under pressure. Reasons include an ageing electricity grid, characterised by increasing planned outage times, an expected rise in electricity consumption and the continued decommissioning of thermal electricity generation capacity in the area. Consequently, outages on the two 400 kV lines linking the grid in Copenhagen to the rest of Zealand can cause intolerable overloads in the electricity grid. Thus, there is a risk that electricity consumers in Copenhagen will have to be disconnected more or less permanently until the damage caused by any overload has been repaired.

Energinet's business case on "Forsyning af København", published in 2017, stated that the socio-economically best solution is to invest in an upgrade of the electricity grid leading into Copenhagen. The Minister for Energy, Utilities and Climate has approved the construction of a new 132 kV cable in the area, which will solve the current problem in Copenhagen. The cable is expected to be operational in early 2019.

However, until the cable is in place, exceptional measures are necessary, since the risk of forced disconnections is considered unacceptably high. One such measure is that Energinet has chosen to order Amager Power Station's unit 3 to run until the cable is commissioned. This decision is based on an assessment of how the challenge faced can be met with the lowest possible socio-economic costs.

Alternatively, as a precaution, Energinet can disconnect electricity consumption in the area to avoid overload in situations of outages on one of the two 400 kV lines.

In late 2017 and early 2018, there were two major faults in the Copenhagen area which led to near-miss incidents:
- A faulty meter led to the disconnection of one 400 kV connection. If the Amager Power Station unit 3 had not been running, the consequence would have been disconnection of electricity consumers.
- An oil leak led to the disconnection of one of the 132 kV connections in Copenhagen. Amager Power Station unit 3 was not in operation. If the remaining power stations had been unable to ramp up electricity generation, it would have been necessary to disconnect electricity consumers.

Use of brownout

The controlled disconnection of electricity consumers (brownout) to handle strained operating situations was not necessary in 2017.

However, there were a few operating situations in which the loss of the largest unit (N-1) in the system could have led to a power shortage due to maintenance work and breakdowns in the electricity system. Had such an incident occurred, it might have been necessary to disconnect electricity consumers.

Operational status

Energinet's electricity system control centre operates with three different operational status types: normal operation, alert state and emergency state.

The electricity system is in normal operation for the vast majority of the time. In 2017, an alert state was registered once in November. The state was triggered by the fault on the 400 kV cable in November, which presented a challenge to the security of electricity supply in Copenhagen. The problem, was quickly resolved, and the upward regulation of Amager Power Station's unit 3 and quick troubleshooting, among other things, ensured that there were no electricity consumer outages in the intervening period.

TABLE 3: LIST OF DANISH INCIDENTS REPORTED TO THE ICS STATISTICS IN 2016 AND 2017.

Incidents are classified in the reporting on a scale from 0-3, where 3 is the most severe level:

• Scale 0 Local deviations with low impact on operational reliability
• Scale 1 Serious incidents and incidents affecting more than one TSO
• Scale 2 Extensive incidents in a large area (e.g. neighbouring TSOs)
• Scale 3 Major incidents resulting in a blackout
Loss of IT tools is only registered for scale 1 and scale 2 incidents in the ICS statistics.

CRITERIA	Scale 0	Scale 1	Scale 2	Scale 3
Incidents with components in the transmission grid	2016: 1 2017: 1	2016: 13 2017: 10		
Violation of voltage standards	2016: 0 2017: 0	2016: 0 2017: 0		
Loss of IT tools	2016: 0 2017: 0	2016: 3 2017: 0		

OPERATIONAL STATUS TYPES

During *normal operation*, the electricity system follows the normal operating conditions, including being able to handle an outage of the largest unit (the N-1 principle).

If incidents in the electricity system threaten normal operation, and there is a risk of operation disruption, the operating situation changes to an alert state. In an alert state, the electricity market can be suspended, and Energinet can use all the options at its disposal to maintain the electricity supply.

If operation becomes unstable, and there are also local/regional outages, the operating situation is changed to emergency state. In an emergency state, Energinet calls in extra crisis staff, and preparations are made to handle extended system disturbances.

An emergency state is declared extremely rarely, and there were no cases in 2017.

European incident reporting
Europe's electricity systems are closely connected, and system disturbances in one country may impact neighbouring countries, or in the worst case all of Europe. Therefore, European TSOs work together to maintain secure operation in a common electricity system.

ENTSO-E has developed an Incidence Classification Scale (ICS). The ICS aims to provide an overview of incidents in the European electricity system through a single common reporting method. ICS statistics only cover events at the 220 kV level or above.

There were 10 incidents in the transmission grid in 2017 against 13 the year before. Four of the incidents in 2017 occurred at KontiSkan, four at Skagerrak and two at the Øresund Link.

No incidents with loss of critical IT tools were registered in 2017 against three in 2016.

Disturbance Statistics and Classification (DISTAC)
Within the ENTSO-E framework, the Nordic and Baltic countries prepare an annual report called DISTAC. The report describes both system disturbances and faults in the HVAC grid over 100 kV and the utilisation of HVDC connections regarding outage times and limitations.

Reporting on the AC (HVAC) grid
A technical incident report is prepared for the HVAC grid, providing insights into failure rates, causes, security of supply and components subject to multiple faults.
In 2017, 53 system disturbances occurred in the Danish electricity grid at voltage levels above 100 kV, with an equivalent 51 disturbances in 2016. The 10-year average from 2008 to 2017 was 55 errors. Four system disturban-

FIGURE 3: ILLUSTRATION OF THE NUMBER OF AC (HVAC) GRID FAULTS.

Source: DISTAC, Nordic and Baltic Grid Disturbance Statistics 2015.

