# Electricity security of supply report 2016

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# Electricity security of supply – status and future initiatives

Danish security of electricity supply ranks among the highest in Europe. Danish electricity consumers have enjoyed very high security of supply for many years. Security of supply must be maintained at a high level in the future, while also implementing the green transition.

Energinet.dk has set a security of supply goal in Strategy Plan 2014. The goal is to maintain the high level of security of supply in the Danish electricity system and continue to rank among the top European countries. This goal reflects the fact that a high security of supply level has great economic value to society. A reliable electricity supply is an important foundation for society and has great economic value.

To ensure a continued high level of security of supply, new mechanisms are needed, such as flexibility in electricity consumption and closer cooperation throughout the entire value chain and across national borders. There is also an increasing need in the years ahead for reinvestment in existing electricity infrastructure, to ensure it supports a high security of supply level. This applies to the distribution and transmission grids, which are both aging.

**Outage statistics**

The security of electricity supply level was high again in 2015, with 22 minutes of outage per consumer. The outage statistics show that the high level of security of electricity supply is not is not challenged.

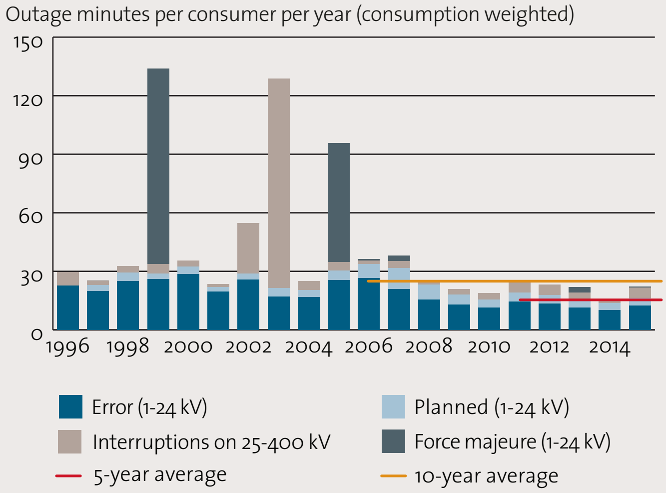



*Figure 1. Outage statistics for Denmark from 1996 to 2015.*

**Incidents**

Consumers were not disconnected during 2015 to ensure stability in the overall electricity system, and there have only been a few incidents of significance to security of supply.

Even though the Danish electricity supply is in transition and the electricity system is being optimised, there are no indications that the number of nearmiss incidents is increasing.

| Criteria | Scale 0 | Scale 1 | Scale 2 | Scale 3 |
|---|---|---|---|---|
| Faults on elements in the transmission sytem (HVDC) | 2013: 12<br>2014: 5<br>**2015: 11** | 2013: 2<br>2014: 10<br>**2015: 8** | | |
| Exceeding voltage levels | 2014: 40<br>**2015: 0** | 2014: 3<br>**2015: 0** | | |
| Loss of IT tools | | 2014: 4<br>**2015: 1** | | |

*Table 1. List of incidents reported to the ICS statistics for Denmark in 2013-2015. Loss of IT tools can only be reported as scale 1 or 2.*

Furthermore, there have not been any hours where a market price could not be reached in the spot market, and only a few alert situations and no emergency situations in Energinet.dk's control centre.

Fewer incidents were reported in 2015 in the European incident statistics (see Table 1). Of greatest note in 2015 was the fact that there were no incidents which led to the voltage standards being exceeded. This is due to the fact that the Energinet.dk control centre had a greater focus on voltage control in 2015. Various market conditions (physical flows across the connections) and the commissioning of the interconnector Skagerrak 4 also contributed to the reduction.

Future initiatives for recording incidents:
- From 2016, N-1 incidents will be included in the Incident Classification Scale report, making it possible to monitor changes in how often the operational situation comes under pressure.
- Work is still being done on improving incident registration in relation to European reporting and other incidents.

**System security**
Purchasing spare capacity and ancillary services gives the Energinet.dk control centre scope to manoeuver in response to faults. Ancillary service costs declined in 2015. In 2015, ancillary service purchases totalled DKK 592 million, versus DKK 735 million in 2014. The reduction is primarily due to a decrease in the costs of automatic reserves in Eastern Denmark as a result of joint procurement with Sweden and purchases of automatic reserves from Norway for Western Denmark.

The costs of purchasing ancillary services from market players fell in 2015, due to the commissioning of the Skagerrak4 interconnector and the synchronous condensers in Fraugde and Herslev.

Changes in the electricity system increases the need to explore long-term opportunities for ensuring properties to maintain power system stability. In 2015, the need for properties required to maintain power system stability was analysed for Western Denmark. The analyses show there is a need until 2018 for one stand-by power plant during the summer period in normal situations, where other grid components are in service. Once the COBRA interconnector is connected, no standby power plant is expected to be needed in normal situations, where other grid components are in service.

Future initiatives for properties required to maintain power system stability:
- **New needs analysis for Eastern Denmark in 2017:** A new analysis of the need for properties required to maintain power system stability for Eastern Denmark was initiated in 2016. The work is expected to be completed in spring 2017.
- **Activation of own grid components:** Several players have pointed to the need to examine how Energinet.dk activates its own grid components in relation to market players' systems. This work has been initiated following the Market Model 2.0 project conducted in autumn 2015.

The cost of providing properties required to maintain power system stability is not expected to increase.

| Adequacy evaluations 2017-2025 | | |
|---|---|---|
| Eastern Denmark | EUE (MWh/year) | Weighted minutes (min/year) |
| 2017 | 98 | 4 |
| 2018 | 177 | 7 |
| 2019 | 86 | 3 |
| 2020 | 138 | 5 |
| 2025 | 431 | 15 |

*Table 2. Results from the adequacy evaluations in Eastern Denmark up to 2025 based on the historical range of maintenance. The evaluations for 2020 are used as basis for further sensitivity analyses.*

During 2015-2016, Energinet.dk assessed the risks to system security for selected cases. The analyses examine the most critical situations and then assess their probability of occurring. The analyses show that some of the risk situations can be addressed through initiatives already planned. Energinet.dk therefore believes there is no need for further initiatives.

- **Assessment of system security risk:** The risk assessment method will be applied to more cases in future. It will also be incorporated into the assessment of future initiatives, so their contribution to system security risk can be included. The first specific project the method will be applied to is the analysis of a new interconnection between Eastern and Western Denmark.

**Generation adequacy**

There have been no cases in 2015 which indicated a power shortage, either through consumer outages or insufficient capacity in the market.

The forward-looking risk assessments show that the risk of consumer outages is different for the two regions. For Western Denmark, the risk of a power shortage is very low for the 2017-2025 period. Energinet.dk estimates that the risk of insufficient power in Eastern Denmark will exceed Energinet.dk's objective of a maximum of five minutes of insufficient electricity supply per consumer in the years ahead. Energinet.dk expects to meet the objective again in 2020, when the Kriegers Flak interconnection is planned to be commissioned. A delay to Kriegers Flak would increase the risk. The objective is expected to be threatened again in 2025.

In the coming years, several grid and transmission systems will undergo replacement or planned outages. This will mean more planned outage than before, which in turn increases the risk of consumer outages due to reduced generation adequacy. Based on the historical scope of maintenance, the risk assessment for Zealand is seven outage minutes in 2018. However, given that the scope of maintenance will increase significantly over the coming years, these assessments are not fully adequate. Instead, if the assessments are based on expectations of outage time as set out in the long-term maintenance plan, it will increase to 30 outage minutes. The difference between 7 and 30 outage minutes corresponds to an expectation that the consumer risks having 99.987% of the demanded energy supplied compared to 99.990%.

A more representative picture of the need for maintenance will only be available when the one-year maintenance plan has been prepared. However, investigations have already been initiated of risk reducing initiatives during high-pressure periods to ensure that the right tools are in place.

Future generation adequacy initiatives:

- **Maintenance planning:** An important tool to address the strained power situation is a high degree of coordination in maintenance planning. In the very short term, Energinet.dk therefore intends to plan the operation of the electricity system so that the risk of outages is minimised. This work encompasses detailed maintenance planning – including rescheduling maintenance on both transmission and generation facilities. Coordination and prioritisation will be based

on the electricity system characteristics, information from market players and international operating agreements. In future there will be more focus on coordination and prioritisation based on economic assessments and the framework from the future network codes.

- **Strategic reserve:** Energinet.dk is still working on obtaining permission to purchase strategic reserves in Eastern Denmark for the 2017-2018 period. The permission to purchase a strategic reserve depends on the European Commission's recommendations for the introduction of capacity mechanisms – expected to be released in late 2016 – to ensure that the purchase is in line with the EU's state aid rules.
- **Electricity connection between Eastern and Western Denmark:** In the longer term, generation adequacy in Eastern Denmark can be improved by an electricity connection between the two regions. A maturation project has been initiated to assess whether a new connection is the most economical solution to ensure power balance on Zealand, or whether there are other more effective solutions.
- **Electricity connection between Eastern Denmark and Poland:** Collaboration has been initiated with the Polish TSO to investigate options for connecting Eastern Denmark to Poland, and thereby contribute to generation adequacy in the long term.

There may be additional costs for maintaining generation adequacy in connection with the initiatives launched to address the power situation. These extra costs include potential payment for a strategic reserve, as well as potential additional costs related to changes in maintenance schedules. The costs incurred by Energinet.dk are expected to be approx. DKK 50-100 million per year until 2018. The potential connections from Zealand to Western Denmark and from Eastern Denmark to Poland are still undergoing a maturation process. The interdependence between the two connections is particularly important to the assessment. It is therefore still not possible to determine whether the investments, including associated costs, are justified.

A working group was appointed in 2015, under the auspices of ENTSO-E, to develop a new market based and probabilistic method for assessing generation adequacy uniformly across borders. There will continue to be a major focus on transnational collaboration on assessing generation adequacy in the future.