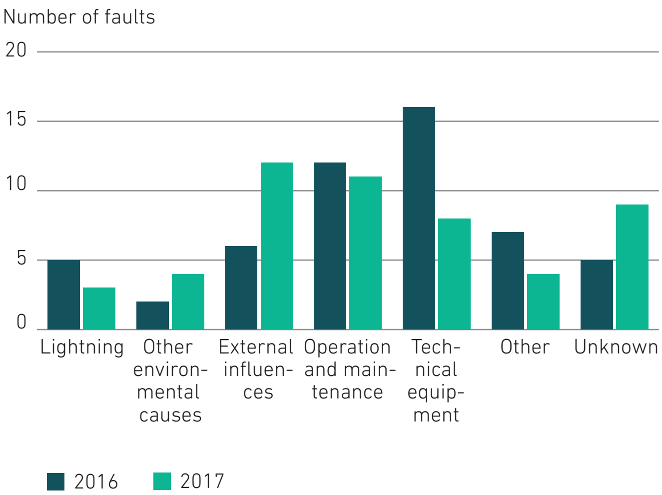
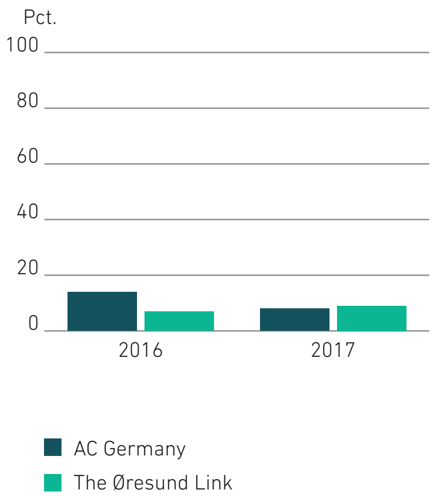


FIGURE 4: RESTRICTIONS ON THE IMPORT VIA DANISH HVAC CONNECTIONS.

Source: Energy Data Service, www.energidataservice.dk.



ce incidents led to disconnection of consumers in 2017. By comparison, there were 13 such incidents in 2016.

Restrictions on AC connections
Energinet monitors the exchange capacity of AC connections in Eastern and Western Denmark. Moreover, import capacity is an important aspect of security of electricity supply.

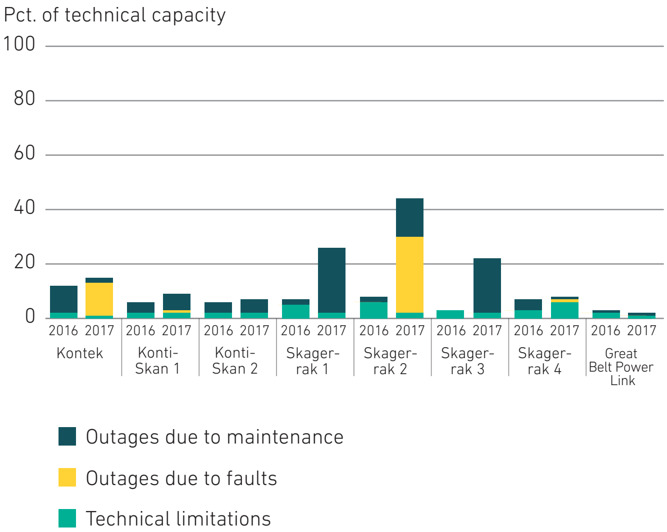
In 2017, the AC connection from Germany (import capacity) was restricted an average 8 per cent of the time, which was lower than in 2016. The Øresund Link (import capacity) was limited 9 per cent of the time on average.

Reporting on HVDC connections
Statistics are prepared for the Nordic HVDC connections, detailing how these are impacted by technical limitations in the grid or by faults and maintenance work. The Danish HVDC interconnectors and the Great Belt Power Link are included in the statistics.

In 2016, 24 faults were registered on connections to/from Denmark, while 18 were registered in 2017. A 102-day cable fault on Skagerrak 2 represented the only long-lasting fault in 2017.

FIGURE 5: CURRENT RESULTS FOR CAUSES OF OUTAGE TIMES AND LIMITATIONS ON THE IMPORT CAPACITY FOR DANISH HVDC CONNECTIONS.

Source: DISTAC, Nordic and Baltic HVDC Utilisation and Unavailability Statistics 2017.



"The system's robustness enables Energinet's control centre to handle most system disturbances without escalating these to emergency incidents"

Availability of central power stations
Average availability of central electricity generation capacity in Denmark roughly matches previous years' levels. In 2017, availability averaged 82 per cent, up from 73 per cent in 2016 and 79 per cent in 2015. Availability is not 100 per cent because maintenance work and breakdowns still take place.

Emergency incidents
Emergency incidents are rare in the Danish electricity system. The system's robustness enables Energinet's control centre to handle most system disturbances without escalating these to emergency incidents. In 2017, only one incident reached proportions that required the preparation of an incident report for the Danish Energy Agency.

This incident involved a fault at a 10 kV substation which then caused a fire in the building. The building was split between an electricity distribution company and Energinet, and the fire quickly spread to Energinet's 132 kV installation. Damage from the fire was so extensive that the station was out of service for some two months after the incident.

On the day of the incident, Energinet rerouted the grid around the damaged station, keeping the grid fully operational and securing grid stability. Contractors could then rebuild the station

Energinet's electricity system control centre in Erritsø.

uninterrupted. The station was put into operation again in steps by criticality; the first part only a month after the incident and the last part some two months after.

To prevent similar incidents, Energinet has launched a study to clarify whether there are other stations where something similar might occur.

2.3 Ancillary services

Ancillary services is the collective term for the electricity generation and consumption resources used to maintain electricity system balance and stability. Energinet purchases ancillary services that can be activated automatically or manually in the delivery hour. Ancillary services consist of reserves, regulating power, properties required to maintain power system stability and other system services such as emergency start-up.

In 2013-2017, Energinet purchased ancillary services at between DKK 600 and 800 million annually. Overall, costs dropped approximately DKK 130 million from 2016 to 2017.

The largest change from 2016 to 2017 is a considerable drop in the cost of manual reserves. Costs were exceptionally high in 2016 because of a special situation in the manual reserves market in the autumn of that year. This was caused by a planned outage at Kyndby Power Station, which is usually the main supplier of manual reserves in Eastern Denmark.

In 2017, the cost of other ancillary services increased from DKK 30 to 112 million. The rise was mainly due to the one-off, long-term situation in Copenhagen, where Energinet is paying for Amager Power Station unit 3 to run continuously. Keeping the power station in operation reduces the risk of overloads and thus disconnection of electricity consumers. Other ancillary services also includes emergency start-up and generation adequacy capabilities.

Costs of procuring properties required to maintain power system stability went down from DKK 48 million in 2016 to 10 million in 2017. Moreover, these costs dropped approximately DKK 130 million from 2015 to 2016. In other words, costs of properties required to maintain power system stability have been reduced by more than DKK 160 million in just two years. The decrease is mainly due to the fact that the generic need for properties required to maintain power system stability has been reduced in recent years, while Energinet has also expanded the grid with synchronous compensators and added automation features to existing grid components.

Local needs for properties required to maintain power system stability in case of breakdowns and planned outages are seen as unchanged because, most often, only one possible supplier is available locally. Therefore, ordering constitutes a large portion of total costs of properties required to maintain power system stability, but out of a much reduced total amount. In 2017, there was no unplanned ordering where Energinet may, at very short notice, make use of the ordering option under the Danish Electricity Supply Act. For further information, please read the Energinet publication "Energinet's use of ordering to secure the security of electricity supply 2016-2017".

Plans to decommission power stations and cancelled outage applications

Energinet coordinates and draws up an annual outage plan. The outage plan ensures that outage times are coordinated with market participants. The outage plan is prepared on the basis of submissions from central power stations, interconnectors and Energinet's own projects. Once approved, Energinet cannot deviate from the outage plan without compensating the affected parties. Energinet did not cancel any outage in the outage plan in 2017.

FIGURE 6: COST OF ANCILLARY SERVICES.

Note: Before 2015, black start was recognised as part. of manual reserves.

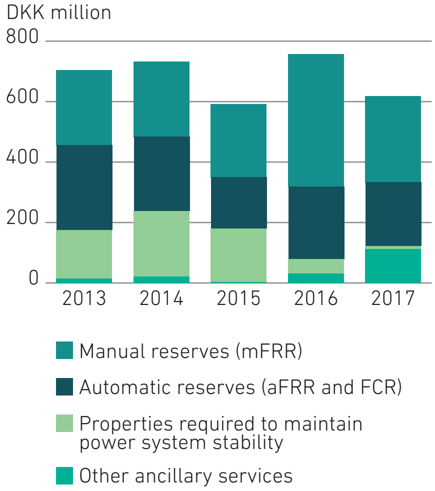


TABLE 4: COSTS OF PROPERTIES REQUIRED TO MAINTAIN POWER SYSTEM STABILITY

Note 1: Stated costs of synchronous compensators include operation and maintenance, electricity consumption, depreciation and financing.

COSTS OF PROPERTIES REQUIRED TO MAINTAIN POWER SYSTEM STABILITY				
DKK million	2014	2015	2016	2017
PLANNED				
• Market contracts	164	171	18	2
• Ordered under the Danish Electricity Supply Act	0	0	30	8
NOT PLANNED				
• Ordered under the Danish Electricity Supply Act	54	6	0	0
Costs of synchronous compensators[1]:	38	54	54	57
Total costs of properties required to maintain power system stability	255	231	102	67

Energinet evaluates all requested scheduled outages from the market participants according to the current technical regulation, the power balance in Western and Eastern Denmark, and the areas combined. The parties may have to adjust their outage requests if deemed necessary. Energinet was unable to grant several requested outages.

In 2017, several applications were made for changes to operating conditions of central power stations. These include, among other things, closures and extended start-up warnings. In each situation, Energinet assessed the security of supply-related consequences.

In a few cases, Energinet found that the change would result in an unacceptable deterioration of the security of electricity supply and could therefore not approve the applications.

3. FORWARD-LOOKING RISK ASSESSMENT

The forward-looking risk assessment takes into account expected developments and challenges in the electricity system. Generally speaking, the forward-looking risk assessment is based on developments in system adequacy, which can be subdivided into generation and grid adequacy, and system security, which can be subdivided into robustness and IT security.

- Generation adequacy analyses for Denmark up to 2025 still show that Eastern Denmark faces the greatest risk of power shortage.
- Grid adequacy may be challenged by an increasing number of reinvestment and connection activities in the electricity transmission grid.
- On the other hand, units required to maintain power system stability and increasing use of automation help to strengthen the robustness of the electricity system.
- The electricity system's increasing dependence on IT requires high uptimes on crucial IT systems.

3.1 Expectations for the future electricity system

The assessment of the future security of electricity supply is based on Energinet's Analysis Assumptions 2017. The analysis assumptions represent Energinet's best estimate of trends in key parameters in the electricity and gas sectors towards 2040.

The main parameters in Energinet's generation and grid adequacy assessment are trends in electricity consumption, electricity generation and exchange capacity. These trends are inherently linked to both short and long-term uncertainties. In this respect, the electrification extent of other sectors, with its matching increase in electricity consumption, and the speed of the green transition, play significant roles.

Electricity generation and exchange capacity

The green transition has brought with it an increase in wind and solar-based electricity generation capacity. Thermal electricity generation capacity has declined correspondingly in recent years. This trend is expected to continue.

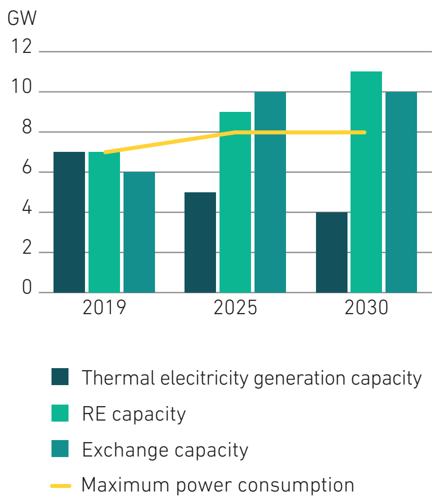
In addition, Denmark will expand its currently significant exchange capacity further in the coming years.

3.2 Generation adequacy

Generation adequacy is the electricity system's ability to meet the overall demand of electricity consumers. Ge-

FIGURE 7: MAXIMUM POWER CONSUMPTION, AND ELECTRICITY GENERATION AND EXCHANGE CAPACITY.

Source: Energinet's Analysis Assumptions 2017.



neration adequacy is closely linked to the electricity market, where inadequacy results in high electricity prices.

FSI MODEL

The Forsyningssikkerhedsindeks (FSI) model is Energinet's tool for analysing generation adequacy in Denmark. The model is stochastic and simulates incidents in the electricity system, which can lead to power shortages, on an hourly basis.

Every year, the security of electricity supply is analysed using a large number of simulations to represent possible incident combinations. The model results thus illustrate an average of all calculations for a single year.