Future generation adequacy initiatives in international cooperation:

- **Development of methods for assessing generation adequacy:** The first generation adequacy assessments under the auspices of ENTSO-E will be released in mid-2016.
- **Common Nordic analysis of generation adequacy:** Within the Nordic cooperation, the four Nordic TSOs decided to prepare common generation adequacy assessments for 2016-2017. The assessments aim to focus on challenges the Nordic countries are facing, and on greater focus on more effective transnational solutions.

Market trends are a key part of ensuring generation adequacy, and there are currently two key market trend areas Energinet.

dk is focusing on: Changes in the European network codes and changes in the future market model. Changes in the future market model are mainly based on the conclusions of the Market Model 2.0 project.

Future initiatives for improving market conditions for ensuring generation adequacy:

- **Ensuring flexibility:** In extension of the Market Model 2.0 project, a number of initiatives have been launched to improve flexibility in the market. These include changes to power imbalance settlement and special regulation rules, and promoting flexibility on the demand side.
- **Raising the price cap in the day-ahead market:** Energinet.dk is working to raise the price cap from EUR 3,000 per MWh to a level which better reflects the real value of electricity. Denmark cannot unilaterally raise the price cap. It must be done in cooperation with the countries in the price-coupled area.

These market initiatives are dependent on changes to existing agreements on international markets, future network codes and changes to the Danish Act on Electricity Supply (Elforsyningsloven).

**Grid adequacy**

The total number of faults in the transmission grid was at the same low level in 2015 as in previous years. There were 8 incidents in 2015 in the HVDC (direct current) system associated with connections to other countries which led to heightened awareness of the operation of the overall electricity system. None of the 8 incidents led to disconnection of consumers.

Future grid adequacy initiatives:

- **Fault and incident statistics at the EU level:** Energinet.dk continues to focus on ensuring greater Nordic and European cooperation on developing statistics for faults and incidents. Knowledge from the statistics will be used for improved operating and planning cooperation across borders and better asset management, and in planning work in relation to security of supply.
- **Reinvestments:** Energinet.dk is facing substantial reinvestments. Intensive work is therefore being done to structure reinvestments in the existing transmission grid. Reinvestment planning takes into account the state of components, and how critical the components are to the whole electricity system.
- **Peak load forecasts:** Energinet.dk is developing a new method to prepare peak load forecasts which takes into account the Danish Ministry of Finance's forecasts for economic growth and Statistics Denmark's population forecasts for the various municipalities. Peak load forecasts will thereby reflect the fact that electricity consumption in a geographical area depends on the demographic shift from peripheral areas to growth areas.

Other than the grid maintenance planned for the coming years, no further grid costs are expected for maintaining security of supply.

**Information security**

A high level of security of electricity supply requires a high level of IT and information security. On the one hand, modern information technology plays a key role in the day-to-day operation of the electricity and gas systems. On the other hand, increased reliance on IT also increases the vulnerability of the electricity system. In 2015, maturity in Energinet.dk was assessed to be above average.

Future information security initiatives:

- **Information security maturity:** Energinet.dk measures IT security based on the ISO 27001 IT security standard. Energinet.dk is working to achieve the objective of a maturity level of 3.5 by the end of 2016. To raise maturity, Energinet.dk is working with IT security at all levels, and to identify potential threats to electricity and gas system operations.
- **Information technologies:** In the longer term, Energinet.dk wants to ensure that modern information technologies are used and seen as an integral part of electricity and gas system design. This means that robustness and security will be considered in connection with data exchange, data storage and data processing as well as processes, systems and components.

**International cooperation**

Denmark is not alone in facing challenges ensuring security of supply as changes are made to the energy system. It is therefore positive that European cooperation is making progress in formulating common rules for the markets and the operation of the energy systems.

During 2015, several market network codes have been approved or sent to the comitology process.

Future work on developing Pan-European network codes:

- **Pan-European network codes and guidelines:** Energinet.dk continues to actively participate in the development of network codes and guidelines and to engage in other European cooperation forums in the energy area.

In 2015, the four Nordic TSOs decided to establish a joint office in Copenhagen. The office will formalise the Norwegian, Swedish, Finnish and Danish transmission companies' operational cooperation. The office is in line with coming EU regulations which will require the establishment of Regional Security Cooperation Initiatives (RSCI) in the area of transmission.

Future work on developing joint Nordic coordination:

- **Nordic office for regional cooperation in 2017:** The establishment of the Nordic office for regional cooperation in Copenhagen significantly strengthens Nordic coordination. The office is to perform coordination tasks in relation to capacity calculations, outage planning and system reliability analyses. The office is expected to open in late 2017.

# 1. Security of electricity supply

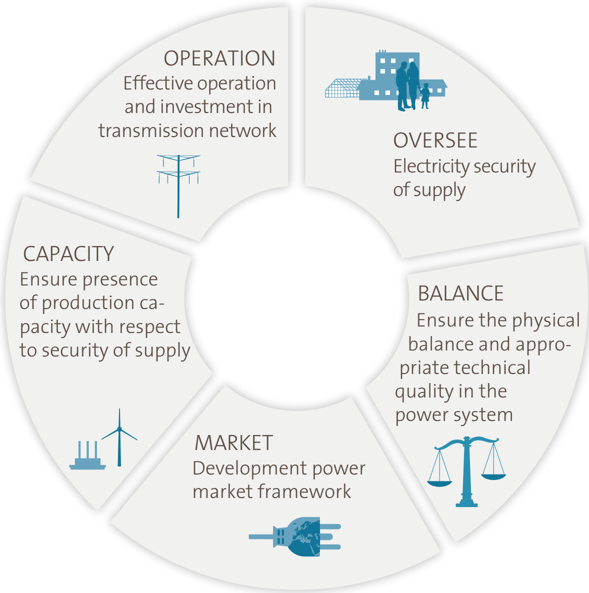
Energinet.dk is Denmark's transmission system operator and is based on the Danish Acts on Energinet.dk and Electricity Supply. Energinet.dk owns and operates Denmark's main electricity and natural gas grids, and is responsible for the security of electricity and gas supply. Through international and market-based solutions, and cooperation across the energy sector's value chain, we strive to achieve balance in a sustainable energy system with increasing amounts of renewable energy.

## 1.1 Energinet.dk's responsibilities

The Danish Act on Electricity Supply contains various provisions regarding security of electricity supply, and various authorities are assigned tasks and competences in relation to this.

To achieve a high and cost-effective security of supply level, the planning and operation of the electricity system must be coordinated with electricity system players, including foreign partners. One group of key business partners is the grid companies, which own and operate the distribution grid. They are responsible for expanding and operating the local grid infrastructure and thereby ensuring final delivery to consumers.

Production and trading companies, as market players, have the opportunity to decide the level of production capacity, consumption flexibility and storage. The commercial players do not have direct responsibility for security of electricity supply, and are not obliged to supply power to the market during normal operation.




Energinet.dk has been assigned overall responsibility for security of electricity supply in Denmark in section 27a of the Danish Act on Electricity Supply. This obligation provides the foundation for Energinet.dk's activities, including:

A. **Monitoring** security of supply in the electricity system for the entire value chain, including the historical trend and expectations for the coming period.
B. Ensuring that physical **balance is maintained** and an appropriate level of technical quality throughout the electricity system.
C. Effectively operating and investing in the **transmission grid**, taking into account security of supply.
D. Ensuring adequate **production capacity** is available, if the market fails to do so.
E. Energinet.dk is responsible for developing the framework for a smoothly functioning and internationally interconnected **electricity market**, which can ensure balance between consumption and production.

It is therefore Energinet.dk's duty to ensure a high and cost efficient level of security of electricity supply – also during the conversion of the energy supply to renewable energy taking place in recent and coming decades.

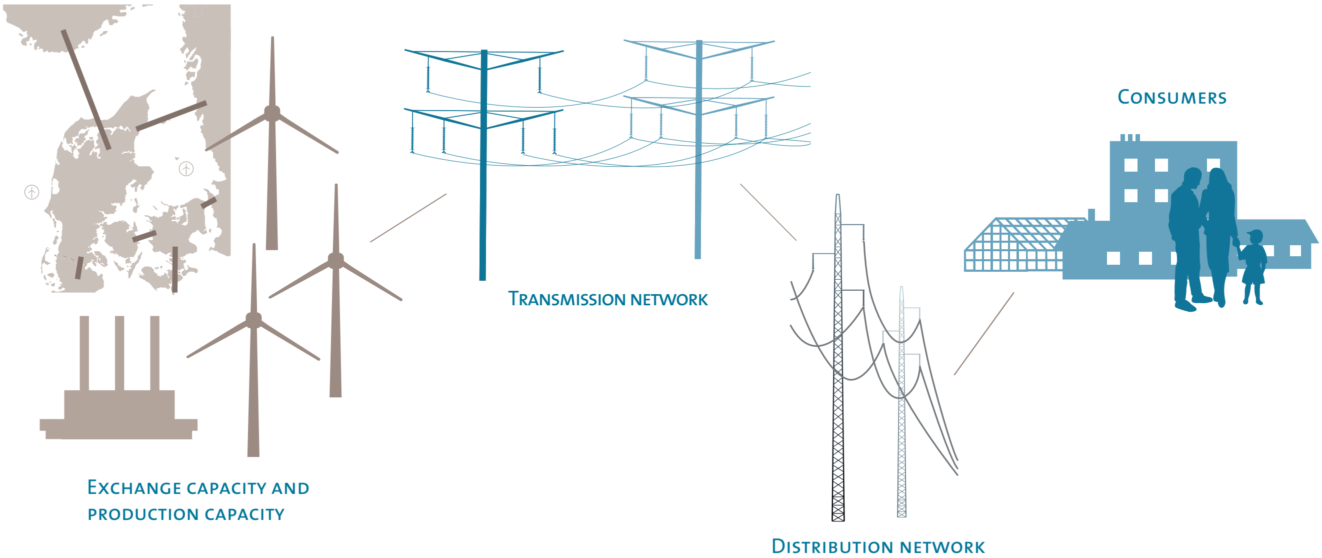



*Figure 2. A traditional power system from production to consumer.*

## 1.2 Security of supply in the European context

The European energy policy is heavily influenced by the European Commission's Directorate-General for Competition, and therefore has a particular focus on deregulation of the energy markets. In addition to the aim of establishing a common deregulated European market, it is intended that the electricity market should play a key role in maintaining high security of supply – and in the longer term that consumers can individually decide what level of security of supply they want.

However, it will be a lengthy process to get the electricity market to play such a central role in maintaining security of supply. Experience in recent years has shown that there continue to be barriers to the development of a smoothly operating single market for energy. There continues to be a national focus in the various member countries which affects the functionality of the single market, and its ability to ensure adequate production capacity and infrastructure on its own.

The next step in the ongoing Europeanisation of energy policies is the proposed Energy Union, which focuses on security of supply, sustainability and competition. Based on these focus areas, the European Commission will implement two significant legislative initiatives in 2016: A proposal for new regulation of security of electricity supply and another for regulation of the electricity market. These two initiatives aim to ensure that the internal energy market is developed so that it meets the objective of ensuring consumers cheap electricity, while also integrating the everincreasing volume of renewable energy without compromising security of supply.

However, a European electricity market cannot alone ensure adequate investment in infrastructure and tools to ensure balance in the electricity system, including the technical quality. This means that other areas also are covered by European energy policy – including operation and grid expansion. As reflected, for example, in common rules via:

- Network codes (common European rules on electricity markets, system operation and grid connection).
- The ten-year network development plans (TYNDPs) are being improved with the aim of ensuring that network expansion occurs where it is most efficient.
- Regional operational cooperation in Regional Security Cooperation Initiatives (RSCIs).

With the deregulation of the electricity market and an electricity supply increasingly based on renewable and more decentralised electricity generation, the electricity system is moving towards a more interconnected system, where countries are becoming more dependent on each other. Security of supply is therefore already a Pan-European concern.

## 1.3 Ensuring security of supply involves risk assessments

Failure to supply power to consumers can be result of a variety of incidents. It is therefore not possible in practice to have 100% security of supply, as this would require infinite backup

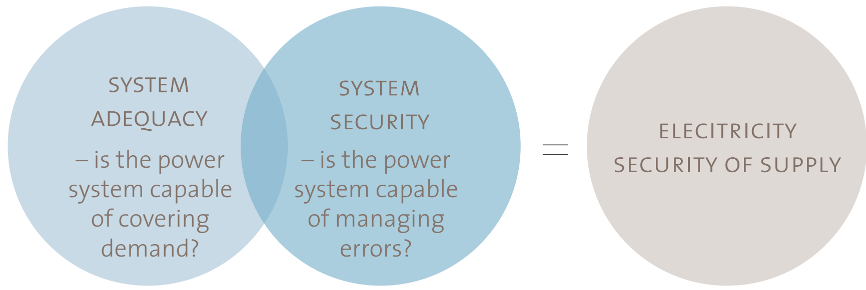



*Figure 3. Illustration of system security and system adequacy that in reality are two overlapping concepts.*

of both generation and infrastructure facilities and would thus be infinitely expensive. In general, security of electricity supply is understood as

*"The probability that electricity is available to consumers on demand".* [1]

It is therefore not the number and size of power stations, wind turbines and power lines that directly determines the level of security of electricity supply. It is rather a product of the complex temporal and geographic interaction between electricity system elements, the electricity market and the consumer. The important thing is whether electricity is available when the consumer demands it.

## 1.3.1 Assessing risks

Risk assessments for the electricity system are divided into two categories: system adequacy and system security.

**Assessing system adequacy** means assessing whether:
- There is sufficient energy to meet consumption (energy).
- There is sufficient infrastructure to transport electricity from the production unit to the consumer (infrastructure).

**Assessing system security** means assessing whether.
- It is possible to:Maintain a constant balance between production and consumption, to ensure technical quality and systemic collapse is avoided (stability).
- The electricity system's ability to handle sudden system disturbances caused by electrical short circuits, a sudden power station or transmission line outage etc. without affecting electricity supply or resulting in power outages (sudden incidents).

1. In line with the report "Elforsyningssikkerhed i Danmark" from the Danish Energy Agency in July 2015.

## 1.3.2 Identifying and implementing mitigating measures

Once the risks to security of supply have been identified, it is evaluated whether it is appropriate to implement mitigating measures to counter these risks. These measures could be actions such as replacing a transformer with a high risk of breakdown or purchasing a strategic reserve.

Cost-efficient security of electricity supply ideally involves assessing whether to implement mitigating measures or accept the given risk of outage. It involves evaluating measures in relation to each other by weighting risk reduction against costs.

In practice, it is not possible to assign probabilities to all risks, and one may need to define some static minimum requirements in order to make a probability-based risk approach operational. Many risks would be cost-intensive to address at a national level. Therefore, a high and cost-effective security of electricity supply in Denmark also involves assessing options through close international cooperation.

# 2. Historical security of electricity supply

Danish security of electricity supply ranks among the highest in Europe. Danish electricity consumers have thus enjoyed very high security of supply for many years. As the green transition is implemented, the security of electricity supply must continue to be maintained at a high level.

Security of electricity supply has also been at a very high level in 2015, with a low number of outage minutes per consumer. In 2015 very few incidents occurred in the electricity system impacting on security of electricity supply.

## 2.1 Outage statistics

Historical outage statistics covering faults and outages in the Danish electricity supply grid have been maintained since 1967. Faults are recorded via Elselskabernes Fejl- & Afbrudsstatistik (ELFAS) and handled by the Research Association of the Danish Energy Association.

The various grid companies report system disturbances at the distribution level, and Energinet.dk reports system disturbances at the transmission level. ELFAS provides a comprehensive basis for analysing Danish security of electricity supply in a historical perspective.

Outage statistics are not calculated at the individual customer level. Once all consumers have received digital electricity meters by 2020, and have been registered in the central DataHub, it will be possible to calculate outages down to the individual consumer.

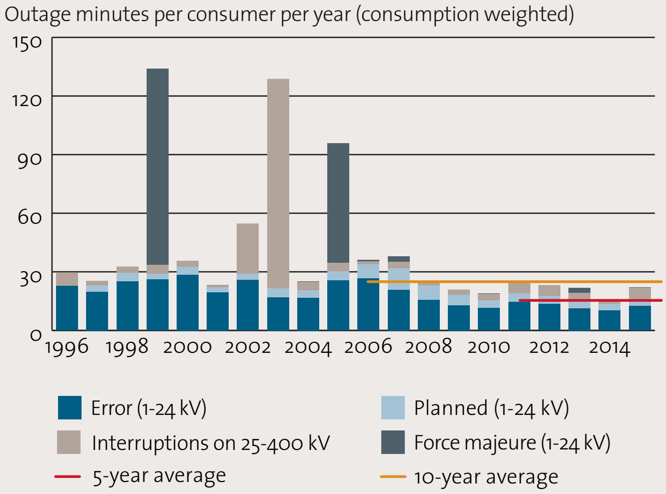



*Figure 4. Outage statistics in Denmark, 1996-2015.*

In 2015, the number of minutes of outage was still very low. There were just over 22 minutes of outage, corresponding to the level for 2013. The figure is slightly higher than in 2014, which had a historically low level of just over 15 minutes of outage.

2 Interruptions on 25-400 kV includes disconnections caused by disturbances outside the 1-24 kV area, including 25-99 kV distribution network and transmission network above 100 kV, but also disconnections caused by errors in consumer installations and neighboring areas are included.Source: Danish Energy Association.

Figure 4 shows the average duration of outages in electricity supply in minutes per consumer per year (consumer weighted) in Denmark [3]. The columns in the figure are divided into 1-24 kV and 25-400 kV voltage ranges. For the 1-24 kV distribution level, where the majority of outages occur, outages are also divided based on cause. Many consumers will experience an outage lasting from a few minutes to several hours in the course of a year, but even more will not experience any outage.

The dark grey (top) section of the columns covers outages in the 25 to 99 kV distribution network and outages in Energinet.dk's transmission grid (132 kV, 150 kV, 220 kV and 400 kV). Power shortages have not historically caused consumer outages in Denmark and have therefore not been included in the figure.

Apart from one-time incidents – such as a relay fault 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 network.

Major faults at transmission level are rare, but affect large numbers of consumers. This was the case in 2002 and 2003. The average outage level should therefore be viewed over a number of years.

| Minutes per year | 5 years | 10 years | 15 years | 20 years |
|---|---|---|---|---|
| Distribution < 25 kV | 17.0 | 21.0 | 26.3 | 31.6 |
| Transmission and distribution >= 25 kV | 4.6 | 3.6 | 12.0 | 10.0 |
| Total | 21.6 | 24.7 | 38.3 | 41.6 |

*Table 3. Average minutes of outage seen over the last 5, 10, 15 and 20 years.*

The force majeure incidents in 2013 were due to the Allan and Bodil storms. Due to extensive underground cable laying for the distribution network in recent years, the impact on consumers was far less than for the storm in 1999.

In Denmark, outages at the distribution level are relatively stable at around 20-30 minutes per average consumer per year. However, these outages have been in a slight downward trend due to conversion of the distribution network to underground cables.

## 2.2 Electricity system incidents in 2015

Incidents of significance to security of electricity supply occur at the market, system, and component level.

4 Specifically, Figure 4 shows the average duration of historical consumer disconnections for 1-24 kV delivery points per year. 1-24 kV delivery points refer to network stations which transform from 10/20 kV to 0.4 kV, or connection points for high voltage customers (with their own 10/20 to 0.4 kV transformer station). Given the large number of such delivery points – and the similar energy consumption at each point – it can be assumed that the outage duration has been weighted in proportion to consumption. In other words, the dataset represents all events in the high voltage grid in Denmark, which means all grids above 1 kV. The figure does not include faults in the low voltage grid (0.4 kV), which are estimated to increase the total down time by around 10%.

## Solar eclipse in March 2015

Thorough preparations were made throughout Europe up to the solar eclipse on 20 March 2015. The solar eclipse led to a sharp drop in production from solar cells in Europe, corresponding to 7 times Denmark's electricity consumption. This meant that it was necessary during the eclipse to start up a power station equivalent to the largest Danish power stations every minute, and to shut one down every minute as the solar eclipse abated, to maintain a stable electricity system.