The FSI model is based on historical time series for electricity consumption and fluctuating electricity generation (wind and solar power). Electricity generation from thermal power stations and imports via interconnectors are stochastic. The stochastic element is represented using probabilities for breakdowns. Thermal generation stations and international connections will therefore be unable to supply energy to meet electricity consumption for a number of hours in each simulation. Planned outages on Denmark's central power stations and international trade connections are placed deterministically in the models based on a planned optimisation of their positions in relation to each other.

The model estimates the risk of outages in the Danish system due to power shortages. The FSI model is best suited to perform calculations on the basis of assumptions resembling the situation today, as the model is based on historical time series and without derived effects of shortage situations, such as flexible electricity consumption.

The FSI model will tend to overestimate the risk of power shortages in a future electricity system which is significantly different from today's system in terms of both physics, the market and international operational cooperation (e.g. in 2025).

In this year's report, future generation adequacy risk assessments are made using the Forsyningssikkerhedsindeks (FSI) model.

The method Energinet uses to perform generation adequacy analyses has been substantially updated compared with previous years' security of electricity supply reports.

The procedure that Energinet's control centre uses to determine the capacity of the Øresund Link in case of a breakdown or planned outage has been partly incorporated in the model. The model's limitations make it impossible to incorporate the procedure fully. The procedure has a major impact on available capacity in the model, as an outage on one of the Øresund link's four lines impacts the exchange capacity of the rest.

The procedure is updated annually to match changes in the grid. Therefore, more exchange capacity will be available in case of planned outages or breakdowns on the Øresund Link in the 2025 simulation. This means that generation adequacy analyses will show more available capacity on the connection in 2025 than previously.

This increased availability in the 2025 simulation is due to an expected upgrade of a domestic connection between the Øresund Link and the Zealand electricity grid. The upgrade is expected to be carried out between 2020 and 2025.

In addition, outage at central power stations and on interconnectors is modelled deterministically as opposed to the previous stochastic approach.

Generation adequacy assessment
Generation adequacy analyses for Denmark up to 2030 still show that Eastern Denmark faces the greatest

risk of power shortage. Reasons include reduced domestic electricity generation capacity and less exchange capacity in Eastern Denmark than in Western Denmark. All analysis results for Western Denmark show a risk of less than one weighted minute per year. Therefore, only results for Eastern Denmark are presented in the following.

Overall, the risk of power shortages in Eastern Denmark is estimated to be increasing over time. This is primarily due to the expected reduced thermal electricity generation capacity as well as to increased electricity and power consumption.

Therefore, Energinet is opening talks with the EU Commission and Danish authorities on the possibility of obtaining an approval for a time-limited introduction of a strategic reserve in order to maintain generation adequacy in Eastern Denmark. Energinet will use these talks to ask for an approval for the period 2025-2029 with an option to extend this period by five years.

Energinet is working determinedly to actualise ongoing electricity market reforms, and new initiatives to ensure increased flexibility both from the electricity generation and consumption sides as well as from new storage technologies will be launched over the coming years.

Eastern Denmark is closely linked to Southern Sweden, and the Øresund Link greatly affects generation adequacy in Eastern Denmark. In 2020, replacement of the Øresund Link 400 kV cables is expected to reduce capacity significantly for 1-2 months. When the exact replacement time is set, Energinet will assess whether extraordinary measures must be implemented, such as long-term outage planning or a tender for temporary extra electricity consumption or generation capacity.

When the Øresund Link is only partly operational, its capacity depends on the domestic electricity grid in Eastern Denmark. Energinet is planning an upgrade of this domestic grid between 2020 and 2025, increasing available capacity in the event of outage times in 2025 compared to today. In the FSI model, the number of 2025 output minutes is halved with these upgrades.

The 11 weighted minutes in 2025 in FSI correspond to the expectation that an average electricity consumer will have 99.9979 per cent of demanded energy supplied.

Note that the expected number of hours with power shortage (LOLE) in the model simulations is low. Consequently, power shortage situations very rarely appear in the simulations.

New method to calculating generation adequacy
Until now, Energinet has used the FSI model but expects to move to the Better Investment Decisions (BID) model going forward. BID model results are not used in this year's security of electricity supply report, as the model's generation adequacy calculation module has not yet been fully implemented in Denmark.

TABLE 5 – FSI RESULTS 2019-2030

Note that outlook for 2025 without upgrades in the domestic grid is 22 weighted minutes and security of supply 99.9957 per cent.

FSI	Weighted minutes (minutes/year)	EUE (MWh/year)	LOLE (affected hours/year)	Security of electricity supply (per cent)
2019	2	53	0.1	99.9996
2025	11	340	0.6	99.9979
2030	42	1,373	2.5	99.9921

GENERATION ADEQUACY INDICATORS

Weighted minutes are consumer-weighted outage minutes, calculated by dividing unserved energy (EUE) by average hourly consumption for Eastern and Western Denmark, respectively, in the simulated year.
EUE (Expected Unserved Energy) indicates unserved energy in the simulations. In other words, total electricity consumption that is expected not to be covered by electricity generation and imports.
LOLE (Loss Of Load Expectation) indicates the number of hours with power shortages, irrespective of the scope of the shortages.

Here, the submarine cable for the EU-subsidised Kriegers Flak project is landed. The project will connect German offshore wind farms to a future Danish offshore wind farm in the Baltic Sea.

BID is used by the other Nordic TSOs, as well as in ENTSO-E's Midterm Adequacy Forecast, which gives Energinet a better opportunity to use the results both nationally and internationally.

Two of the main differences between FSI and BID are that BID incorporates both modelling of the power situation throughout Europe and compulsory heat production for power stations. FSI only models selected neighbouring areas. Better modelling of other countries can mean more and less available power compared to FSI. On the other hand, the incorporation of power stations' compulsory heat production is expected to worsen the power situation.

Both models basically use the same methods to assess the risk of power shortages in the system.

Even though there are many similarities to the methods in FSI and BID, there are also model-specific qualities, and therefore, the models will not present the exact same assessment of Danish generation adequacy levels. As a result of the technical differences between the models and updates in assumptions, next year's report cannot be expected to show exactly the same results.