Extensive preparations and close cooperation among the European transmission companies meant that the electricity grid was very stable throughout the solar eclipse. Experience from the solar eclipse shows that with the right planning and close international operational cooperation, situations like this can be managed.

### 2.2.1 Generation adequacy – market

As has been the case historically, there were no incidents in 2015 related to power shortages in the Danish electricity system. There were thus no market-related shortages in 2015 which led to failure to reach a market price.

Failure to reach a market price means the price in the day-ahead market meets the price cap of EUR 3,000 per MWh. The last time spot prices hit the price cap was on 7 June 2013 in Western Denmark – but this did not lead to consumer outages.

### 2.2.2 Use of brownout

The controlled disconnection of consumers (brownout) to handle strained operating situations has not been necessary in 2015.

### 2.2.3 System security – operations status

Daily operation of the electricity system must ensure that electricity generation and electricity consumption balance at all times. Through active and ongoing updating of forecasts and operational planning towards the individual delivery hour, it is possible to minimise imbalances before they occur at the moment of delivery.
These measures help Energinet.dk's control centre to be continuously aware of what resources are available. Together with written procedures, the information is used to improve system security, as system critical situations can be better prevented and managed faster.

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 [4]). The electricity system is in normal operation for the vast majority of the time.

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 market can be suspended and Energinet.dk can pull all the levers at its disposal to maintain electricity supply. The operating situation occasionally enters an alert state, but the market is very rarely suspended. An alert state was registered three times in 2015. Once in connection with:
• The solar eclipse in March 2015
• An IT incident in December 2015

If operation becomes unstable and there are also local/regional outages, the operating situation is changed to emergency state. In an emergency state, Energinet.dk calls in extra staff and preparations are made to handle extended system disturbances. It is extremely rare that an emergency state is declared, and there have been no cases in 2015.

### 2.2.4 System security – European reporting

The European electricity system is closely connected and distur-

4 The N-1 principle means that the power system is able to handle any disturbance, and within 15 minutes be ready to handle any new disturbance without any of the disturbances leads to incontrollable decoupling in the grid, which can influence neighboring areas.

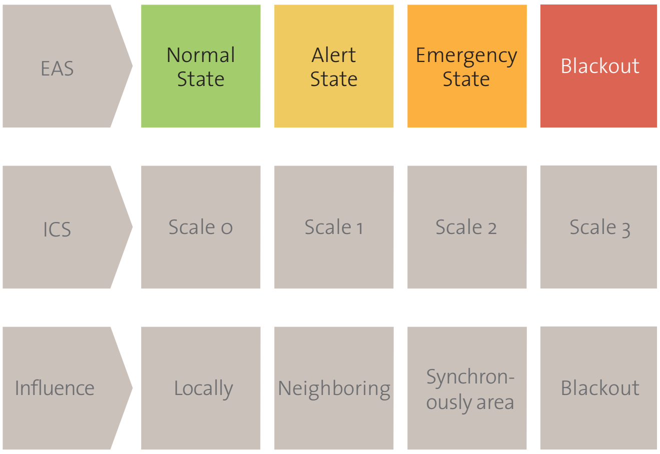



*Figure 5. Illustration of link between The European Awareness System (EAS) and Incident Classification Scale (ICS).*

| Criteria | Scale 0 | Scale 1 | Scale 2 | Scale 3 |
|---|---|---|---|---|
| Faults on elements in the transmission system (HVDC) | 2013: 12<br>2014: 5<br>**2015: 11** | 2013: 2<br>2014: 10<br>**2015: 8** | | |
| Exceeding voltage levels | 2014: 40<br>**2015: 0** | 2014: 3<br>**2015: 0** | | |
| Loss of IT tools | | 2014: 4<br>**2015: 1** | | |

*Table 4. List of reported incidents to ICS statistics Denmark in 2013, 2014 and 2015.*

bances in one country can impact neighbouring countries, or in the worst case, all of Europe. European TSOs therefore work together to ensure the secure operation of a common electricity system.

ENTSO-E has developed two tools to improve joint European operations. These are:
- European Awareness System (EAS)
- Incidents Classification Scale (ICS).

The EAS is a common European real-time system which provides online information to each TSO on operating status of the electricity system in each region. The EAS effectively provides a continuous green, yellow or red signal for the operating status in the various regions. The system provides information on the flow in international connections and critical incidents in neighbouring countries which could affect operation of the local system.

The EAS has provided the background for the methodology in ICS reporting method. 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. The methodology and scope of reporting are being continuously developed.

Incidents are classified in reporting on a scale from 0-3, where 3 is the most serious level:
- **Scale 0.** Local deviations with low impact on operational reliability.
- **Scale 1.** Serious incidents and events affecting more than one TSO.
- **Scale 2.** Extensive incidents in a large area (synchronous area, area of responsibility, neighbour TSOs).
- **Scale 3.** Major incidents resulting in a blackout.

Denmark began reporting to the ICS statistics in 2013. In 2013, the only reported incidents were faults in HVDC facilities. HVDC faults were reported in 2013 as scale 0 incidents. Since 2014, HVDC faults have been reported as scale 1 incidents.

Of greatest note in 2015 was the fact that there were no incidents resulting from voltage standards being breached. This is because Energinet.dk established a new TSO monitoring function focusing on voltage control in 2015. Various market conditions (such as extensive imports via Skagerrak) and technical conditions (such as the commissioning of Skagerrak 4) also contributed to the reduction in voltage limit breaches.

Seven major incidents involving IT tools which affected the control centre were reported in 2015. One of these was registered as a scale 1 incident in the ICS statistics. Loss of IT tools is only registered for scale 1 and scale 2 incidents in the ICS statistics.

There were 8 HVDC incidents in 2015, compared to 10 the previous year. 5 of the incidents in 2015 occurred at Konti-Skan, 2 at Kontek and 1 at Skagerrak.

It is planned that incidents where the N-1 criterion is not upheld will be included in the ICS statistics from 2016.

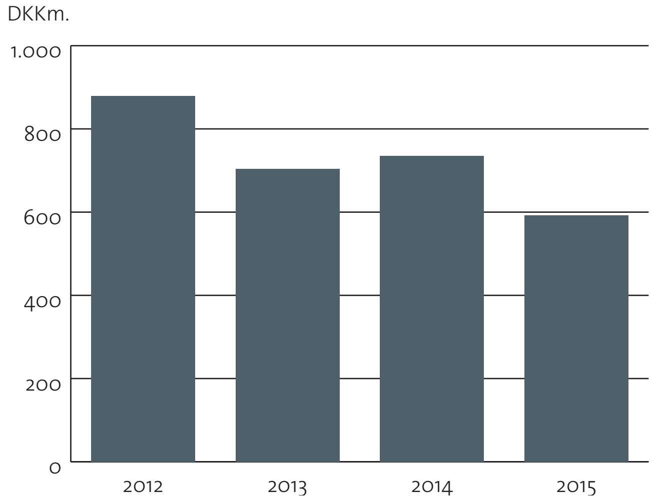



*Figure 6. Cost for ancillary services for electricity in 2012-2015. Costs are covering both reserves and properties to maintain power system stability.*

## 2.2.5 Ancillary services

Ancillary services refer to the production and consumption reduction resources which are available during the delivery hour, and activated automatically or upon request from the transmission system operator. The aim of their use is to maintain balance in the electricity market and the overall stability of the electricity system.

In 2015, ancillary service purchases totalled DKK 592 million, versus DKK 735 million in 2014. The reduction is due primarily to a decrease in the costs of automatic reserves in Eastern Denmark, as a result of joint procurement with Sweden and purchases of automatic reserves from Norway for Western Denmark.

In addition to reserves, properties required to maintain power system stability are also purchased. These properties can be provided by network components, synchronous condensers and power stations. Part of the need is met by activating thermal power stations. Energinet.dk purchases power plants that can provide properties required to maintain power system stability on a monthly basis, through tenders, or by orders when tenders are not possible. From the summer of 2015, purchases have also been made on a weekly basis for the summer months (May-August). The procedure aims to create transparency regarding the needs and the costs of activation. Monthly purchases are made when Energinet.dk estimates there is an insufficient number of power stations or other system supporting units on the grid.

| Costs for procurement of properties to maintain power system stability | | | |
|---|---|---|---|
| DKKm | 2013 | 2014 | 2015 |
| Market contracts | 104 | 164 | 171 |
| Ordering | 57 | 54 | 6 |
| In total | 161 | 218 | 177 |

*Table 5. Cost for procurement of properties from the market operators to maintain power system stability.*

Orders are used as a tool to obtain properties required to maintain power system stability in situations involving breakdowns at power station or in parts of the transmission grid etc. Following up on Market Model 2.0, a project has been launched involving market players on greater transparency in relation to needs in the short and long term and clear price signals to ensure socio-economic procurement.

The total cost of purchasing properties required to maintain power system stability fell by approx. DKK 40 million from 2014 to 2015. The decline is partly due to a reduced need to purchase properties required to maintain power system stability in Western Denmark following commissioning of Skagerrak 4 and the synchronous condenser in Fraugde in 2014. The need to purchase properties required to maintain power system stability in Eastern Denmark has been reduced following commissioning of the synchronous condenser in Herslev on Zealand in 2014.

## Properties required to maintain power system stability

Properties required to maintain power system stability are services necessary to maintain secure operation of the electricity system that are not procured on the reserve capacity markets for electrical energy.

- **Frequency stability:** Maintaining a stable frequency in addition to what balancing in the active power markets is capable of achieving. Frequency stability is linked to inertia, frequency reserves and more dynamic reserves.
- **Voltage stability:** Maintaining a stable voltage with as little transport of reactive power as possible and maximisation of the active power transport. Voltage stability is linked to Mvar reserves and voltage quality.
- **Short-circuit power:** Maintaining a suitable short-circuit power level which permits operation of the electricity system, so both classic HVDC connections and relay protection can function properly.

Properties required to maintain power system stability are provided by thermal plants in operation and synchronous condensers, and cannot be transported far. For example, an ancillary services unit in North Jutland can provide 'strong' properties for system stability in North Jutland, but 'weaker' properties in South Jutland.

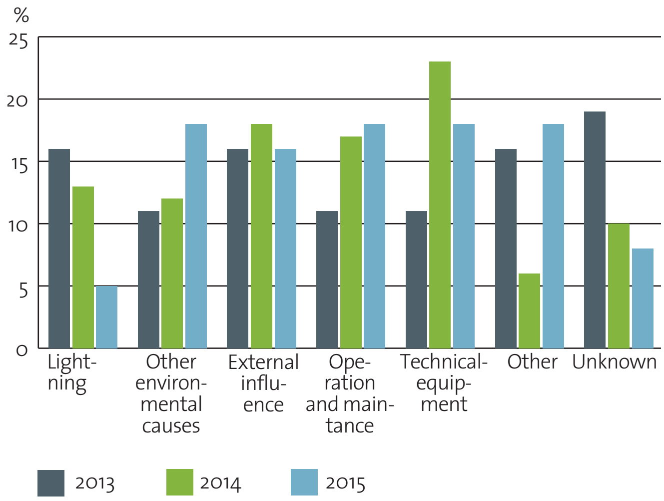



*Figure 7. Illustration of the percentage distribution of faults in the HVAC grid. Source: DISTAC, Nordic HVDC Utilization and Unavailability Statistics 2014.*

Low spot prices in 2015 have led to upward pressure on the cost of purchasing active power stations in operation. In 2015, Energinet.dk purchased standby power stations using market contracts for the first time.

Power station orders represented a limited share of total cost of obtaining properties required to maintain power system stability in 2015.

**Plans to close power stations and cancelled maintenance applications**
A machinery maintenance plan is prepared each year showing central power station maintenance. The machinery maintenance plan is coordinated among power stations, neighbouring TSOs and Energinet.dk. Once the machinery maintenance has been approved by Energinet.dk, Energinet.dk cannot deviate from it without compensating the power station. Energinet.dk did not cancel maintenance planned in the machinery maintenance plan in 2015.

There have been no applications for mothballing, changed start-up warning times or decommissioning for thermal power stations in 2015 that Energinet.dk assessed would have an impact on security of supply.

### 2.2.6 Faults in the grid

Knowledge of failure rates in the grid etc. is used to assess and plan future system security and in asset management. Faults in individual components or alarm systems rarely lead to failure to supply energy to the consumer.

Disruptions and faults in the grid above 100 kV for direct current and alternating current are reported on each year. The analyses and statistics are published via ENTSO-E and prepared by DISTAC, the Nordic and Baltic group (Nordic Disturbance Statistics). The aim of DISTAC is to develop a uniform method to classify and calculate the number of disruptions and faults for the entire Nordic and Baltic region. This provides the opportunity to share knowledge across borders and draw on experience from other countries.

**Reporting on the HVAC grid**
The 'Nordic and Baltic Grid Disturbance Statistics' for the HVAC grid is a technical incident report providing insight into failure rates, causes, components subject to multiple faults and security of delivery.

There were 77 faults in the Danish grid above the 100 kV level in 2014, compared to 63 in 2013. The number of annual faults has been rising over the last few years, but without increasing the 10-year rolling average significantly. The 10-year average rose by a single fault to 64 from 2013 to 2014.

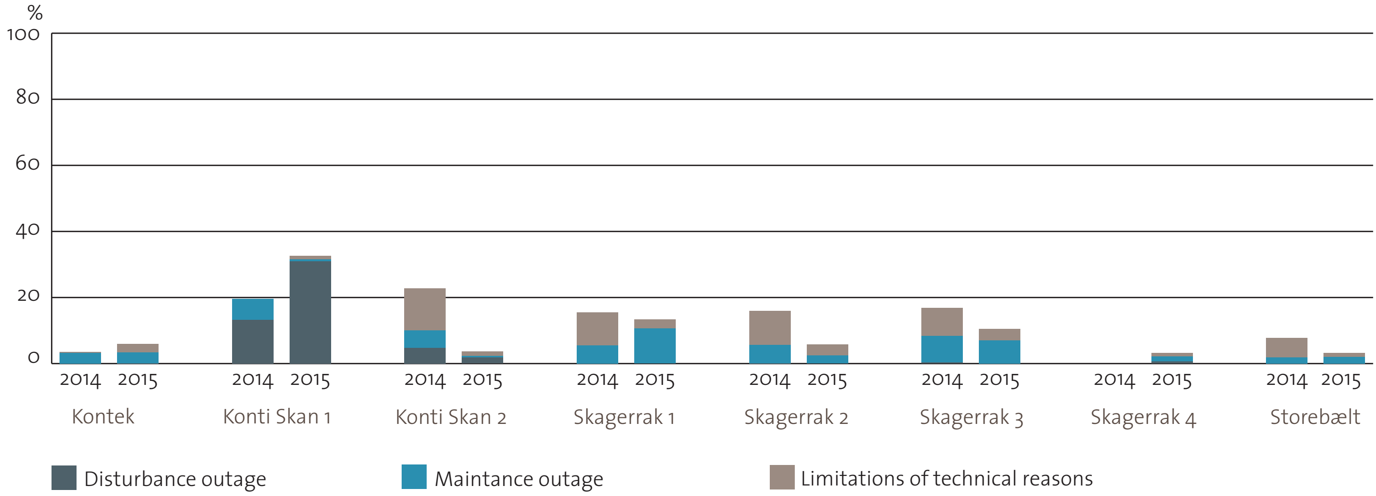



*Figure 8. Overview of outages/limitations as a percentage of technical capacity for each HVDC connection to or from Denmark in 2014 and 2015, divided by cause. Data: DISTAC, Nordic HVDC Utilization and Unavailability Statistics 2014.*

In 2015, approx. 79[5] faults are expected in the Danish grid above the 100 kV level.

**Reporting on the HVDC grid**
Within Denmark, the direct current grid covers a number of international connections and the Great Belt Power Link. DISTAC's 'Nordic and Baltic HVDC Utilisation and Unavailability Statistics' report contains information on how the Nordic HVDC connections are impacted by technical limitations in the grid and by faults and maintenance.

There were 64 faults in HVDC connections in the Nordic region in 2014 (including 24 in connections to or from Denmark). The three biggest events in the Nordic region occurred on Konti-Skan 1, Konti-Skan 2 and Estlink 1. The biggest incident happened at Konti-Skan 1 due to a cable fault. The cable was out of service from 11 November to the end of the year.

Approx. 24[5] faults on connections to/from Denmark are expected in 2015.

When comparing Nordic HVDC connections, Kontek and Great Belt have some of the lowest outage times. The Skagerrak connections are slightly above the average, and the Konti-Skan connections are in third and fourth place on the list of connections with highest outage times in 2014.

5 Data for 2015 has not yet been checked for consistency with the other TSOs in the DISTAC cooperation.

### 2.2.7 Emergency incidents

Incidents occur regularly in the electricity system. Most of these are handled by the normal duty operator structure, and are therefore not viewed as emergency incidents.

Emergency incidents are rare, but can have a major impact on security of supply. Emergency incidents are often complex, and require several fun-ctions and companies to work together. Emergency incidents often require cooperation with players outside the sector – such as the police, fire department and emergency response services.

When an emergency response has been activated, the incident must be reported to the Danish Energy Agency, giving an account of the incident and points for follow up. The annual emergency preparedness reports cover the incidents where a significant part of the emergency response apparatus has been activated.

Incidents relevant to emergency preparedness in 2015:
- Fire/melting in the emergency power room in Erritsø in August 2015.
- Blizzard in November 2015.
- IT incident in December 2015.

None of these incidents led to supply disruptions for consumers.

# 3. Future risk assessment

Risk assessments for the electricity system are divided into two categories – system adequacy and system security.

Assessing system adequacy means assessing the electricity system's ability to meet total consumer demand, and can be subdivided into generation adequacy and grid adequacy. Generation adequacy is the system's ability to produce sufficient electricity for consumers, at the times it is needed. Grid adequacy is the transmission and distribution system's ability to transport sufficient electricity from where it is produced, to where it is demanded.

Assessing system security means assessing the electricity system's ability to handle sudden system disturbances caused by electrical short circuits, a sudden power station or transmission line outage etc. without affecting electricity supply or resulting in power outages.

Future risk assessment will focus primarily on:
- Market trends
- Generation adequacy
- Grid adequacy
- System security
- Daily operations
- Information security

Risk assessment is used to evaluate whether mitigating initiatives need to be effected to meet Energinet.dk's objective of 50 outage minutes overall[6].

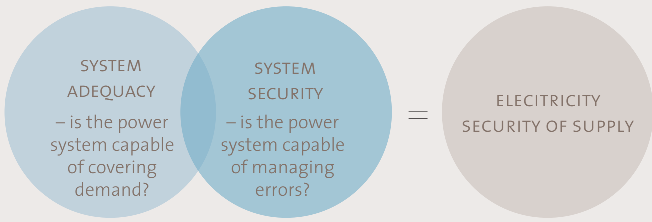



*Figure 9. Illustration of system security and system adequacy that in reality are two overlapping elements.*

## 3.1 Market trends

Since deregulation of the electricity market, the current market model has contributed to optimising the use of existing generation facilities and helped ensure balance between consumption and production. Under the market model, production and trading have been passed onto market players, who generally decide the level of production capacity, consumer flexibility and storage. The commercial players do not have direct responsibility for security of electricity supply, and are not obliged to supply power to the market during normal operation. Energinet.dk is responsible for developing the framework for a smoothly functioning and internationally interconnected electricity market, which can ensure balance between consumption and production.

6 Outage minutes expresses the amount of expected energy not served compared to the amount of electricity consumed per minute in Eastern and Western Denmark respectively. This means that outage minutes are consumption weighted, and it is calculated by dividing energy not served with average hourly consumption.

## What are network codes?

Network codes are the European regulations governing and supporting the development of a smoothly operating single market for electricity.

They are adopted in EU legislation in the form of 'Network Codes' (NC) or 'Guidelines' (GL), which apply directly in Denmark. Network codes are developed jointly by ACER (Agency for the Cooperation of Energy Regulators) and ENTSO-E. Network codes cover market, operating and connection conditions. Guidelines often define a framework which serves as a subsequent basis for more detailed common rules.