Sensitivities of future generation adequacy levels

The risk assessments of future generation adequacy are greatly influenced by input data. This is illustrated in the following sensitivity analyses, which were performed using the FSI model in the simulation year 2025. The different parameter variations are illustrative

BID model

The Better Investment Decisions (BID) model is an electricity market model which, among other things, can be used to assess generation adequacy. The model simulates the electricity market across Europe, thus reflecting Denmark's relations to the world around us.

Power station breakdowns and interconnectors are stochastic elements. The model assesses generation adequacy in all modelled price areas, thus incorporating other nations' impact on Danish generation adequacy. Unlike FSI, the model can handle flexible electricity consumption directly.

examples and do not reflect Energinet's assessment of input parameter uncertainties.

Sensitivities show a risk of power shortages in Western Denmark of no more than one weighted minute per year, attributable to e.g. the commissioning of COBRAcable to the Netherlands and Viking Link to the UK. Therefore, only results for Eastern Denmark are presented in the following.

Increased electricity consumption flexibility
Currently, efforts are made to present electricity consumers with better options to participate in the electricity market. This may lead to an increase in the incentive for electricity consumers to move electricity consumption to hours with lower electricity prices.

The analysis assumes that it will be possible to move 100 MW in both Western and Eastern Denmark. This will happen if electricity prices exceed €100/MWh.

As expected, results show that increased electricity consumption flexibility will improve generation adequacy.

Phasing out of thermal electricity generation capacity
Thermal electricity generation capacity is an important aspect of risk assessments of the power situation. Therefore, the extent to which faster phasing out of electricity generation capacity affects the power situation is examined.

"As data centres are large energy consumers, their electricity consumption could greatly influence the overall generation adequacy of the Danish electricity system."

Sensitivity-wise, a total reduction in the Danish electricity system generation capacity of 1.5 GW is assumed, compared with Analysis Assumptions 2017. The reduction is divided into 1 GW in Western Denmark and 500 MW in Eastern Denmark, distributed fairly equally between central and decentralised power generation capacity.

The reduction has a negative impact on generation adequacy. Results show a significantly higher risk of power shortages in Eastern Denmark than electricity consumers face today.

TABLE 6: RESULTS OF SENSITIVITY ANALYSIS IN EASTERN DENMARK IN 2025.

SENSITIVITY ANALYSIS EASTERN DENMARK				
2025	Weighted minutes (minutes/year)	EUE (MWh/year)	LOLE (affected hours/year)	Security of electricity supply (per cent)
" Base case"	11	340	0.6	99.9979
Electricity consumption flexibility	6	195	0.4	99.9988
Thermal electricity generation capacity	64	1,943	3.6	99.9878
Increased data centre expansion	19	610	1.1	99.9964
Increased data centre expansion and phasing out of thermal electricity generation capacity	84	2,720	5	99.9841

Increased data centre expansion
The interest in placing data centres in Denmark has been high in recent years. As data centres are large energy consumers, their electricity consumption could greatly influence the overall generation adequacy of the Danish electricity system.

A continuous power draw totalling 667 MW is assumed. The assumption matches the "Exponential growth" trend in COWI's "Temaanalyse om store datacentre" report, published by the Danish Energy Agency on 13 April 2018. This is an increase of 257 MW, distributed equally between Western and Eastern Denmark, compared to Analysis Assumptions 2017.

The power draw increase from data centres triggers an increase in the risk of power shortages in Eastern Denmark.

More data centre expansions and phasing out of thermal electricity generation capacity
A simultaneous increase in data centre expansion and faster phasing out of thermal electricity generation capacity may occur. Therefore, the extent to which both parameters affect generation adequacy is assessed.

Also for this sensitivity, a fixed data centre power draw of 667 MW is assumed. A 600 and 400 MW reduction in electricity generation capacity is assumed for Western and Eastern Denmark, respectively.

The combination of a greater extent of phasing-out of thermal electricity generation capacity and the increased impact of data centres will lead to a very high risk of power shortages in Eastern Denmark. Evidently, the combination offers an overall higher risk of power shortages than indicated by the sensitivities of the individual parameters.

TABLE 7: MAF 2017 RESULTS ("BASE SCENARIO") FOR EASTERN DENMARK.

MID-TERM ADEQUACY FORECAST EASTERN DENMARK				
	Weighted minutes (minutes/ year)	EUE (MWh/year)	LOLE (Affected hours/year)	Security of electricity supply (per cent)
2020	1	40	0.4	99.9997
2025	10	300	0.9	99.9981

ENTSO-E Mid-Term Adequacy Forecast 2017
Within the ENTSO-E framework, a comprehensive European-level risk assessment of generation adequacy is carried out. Results are reported annually in the Mid-Term Adequacy Forecast (MAF) report.

The method is basically the same as that used in Energinet. Analyses are carried out in four different simulation tools (including BID) for 2020 and 2025. The models in the study do not include a number of country-specific aspects, such as the procedure for determining capacity on the Øresund Link in case of a breakdown. Therefore, European generation adequacy assessments may differ from the individual countries' own assessments.

As is the case with Energinet's own assessments, MAF shows that the risk of power shortages increases towards 2025 in Eastern Denmark, while Western Denmark faces no immediate challenges. Therefore, only results for Eastern Denmark are shown.

Nordic Perspectives on Mid-Term Adequacy Forecast 2017
Complementary to MAF 2017, the four Nordic TSOs Fingrid, Svenska Kraftnät, Statnett and Energinet have prepared a report called "Nordic Perspectives on Mid-Term Adequacy Forecast 2017". The report covers a number of sensitivities particularly relevant to the Nordic countries.

These sensitivities have been selected on the basis of an assessment of changes in the electricity system that will impact adequacy in the Nordic area most. The analyses cover:

- Faster phasing out of thermal electricity generation capacity in the Nordic countries.
- No exchange capacity between Finland and Russia.
- Extreme climatic conditions.
- Location of wind in the Norwegian and Swedish price areas.
- Exchange capacity limitations between Denmark and Germany.

Cooperation with electricity distribution companies

Energinet and the electricity distribution companies cooperate on a number of platforms to promote the optimal use of both distribution and transmission grids.

This cooperation covers both operational and market aspects and is formalised in a grid collaboration committee and market collaboration committee.