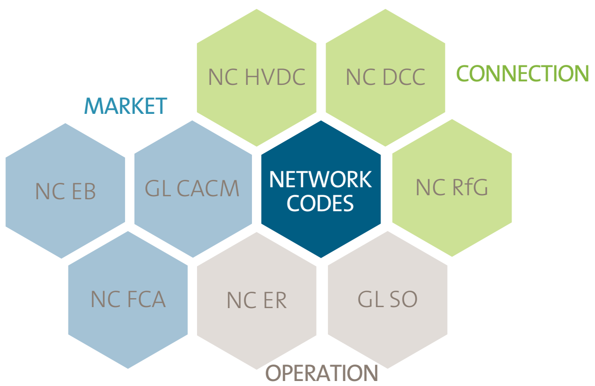



*Figure 10. Illustration of network codes and their internal relationships.*

The connection network codes comprise:
- Grid connection for **demand facilities** (NC DCC): Connection conditions for demand facilities. This network code is expected to be approved in autumn 2016.
- Grid **connection of generators** (NC RfG): Connection conditions for generators. This network code is expected to be approved in autumn 2016.
- Connection and operation of **HVDC connections** (NCHVDC): Connection conditions for HVDC connections. This network code is expected to be approved in autumn 2016.

The operation network codes comprise:
- **Operation of the electricity system (GL SO):** Rules and framework for operation of the electricity system. This guideline was adopted in the Cross Border Committee on 4 May. It is expected to come into force at the end of 2016.
- Handling **emergency situations** (NC ER): Handling emergency situations and restoring supply. This network code is being evaluated and is expected to be approved in autumn 2016.

The market network codes comprise:
- **Capacity allocation** (GL CACM): Handling cross-border capacity congestion with rules for capacity calculation, the day-ahead market and intraday market. The CACM regulation came into force on 14 August 2015.
- **Forward capacity allocation** (NC FCA): Defines the rules for purchasing transmission rights, i.e. the right to use capacity on a transmission line in a given period. FCA is expected to come into force during summer 2016.
- Rules for electricity **balancing** (GL EB): Rules for structuring a Pan-European market to handle imbalances after the day-ahead and intraday markets have closed. This network code is expected to begin the comitology process in summer 2016.

Follow the work on network codes at //networkcodes.ENTSOE.eu/

In the longer term, it is expected that the market model will be developed in a direction where each consumer sets the limit for what they are willing to pay directly in the market. Energinet.dk therefore expects in the longer term that consumers will more actively contribute to reducing consumption when power shortage situations arise. Other solutions may be brought into play in the short term, such as strategic reserves to achieve the desired generation adequacy level.

There are currently two key areas within market trends:
- Development of European network codes for the electricity market. Network codes contribute to security of supply by harmonising market regulations and thereby opportunities to better utilise production and transmission capacity across borders.
- Development of the future market model based on the energy-only market, where clear price signals must ensure sufficient capacity, as concluded in the Market Model 2.0 project.

**Market Model 2.0**

Three key issues for the future electricity market were identified in connection with the Market Model 2.0 project from 2015, all of which contribute to maintaining a high security of electricity supply:

- **Capacity:** If the existing electricity market is retained, the risk increases that sufficient power to maintain Energinet.dk's objectives will not be established under market conditions.
- **Flexibility:** Wind and weather are set to change the electricity system. The electricity market lacks incentives to continue the trend whereby producers and consumers contribute to flexibility. For example, using more electricity when it is cheap and less when it is expensive.
- **Critical properties:** Who is to supply electricity when the power stations are not running? Some of the properties that are critical to operating an electricity system are currently provided by of the power stations. But power stations are operating less and less.

These three challenges are all important to the security of supply, i.e. the degree to which the market is able to directly ensure sufficient flexibility, and the right properties to maintain security and generation adequacy. Three development needs were identified as initiatives:

- **Capacity:** Mechanisms are needed to allow Energinet.dk's security of supply objective to be met. These should primarily be based on clear price signals within an energy-only market approach.
- **Flexibility:** There is a need for more flexibility among consumers and incentives for greater flexibility among producers and consumers. Market rules therefore need to be adapted, and new business models must be introduced to the market.
- **Critical properties:** There is a need to investigate what future needs exists, and whether new ways to obtain and pay for critical properties can be designed.

Regarding the capacity challenge, efforts to raise the price cap in the day-ahead, intraday and regulating power markets via the European market cooperation will continue. Further work will also be done on the market options for obtaining extra capacity via a strategic reserve. (See section 3.2.5 for further details).

The challenge of ensuring there are flexibility incentives in the market will initially be addressed by:

- Revising the balance requirement prior to the day of delivery.
- Examining the possibility of adjusting power imbalance settlement, special regulation and security for bids in relation to reserve requirements.
- Promoting flexibility on the demand side, for example through the establishment of an aggregator model.
- Framework for the integration of new technologies.

These market initiatives are dependent on changes to existing agreements on international markets, future network codes and changes to the Danish Act on Electricity Supply.

The challenge involving critical properties is divided into three phases: Needs analysis, provision options and implementation. Needs analysis is currently underway, and work is being done on analysing possible provision models and legal options (section 3.4.1).

## FSI model

The FSI model is Energinet.dk's current tool to analyse expected future generation adequacy situations. The model is stochastic and uses Monte Carlo simulations.

The model simulates incidents in the electricity system which can lead to a power shortage on an hourly basis. A number of calculation runs (typically 300) are performed for each year being analysed, to represent possible combinations of incidents. The model results thus illustrate an average of all calculation runs for a single year.

The FSI model is based on historical hourly series for consumption and fluctuating production (wind and solar power). Production from thermal power stations and imports via international connections are stochastic. The stochastic element is represented using probabilities for breakdowns or maintenance. Thermal generation plant and international connections will therefore be unable to supply energy to meet the consumption for a number of hours in each calculation run. Which hours are decided at random. During the hours when a large generation plant and/or an international connections drop out, consumption must be met by fluctuating production from wind and solar power or the remaining thermal plants and international connections.

The model estimates the risk of outages in the Danish system due to power shortages. Since the model is hourly based, variations within each hour of delivery are not covered.

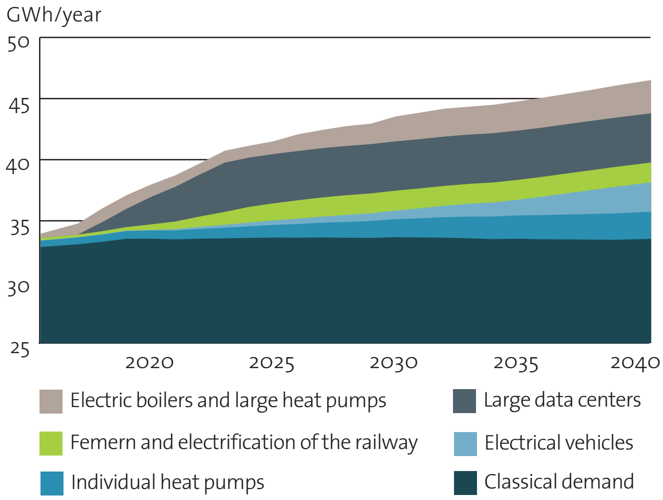



*Figure 11. Annual projection of gross electricity consumption for Denmark. Source: Energinet.dk's analysis assumptions 2016*

## 3.2 Generation adequacy

Generation adequacy refers to the system's ability to generate sufficient electricity to satisfy consumption at all times. Generation adequacy is closely linked to the electricity market. Power shortages can arise if there is a risk that insufficient electricity can be generated to meet the desired consumption.

Energinet.dk's objective is that the risk of power shortage should not be larger than it is currently. This corresponds to a target of a maximum of 5 outage minutes for an average consumer in an average year being caused by power shortages in the Danish system.

Future risk assessments will be carried out using Energinet.dk's FSI model. This model estimates the risk of power shortage in the Danish electricity system. The results are calculated separately for Eastern and Western Denmark.

### 3.2.1 Input data

The risk assessment is based primarily on Energinet.dk's analysis assumptions[7]. Specifically, these are expectations regarding trends in consumption, production capacities and foreign capacities. Another key input is the availability of production and exchange capacities, which are estimated based on historical data.

**Electricity consumption**

Electricity consumption is expected to rise in the coming years. An increase in consumption is mainly expected from new types of demand such as data centres, heat pumps, etc. The primary electricity consumption will continue to be classic electricity demand. The maximum electricity consumption per hour is also expected to rise considerably. Production and exchange capacity must therefore meet a greater demand during hours with very high electricity consumption.

**Production capacity**

The composition of production capacity is expected to follow development trends seen over recent years. This means that thermal capacity will be further reduced, while wind and solar power continue to increase.

7 Energinet.dk's analysis assumptions: http://energinet.dk/DA/El/Udvikling-af-elsystemet/Analyseforudsaetninger/Sider/default.aspx.

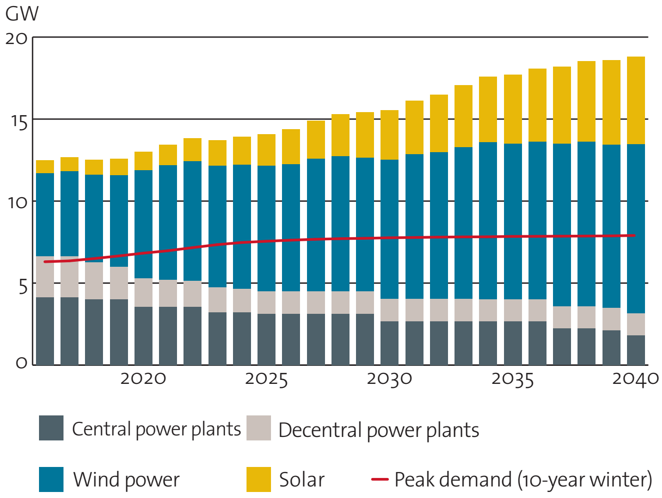



*Figure 12. Energinet.dk's expectations for changes in production capacity during 2016-2040, and the peak load demand in a 10-year winter Source: Energinet.dk's analysis assumptions 2016.*

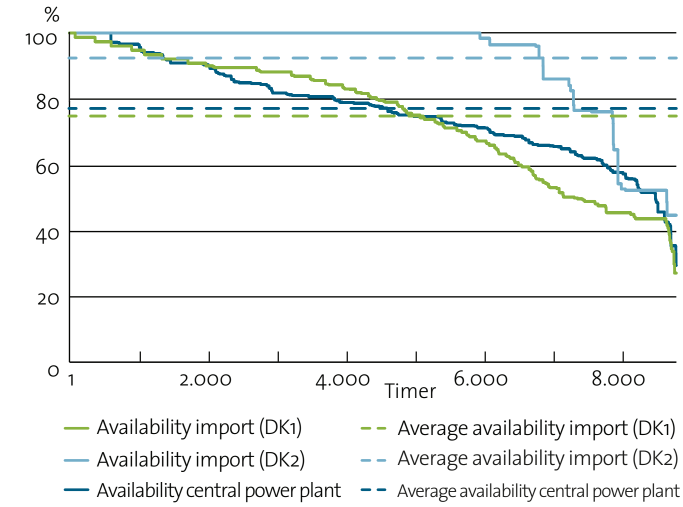



*Figure 13. Duration curves for 2015 for availability of import capacity for DK1 (West Denmark) and DK2 (East Denmark), compared with availability of central power stations. Source: Market data, Energinet.dk and UMMs (Urgent Market Messages) from Nord Pool Spot.*

**Exchange capacity**
Danish exchange capacity is expected to rise in the years ahead. Partly due to the coming connection via Kriegers Flak offshore wind farm, expected to be operational in late 2018. Partly via COBRAcable, a 700 MW connection from Western Denmark to the Netherlands, expected to come online during 2019. There are also plans to add UK exchange capacity via Viking Link. Viking Link is a 1,400 MW interconnection, expected to come online in late 2022. Capacity between Western Denmark and Germany is also expected to be increased in two stages, in 2020 and 2022.

**Availability of production and exchange capacity**
The availability of production and exchange capacities is estimated based on historical data.

Electricity generation from wind and solar sources has no break-down or maintenance probabilities, as this production follows estimated hour-based profiles.

- **The data from 2015 shows:** The central power stations had an average availability of approx. 80 % in 2015.
- **Import capacities** varied greatly for Western and Eastern Denmark in 2015. In Eastern Denmark, import capacity was at its maximum value for approx. 5,500 hours of the year. On average, the capacity was around 96 % of the maximum capacity. Import availability was significantly lower for Western Denmark, averaging around 77 % of maximum capacity.[9]

| | Probability of breakdown |
|---|---|
| Decentral power plants | ~ 23%.<br>Estimated from ~53 days revisions per year and a breakdown probability at ~8 %. |
| Central power plants | ~ 19%.<br>Estimated from ~40 days revision per year and different breakdown probabilities for each plant. |
| Exchange | 5% for AC, and 8% for DC.<br>In addition there is a risk of insufficient capacity in neighboring countries[8]. |

*Table 6. Estimated outage rates for production and exchange facilities.*

## 3.2.2 Generation adequacy analyses

Analyses of generation adequacy in Denmark up until 2025 show that the risk of outages for consumers in Western Denmark remains low. All analyses result in an average risk per year for Western Denmark of less than one outage minute.

8 The areas NO2 and SE4 are modelled endogenously in the FSI-model, while the rest of the neighboring areas are assigned exogeniously defined probabilities for delivering adequate power to Denmark.

9 The data from 2015 only represent one single year of observation, whereas the data in Table 6 is seen over a longer time period.

## Goals for generation adequacy

- **EUE (Expected Unserved Energy)** indicates unserved energy per year in the simulations by including the risk of blackout, i.e. the total energy consumption which cannot be met by production.
- **Outage minutes** are consumer-weighted outage minutes, calculated by dividing unserved energy by average hourly consumption for Eastern and Western Denmark, respectively, in the simulated year.
- **LOLE** (Loss Of Load Expectation) indicates the number of hours with a power shortage.
- **LOLP** (Loss Of Load Probability) indicates the probability of a power shortage in a given hour (LOLE=8760 x LOLP).

The situation is different in Eastern Denmark up until 2025, and more strained. Results are therefore only shown for Eastern Denmark for both base and sensitivity analyses.

The first calculations (Table 7) have been based on historical values for maintenance (Table 6). This means that the risk of power shortage increases if more maintenance is expected in a given year than the average historical outage time.

The results for 2018 show that the risk of power shortage exceeds Energinet.dk's 5-minute objective. The strained power balance is partly due to expectations of declining thermal production capacity. Generation adequacy improves in 2019 with the opening of the international connection via Kriegers Flak to Germany. Leading up to 2025, generation adequacy is again expected to be strained.

| Eastern Denmark | | | | |
|---|---|---|---|---|
| | EUE (MWh/year) | Weighted minutes (min./year) | LOLE (hours/year) | LOLP (%) |
| 2017 | 98 | 4 | 0.26 | 0.00% |
| 2018 | 177 | 7 | 0.5 | 0.01% |
| 2019 | 86 | 3 | 0.21 | 0.00% |
| 2020 | 138 | 5 | 0.32 | 0.00% |
| 2025 | 431 | 15 | 0.84 | 0.01% |

*Table 7. Results from the adequacy evaluations in Eastern Denmark up to 2025 based on the historical range of maintenance. The evaluations for 2020 are used as basis for further sensitivity analyses.*

The expected number of hours with a power shortfall is low. The risk relates to rare incidents which can lead to supply disruptions to consumers. This means that the conditions do not have to change much before the risk increases.

The base calculation of the results in Table 7 uses average availabilities for production and exchange capacity. However, some of the maintenance to be carried out in 2018 is already known. For example, the 400 kV Øresund cables have to be replaced, and there are power stations which need to have their lifetime extended or be converted to biomass. When the expected maintenance periods for thermal power stations and international connections are used as conditions, the risk of power shortage is increased.

Due to the increased risk in 2018, Energinet.dk has placed greater focus on maintenance planning. Other potential mitigating initiatives are also being considered to alleviate the strained power situation in Eastern Denmark. The power situation in the 2016-2018 period is estimated to be more strained than the evaluations carried out in 2015 due to the failure to purchase a strategic reserve.

| Revisions- 2018 | | | | |
|---|---|---|---|---|
| Eastern Denmark | EUE (MWh/ year) | Weighted minutes (min./year) | LOLE (hours/ year) | LOLP (%) |
| Historical revisions | 177 | 7 | 0.5 | 0.01% |
| With known revisions and strategic reserve | 256 | 10 | 0.54 | 0.01% |
| With known revisions | 853 | 32 | 1.59 | 0.02% |

*Table 8. Results from the adequacy evaluations in Eastern Denmark for 2018 with different assumptions in relation to number and placement of revisions. Notice that the two calculations with known revisions assume that no other revisions are placed in the period, where the Øresund cables are out for revision. Furthermore, these calculations includes an additional contribution to the adequacy gap due to operational restrictions in the grid.*

## 3.2.3 Generation adequacy sensitivity

Sensitivity analyses illustrate how changes in input data impact on the risk assessment. Sensitivity analyses have been completed for Eastern Denmark in 2020. Variations in the input parameters are illustrative examples only, and do not reflect Energinet.dk's assessment of the input parameters' uncertainty.

**Power shortages in neighbouring countries**
Denmark's import options will be reduced when there are power shortages in neighbouring countries.

| Sensitivity neighboring areas - 2020 | | | | |
|---|---|---|---|---|
| Eastern Denmark | EUE (MWh/ year) | Weighted minutes (min./year) | LOLE (hours/ year) | LOLP (%) |
| Basis 2020 | 138 | 5 | 0.32 | 0.00% |
| Probability for adequacy issues in neighboring area doubled | 400 | 15 | 0.83 | 0.01% |
| Probability for adequacy issues in neighboring area halved | 81 | 3 | 0.18 | 0.00% |

*Table 9. Results from the sensitivity analyses of adequacy issues in neighboring countries for 2020.*

The sensitivity analysis shows, for example, that Eastern Denmark is dependent on power availability in Sweden. If the power shortage is doubled in neighbouring regions, the outage minutes are tripled.

**Availability of international connections**
The availability of transmission connections has a direct impact on import options – no cable means no energy.

The sensitivity analyses show that doubling the outage probability on the international connections, including Great Belt, increases the risk to over 30 outage minutes. The result shows that in years with a higher number of or extended breakdowns on international connections, the risk of outages is particularly

| Sensitivity exchange connection - 2020 | | | | |
|---|---|---|---|---|
| East Denmark | EUE (MWh/ year) | Weighted minutes (min./year) | LOLE (hours/ year) | LOLP (%) |
| Basis 2020 | 138 | 5 | 0.32 | 0.02% |
| Outage probability doubled | 839 | 31 | 1.95 | 0.01% |
| Outage probability halved | 79 | 3 | 0.15 | 0.00% |

*Table 10. Results from the sensitivity analyses of different outages probabilities for transmission lines and power plants for 2020.*

| Sensitivity power plants – 2020 | | | | |
|---|---|---|---|---|
| East Denmark | EUE (MWh/ year) | Weighted minutes (min./year) | LOLE (hours/ year) | LOLP (%) |
| Basis 2020 | 138 | 5 | 0.32 | 0.02% |
| Outage probability for decentral power plants in DK1 and DK2 reduced with by 25%. | 253 | 9 | 0.5 | 0.01% |
| Outage probability for decentral power plants in DK1 and DK2 reduced with by 40%. | 330 | 12 | 0.7 | 0.01% |
| Outage probability for all power plant doubled | 453 | 17 | 1.05 | 0.01% |

*Table 11. Results from the sensitivity analyses of power plants for 2020.*

heightened. Conversely, the risk is also lower in years with greater availability.

**Availability of thermal power stations – decentral and central**
The sensitivity analyses investigate the impact of lower local production capacity and lower central capacity availability. Both parameters affect the capacity available in each delivery hour.