"Reinvestments are made in the transmission grid in combination with expansion and upgrading to underpin- the objective of maintaining the current level of grid adequacy"

Results in the Nordic perspectives are on par with the conclusions in MAF 2017 for the Nordic region. Most of the sensitivities affect Danish generation adequacy negatively.

3.3 Grid adequacy
Grid adequacy is defined as the electricity transmission and distribution systems' ability to transport sufficient electricity from generation site to consumption site.

Electricity transmission grid development is determined by expectations for future power consumption, renewable electricity generation capacity and interconnectors, and the state of the existing transmission grid. Furthermore, the electricity transmission grid is also affected by the expansion of renewable electricity generation capacity in the distribution grids, and this leads to local challenges.

Reinvestments are made in the transmission grid in combination with expansion and upgrading to underpin the objective of maintaining the current level of grid adequacy.

Electricity transmission grid expansion is coordinated with reinvestments and upgrading projects that result from visual enhancement and other necessary conversions. This planning work is described in Energinet's annual "Reinvestering, Udbygning og Sanetering" (RUS) plan, which details projects over the next 10 years.

The number of reinvestment projects in the electricity transmission grid is rising. A majority of the existing 132 kV and 150 kV grids were established between 1960 and 1980. As several installations have a service life of about 40-50 years, large parts of the grid are looking at reinvestments in the coming years. Reinvestment projects often require extended outage times, and there may be limited options to quickly restoring installations.

Electricity transmission grid expansion continues as a result of the green transition, declining thermal electricity generation capacity, growing exchange capacity, and electricity consumption trends. The RUS plan describes the expected need for approximately 750 kilometres of new cables and overhead lines over the next 10 years, in addition to the projects that Energinet is currently working on.

Transmission grid upgrading includes conversion to cables of selected overhead lines through areas of natural resort and urban areas. By establishing new 400 kV overhead lines, existing overhead lines at lower voltage levels may be converted to cables. A general framework for where to convert to cables is being prepared by Danish authorities.

In the coming years, several projects must be carried out in the electricity transmission grid, including reinvestments, expansion and upgrades. Energinet is focused on optimising and coordinating all these projects to maintain the current security of electricity supply level.

Outage planning

Outage planning plays an important part in safeguarding security of electricity supply. As a result of the many reinvestments planned, Energinet is expecting a rise in outage times in the electricity grid. Outage in the electricity grid and at power stations must be coordinated to avoid periods of lacking robustness, grid or power adequacy.

3.4 Robustness

Robustness is defined as the electricity system's ability to handle unexpected system disturbances. The electricity system must be robust when faced with the breakdown of components, power generation capacity and interconnectors, so that such incidents do not affect system stability. Robustness relates to the system's dynamics at the moment a fault occurs and in the ensuing minutes.

Local challenges in Western Lolland

Several parts of the Danish transmissions grid are facing local challenges of transmission grid overload as a consequence of the rise in electricity generation from renewable energy sources in the distribution grid. One example is the transformer at Western Lolland station.

The long-term solution is an expansion of the transformer station, but until this has been completed, alternative solutions is required.

A cooperation established between Energinet, Danish Energy and the electricity distribution companies aims to find solutions to these challenges. Electricity distribution companies have the right to down-regulate wind turbines in the distribution grid. In this case, wind turbines have been down-regulated several times since September 2017. At the same time, an Energinet compensation model is being developed to compensate wind turbine owners for any lost electricity generation.

The group is also working to adopt a long-term solution with market-based settlement of local flexibility for Energinet, electricity distribution companies and balance-responsible parties.

Construction of COBRAcable at Endrup station in Western Jutland.

Risk assessment of incidents which could affect robustness
Risk assessment is based on broad analyses and selected critical situations. There are an endless number of critical situations that could lead to power outages. Therefore, it is not practically feasible to assign probabilities to all outage risks. Assessing and securing robustness must be based on technical system requirements and follow-up analyses.

It is important to define the technical requirements for the components of the network to ensure long-term robustness. Energinet establishes grid connection requirements for electricity generation and electricity consumption installations, so that any new grid connections do not challenge the security of electricity supply in the Danish electricity system.

For several years now, Energinet has worked on the gradual harmonisation of grid connection requirements across technologies and voltage levels. Energinet will continue to update these requirements to ensure that, for example, renewable energy technologies such as wind and solar installations increasingly contribute to, or at least do not weaken, electricity system robustness. One example is the Fault-Ride-Through requirement where newer wind turbines must remain connected to the grid in case of faults, whereas wind turbines were previously allowed to disconnect in such events as a means of self-preservation.

Any negative influence of electricity generation installations on robustness affects not only the Danish system but also those in neighbouring countries. Therefore, common technical requirements for grid connections are needed across Europe, and this is ensured, for example, through the implementation of the Requirements for Generators (RfG) network code.

As the system constantly changes, it is important to make follow-up analyses. The purpose of the analyses is to determine the degree of system robustness in critical situations and ensure continuous improvements of the existing operational framework. Particularly relevant are analyses of the need for properties required to maintain power system stability.

As new requirements for electricity generating installations and Energinet' own components are introduced, a more extensive audit scope becomes necessary. If installations fail to meet requirements set for fault situations, Energinet will not be able to operate the electricity system "closer to the limit".

Strategy for properties required to maintain power system stability

In 2015-2017, Energinet analysed the need for properties required to maintain power system stability in relation to secure electricity system operation in the event of faults. The analyses covered a wide range of scenarios and showed that the system is more robust than previous analyses indicated.
For further information, please read Energinet's publication "Necessary properties required to maintain power system stability in Denmark".

The overall need for properties required to maintain power system stability is determined, as the analyses

Properties required to maintain power system stability

Properties required to maintain power system stability are the services necessary to maintain secure and stable operation of the electricity system:

- **Frequency stability:** Maintaining a stable frequency in addition to what balancing in the active power markets is capable of achieving. Inertia is the relevant property.
- **Voltage stability:** Maintaining a stable voltage with as little transport of reactive power as possible and maximisation of active power transport. Dynamic voltage control is the relevant property.
- **Short-circuit power:** Maintaining a suitable short-circuit power level which permits operation of classic HVDC connections and ensures that relay protection works as intended.

Properties required to maintain power system stability are provided by thermal power stations in operation and synchronous condensor, and the power is reduced over long distances.

are designed to show the collective needs of the system. Needs are assessed nationally and locally.

> "Automation heightens robustness by helping to ensure that the system is operated optimally and safely in normal situations and that incidents do not escalate"

National analyses show that the system's components cover any need for properties required to maintain power system stability in intact grid situations, i.e. when all components with a significant impact on these properties are available.

Analyses are also performed for any local challenges posed by grid outage. Moreover, outage may cause a need for specific components required to maintain power system stability in the grid. For example, this need may arise from the maintenance of an overhead line in an area with few central power stations, where robustness can only be guaranteed by a specific component required to maintain power system stability in the grid. Energinet continuously focuses on optimising operation and expansion of the electricity grid, so that local dependencies on specific components required to maintain power system stability in the grid are reduced.

It is not possible to completely dispense with installations required to maintain power system stability in the grid due to the need for voltage control in fault situations. This need is based, for example, on the amount of old wind turbines which adversely affect electricity system stability in fault situations. However, with new components such as COBRAcable in the grid and better utilisation of existing components, such as new wind turbines' properties and automation features, it is possible to reduce the current need for installations required to maintain power system stability in the grid.

Control and automation

Currently, Energinet has dedicated a great deal of resources to incorporating more automation in the electricity system, i.e. automatic use of components in the electrical system.

Automation heightens robustness by helping to ensure that the system is operated optimally and safely in normal situations and that incidents do not escalate.

Moreover, automation lowers the risk of human errors as it can react more quickly to changes in the system and operate "closer to the limit" than would otherwise be practicable.

The level of investments in the grid is also reduced, as an automated grid is better utilised.

There are three reasons why automation is currently needed:

- The complexity of the electricity system is growing, due to, for example, more and more HVDC connections and complex AC cable installations such as the landing of electricity generation from offshore wind farms.
- Electricity generation is becoming more fluctuating. This means more frequent and faster changes in flow on both domestic connections and interconnectors.
- Energinet wants to operate the electricity grid "closer to the limit".

One of the initiatives that Energinet is working on is the so-called reactive power controllers (RPCs). RPCs facilitate proper functioning of the electrical system by connecting and disconnecting reactive components. This helps to maintain an optimal reactive balance and prevents overvoltages in the electrical grid. Improved utilisation of voltage regulation from new wind farms also helps to maintain a constant voltage level.

Another measure is the so-called system protection, which can quickly adjust flows if faults occur in the grid. This also makes it possible to operate the electricity grid "closer to the limit" under normal operating conditions.

Automation connects and disconnects components and makes changes to control set points, which Energinet's control centre would otherwise have to do. Without automation, many local areas would require significantly closer monitoring.

For now, automation is only implemented locally to address local challenges.

But Energinet's long-term ambition is to implement automatic optimisation of flows and voltage using centralised calculations for the overall grid. This would not substitute decentralised control, but merely supplement it. Expected results include less energy loss in the grid as well as increased stability and security.

3.5 IT security

IT systems are increasingly used to monitor and control components in the electrical system. Increased digitisation and new technological solutions not only provide electricity companies and electricity consumers with new opportunities. The greater reliance on IT also means that the electricity system is left more vulnerable at times when IT systems are unavailable or faulty. Consequently, Energinet focuses particularly on both high uptimes of in-house IT and external threats to IT security. Energinet depends more heavily on IT but so do electricity distribution and electricity generation companies and balance-responsible parties.

A few breakdowns and data errors typically do not affect the security of electricity supply, because redundancy has been built into the systems. However, extensive and simultaneous breakdowns may affect the security of electricity supply.

Threat assessment

The most recent threat assessment from the Centre for Cyber Security (CFCS) concludes that there is increased probability of organised destructive cyberattacks against Danish companies or authorities. CFCS considers it less likely that organised destructive cyberattacks will target critical infrastructure in Denmark.

IT system breakdowns

Historically, information security breaches or IT system breakdowns have not had serious impacts on the Danish security of electricity supply. However, in recent years, IT system errors have led to situations of alert state operation. For example, the only alert state situation recorded in 2016 owed to an IT incident that temporarily affected the electricity system control centre's monitoring of the electricity system and suspended the electricity market for a short time.

The influence of IT systems on a country's security of electricity supply was further highlighted in December 2016, when Ukraine experienced a cyberattack that left parts of the country without electricity for several hours.

On the other hand, the risk of participants in the electricity system suffering "non-targeted" attacks is increasing. Depending on the participant's area of responsibility, the outage of a single party will not have a significant impact. However, if a number of participants come under cyberattacks at the same time, this may have a significant impact on the security of electricity supply.

Even if targeted attacks are seen as less likely, the general use of the same type of IT systems in the electricity system means that "non-targeted" attacks can affect several sector participants at the same time.

International cooperation
IT security threats are spread instantly via networks. This means that a threat or the discovery of a new vulnerability in a program is global the second that systems are connected to the internet. Consequently, Energinet must be able to locate any vulnerability before it is exploited. Energinet must have access to knowledge from others and be able to share it in order to effectively protect IT systems. Therefore, international and national cooperation is a necessity.

Internationally, both the EU and NATO run initiatives that allow member states to share information about cyberattacks and threats quickly.

The objective of preparedness in the electricity sector is to ensure that electricity supply is maintained or restored with minimal impact thereon. The Executive Order on IT preparedness for electricity and natural gas sectors instructs Energinet to monitor IT systems and IT information shared between several participants in the electricity system.

In the Nordic preparedness collaboration, Energinet and the Danish Energy Agency are joined by Nordic colleagues to share knowledge about threats, risks and vulnerabilities. Moreover, the Nordic TSOs have also established a cooperation for dealing with major cyberattacks. One initiative planned is a major Nordic drill in 2018.

3.6 Operational and market development
As electricity systems are increasingly integrated across borders, the need for an overview of regional challenges and solutions increases. Across Europe, a wide range of operational and market development projects have been launched with the ultimate shared goal of safeguarding the security of electricity supply efficiently.

New market platforms for ancillary services
The Balancing Guideline network code requires the creation of joint electricity market platforms for the activation of automatic reserves, aFRR, and manual reserves, MFRR. By 2021, all TSOs must have enabled reserves to deal with imbalances from these platforms. Common European requirements must be laid down for the reserves so that they can be traded as standard products on the respective electricity market platforms.

The introduction of electricity market platforms will allow Danish participants to compete with their counterparts across borders - in principle similar to the day-ahead market. More intense competition should result in increased liquidity and reduced balancing prices overall. However, some areas may experience an increase in prices due to export growth.

Electricity market platforms are designed to secure a socio-economically optimal use of reserves across Europe. At the same time, Energinet

MONITORING IT SECURITY

Energinet has devoted dedicated resources to continuous monitoring of IT security, so that Energinet can respond proactively to incidents, threats and abnormal data flow patterns. Knowledge gained allows Energinet to not only improve its own IT security but also contribute to the cooperation with the sector's companies, authorities and neighbouring TSOs.

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gains improved access to balancing resources, for example in situations of insufficient Danish generation adequacy.

Development of Nordic balancing concept

As part of the development of the new Nordic balancing concept, the five Nordic TSOs have signed a new co-operation agreement. This agreement redefines the roles and responsibilities of TSOs in the Nordic region.

Moreover, the framework for the development of new electricity market platforms will form the basis for the common balance markets in the new balancing concept. In addition to the above European platforms, the Nordic region will create joint Nordic platforms for the procurement of reserve capacity. The new balancing concept is a modernized version of the ACE (Area Control Error) principle, used in the rest of Europe and Western Denmark. Implementing this concept facilitates the connection between the Nordic system and the European electricity market platforms for activation of reserves.

Under the System Operation Guideline, the first step in establishing a functional cooperation is to create a joint Nordic balancing area (an LFC block), divided into small areas matching the price ranges (LFC areas). This division gives TSOs a better overview, thus improving their ability to balance the system in the event of imbalances.

The creation of a Nordic LFC block is an important element of the System Operation implementation. This guideline specifies the general requirements for reserve dimensioning. Detailed requirements are to be set within the LFC block.

Regional cooperation – establishment of Nordic Regional Security Coordinator (Nordic RSC)
European TSOs have decided to establish regional units to cooperate on regional challenges. Subsequently, this has become mandatory with the adoption of the System Operation Guideline and Capacity Allocation and Congestion Management Guideline network codes.

Establishing the joint Nordic RSC office will greatly strengthen Nordic coordination and contribute to a uniform regional view of the system. Similar RSCs have been or are being established in EUs other regions. Regional coordination is expected to contribute to an improved security of electricity supply.

Nordic RSC was established in Copenhagen in 2016, and 2017 focused on being able to provide, for example, coordinated capacity calculations and outage time planning.

RSC services were developed and tested in 2017. They should be fully implemented in 2018. In 2017, sharing data proved to be a challenge due to the individual countries' legislation in the information security area.

New exchange capacity methods
In 2018, European regulators are expected to approve new methods for determining exchange capacity. These methods are expected to be implemented in day-to-day operation in mid-2020, dependent on them meeting established quality requirements. The implementation of the methods is laid down in the Capacity Allocation and Congestion Management network code. The aim of the new methods is to utilise exchange capacity between price areas optimally.

In the Nordic region, a Flow-based method will most likely be implemented. Flow-based focuses on AC connections and therefore considers the physical laws governing the power system more explicitly when setting exchange capacity.

THE EMERGENCY AND RESTORATION NETWORK CODE

The Emergency and Restoration network code requires that Energinet prepares a description of plans for the system's restoration and defence. Generally speaking, the framework is broadly identical to that in force today.

Using this price algorithm, the electricity market determines the flows with the greatest socio-economic value given the physical limitations of the grid.

For HVDC connections out of the Nordic region, the Coordinated Net Transmission Capacity (CNTC) method is expected to be implemented. This will be closely linked to the Flow-based method.

Overall, common calculation methods across borders should result in a sounder economy by utilising existing European interconnectors more fully.

New method for cable optimisation and maintenance
Energinet depends heavily on its electricity transmission grid components for transferring electrical energy from generation site to consumption site. With an ageing electricity grid, a large part of the effort to maintain a high level of grid adequacy consists of optimising and maintaining existing components such as cables and transformers.

Part of the optimisation of the use of installations is to analyse errors and reduce outage times. One example is Energinet's interdisciplinary project that reduced time spent troubleshooting oil cables by using machine learning.

Historically, the process of identifying leaks by troubleshooting has been time-consuming. Previously, correcting an error took anywhere from 6 months to a year, with a corresponding outage time of about 3 months. With the new method, outage times should drop to about 14 days from the cable is disconnected until a fault has been corrected.

Reducing time spent identifying oil leaks has several advantages. The security of electricity supply is strengthened as cable outage times are significantly reduced. Costs are expected to be reduced by half. Moreover, the environmental impact should be significantly reduced, as leaks are more quickly identified, minimising oil spills.

Market-wise, Energinet is working on several fronts to promote electricity consumption flexibility
Digitisation trends and new technologies make it possible to exploit the potential for electricity consumer flexibility. Energinet has also collaborated with external parties to test whether, for example, batteries in electric cars could provide ancillary services. Experience gained is expected to result in the adjustment of requirements and other conditions to promote the use of electricity consumption flexibility.

Towards 2021, hourly read electricity meters are rolled out, allowing Danish electricity consumers to opt for hourly settlements and thus giving a greater incentive to react to fluctuations in electricity prices. In continuation hereof, Energinet is working with the industry to implement the aggregator role which will enable new business models to emerge. Implementation of the aggregator role is expected to coincide with the completion of the hourly read electricity meters and hourly settlement project.

Increasing flexible electricity consumption may help alleviate future local and national challenges of generation and grid adequacy. For example, electricity distribution companies are also expected to have an incentive to activate flexible units to solve challenges in their local grids in the long term. Local challenges do not always match those in the electricity transmission grid. Therefore, situations may well arise where Energinet will have a need for an upward regulation in the grid while an electricity distribution company is experiencing overload and needs to regulate downward. Here, market solutions must be applied that create an incentive to offer flexibility as well as solutions that ensure that the same resources are not activated with conflicting effect.

Asset Management

As owner of the electricity transmission grid, Energinet continuously carries out risk assessments of grid components with a view to operating installations with the highest possible up-time and at the lowest possible cost. Installation assessments include e.g.:

- Condition
- Criticality
- Uptime
- Finance

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Document no. 17/10922-62