The basic conditions include a drop in local capacity due to expiry of the subsidy in 2018. The sensitivity analyses assess a further reduction in the total capacity available over the year.

The level of generation adequacy is also impacted by the availability of the thermal power stations. The selected sensitivity analysis evaluates an increase in the probability that the central power stations are not available in a given hour of delivery.

A 25% reduction in local capacity increases the number of outage minutes by over 4, while a 40 % reduction increases them by 7 minutes. Doubling the outage probability on central power stations increases the outage minutes by almost 12.

A 40% reduction in local capacity corresponds to a total reduction of almost 200 MW in Eastern Denmark. When the outage

| Sensitivity nuclear power plants in Sweden - 2020 | | | | |
|---|---|---|---|---|
| East Denmark | EUE (MWh/ year) | Weighted minutes (min./year) | LOLE (hours/ year) | LOLP (%) |
| Basis 2020 | 138 | 5 | 0.32 | 0.02% |
| Reduction of 1000 MW in SE4 | 311 | 11 | 0.7 | 0.01% |
| Probability for adequacy issues in SE3 doubled | 242 | 9 | 0.5 | 0.01% |

*Table 12. Results from the sensitivity analyses of nuclear power in Sweden for 2020.*

| Sensitivity analyses of Kriegers Flak - 2020 | | | | |
|---|---|---|---|---|
| East Denmark | EUE (MWh/ year) | Weighted minutes (min./year) | LOLE (hours/ year) | LOLP (%) |
| Basis 2020 | 138 | 5 | 0.32 | 0.02% |
| Kriegers Flak intercon-nector is delayed till after 2020. | 498 | 18 | 1.2 | 0.01% |

*Table 13. Results from the sensitivity analyses of the interconnection Kriegers Flak for 2020.*

probability for the central power stations is doubled, it corresponds to an average of 200 MW less over the year. However, during some hours capacity is reduced by more than 200 MW, for example when a power station unit cuts out.

Comparing the results of these two sensitivity analyses shows that the system is more sensitive to major outages than to multiple smaller outages, despite the same average reduction in capacity. It also shows there is great value in the probabilistic approach, as the traditional deterministic approach results in the same risk for the two sensitivity analyses.

**Nuclear power in Sweden**
Swedish nuclear power plants are under financial pressure, and the closure of several Swedish reactors is being considered. For technical reasons, the closures have been modelled by:
- Removing approx. 1,000 MW thermal capacity in SE4.
- Doubling the probability of power shortage in SE3.

The results show that Eastern Denmark is dependent on the Swedish system. The risk of power shortage roughly doubles if the power situation in Sweden is weakened.

**Kriegers Flak**
The last sensitivity analysis examines the impact on generation adequacy of the new international connection from Zealand via Kriegers Flak to Germany.

Without the Kriegers Flak connection, the risk of power shortage is tripled.

### 3.2.4 Joint Nordic and European generation adequacy assessments

This method is based on probabilistic principles. But instead of a spredsheet based methodology, as used in the FSI model, the BID electricity market model is used. The BID model simulates the electricity system hour by hour, and takes into account exchanges between regions and production per power station unit. In this way, the BID model has several neighbouring regions endogenously in the model, compared to the FSI model.

The method is more suitable for evaluating how interconnections contribute to generation adequacy and add other types of risk. The BID model is also ideal for analysing hydrological conditions, and can analyse how wet and dry years affect generation adequacy. Since the method does not yet include outage probabilities for HVAC connections (such as the Øresund cables from Zealand to Sweden) it is not yet used to calculate generation adequacy risks for Denmark.

### 3.2.5 Strategic reserve in Eastern Denmark

As one step towards ensuring generation adequacy in Eastern Denmark, Energinet.dk has wanted to create a strategic reserve in Eastern Denmark during the 2016-2018 period, to contribute to supply in highly critical situations However, Energinet.dk decided to cancel the call for tenders in December 2015. The tender was cancelled because Energinet.dk did not expect to be able to implement it, as the European Commission saw the reserve as being in breach of the EU rules on state aid. Energinet.dk still believes it is necessary to build a bridge from the existing system to the future European solution, and that a strategic reserve is an appropriate tool.

As a result, Energinet.dk is continuing to work towards establishing a strategic reserve in Eastern Denmark. Preparation of a procurement period and model for a strategic reserve is awaiting the European Commission's sector investigation into the financial aid EU Member States give electricity generators and consumers to guarantee security of supply.

The European Commission plans to publish a final report on the sector investigation later in the year. Based on the information gathered from the sector investigation, the report will assess whether the capacity mechanisms fulfil the EU's state aid rules. This assessment will provide a basis for the ongoing work on the application for a strategic reserve for Eastern Denmark in the period up to the commissioning of the Kriegers Flak connection to Germany.

### 3.3 Grid adequacy

Grid adequacy is the transmission and distribution system's ability to transport sufficient electricity from where it is produced, to where it is demanded.

It must be possible to supply the required power in normal operating situations with an intact grid, during maintenance, and in situations where there are faults and outages in the grid. Outages in the transmission grid can affect many consumers

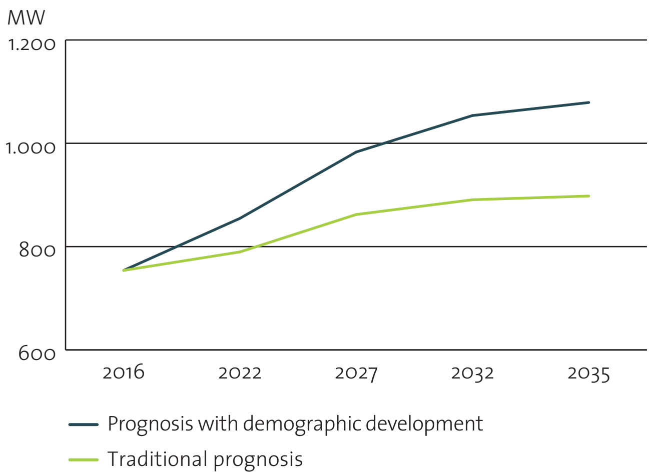



*Figure 14. Prognoses for the maximum grid load in Copenhagen with and without demographical changes. Maximum grid load is measured in MW, and it is this load that the grid has to be dimensioned after, even though less the load is lower the rest of the year.*

and players. The transmission grid therefore has builtin redundancy through ring structures, so the supply to all stations can be maintained in case of an outage on any single connection.

## 3.3.1 Expected transmission grid renovation and expansion

Energinet.dk produces a 20-year network development plan every two years, which describes the expected renovation and expansion to the Danish transmission grid. The network development plan is used in the ongoing detailed planning for transmission grid renovation and expansion.

The long-term and detailed planning are both based on set international planning criteria. These criteria aim to ensure grid adequacy, so that:
- Security of supply is maintained.
- New renewable energy production capacity can be integrated.
- Market functioning, emergency preparedness factors and any ministerial orders can be supported.

Adequate and secure electricity infrastructure involves not only timely planning of new grid components, but also timely and costeffective maintenance of existing electricity infrastructure.

The peak load forecast for electricity consumption defines the load the grid must be able to supply sufficient power to meet. The peak load forecast is used together with the production and capacity forecasts for international connections to ensure adequate, timely and costeffective planning.

Energinet.dk's primary components have an expected life of 40 years. With an asset portfolio of approx. 250 substations, 4,800 km of overhead line and 2,100 km of submarine and land cable, average reinvestments include over 6 substations per year and about 52 km of cable and 120 km of overhead line per year.

**Peak load electricity forecasts**

Forecasts for changes in peak load have traditionally been evenly divided across the country in line with the historical trend. The new peak load forecasts are instead based on the Danish Ministry of Finance's forecasts for economic growth and Statistics Denmark's population forecasts for the various municipalities. The effect of the demographic shift from remote areas to growth centres on the geographical distribution of electricity consumption is thereby included.

The electricity transmission grid in and around Copenhagen has been in need of expansions and major reinvestments in recent years. Peak load forecasts must be prepared in order to assess what expansion and reinvestments are needed. The forecasts must take into account the expected growth in electricity consumption in and around Copenhagen.

## Electricity transmission grid in Copenhagen – reinvestment project

There is a need for major reinvestment in the transmission grid in Copenhagen in the years ahead. Energinet.dk has therefore initiated a project to work out a reinvestment plan for the grid's long-term development. The plan aims to ensure the cheapest possible solution, such that the residual life of existing plant is best utilised and the most pressing reinvestments are made first. The project also focuses on minimising inconvenience to residents and motorists.

The electricity transmission grid in Copenhagen was established incrementally between 1950 and 2000:

- The total length of the 132 kV cable network in Copenhagen is almost 130 km.
- Over 60 km of these cables were established prior to 1975, and are therefore 40-60 years old.
- The rest was mostly established between 1975-1995 and is 20-40 years old.
- Only 1 km was installed after 1995 and is less than 20 years old.

Solely on the basis of this age distribution, Energinet.dk expects regular reinvestments in new cables and switchgear will be necessary. Some of the oldest 132 kV cables are in poor condition, and it may therefore be necessary to install replacements for them within a few years.

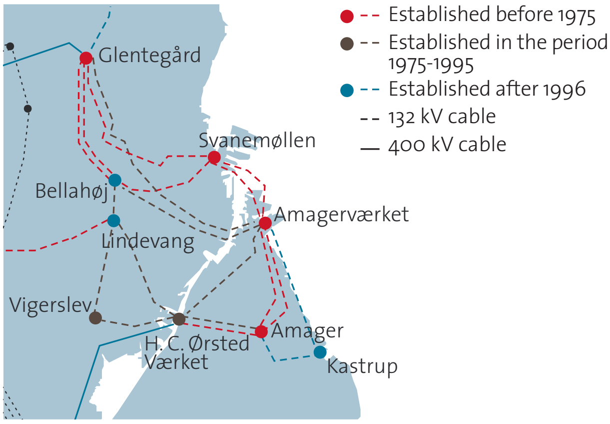



*Figure 15. Age distribution of cables and 132 kV stations.*

The rise in electricity consumption in Copenhagen combined with the decommissioning of several thermal power stations also means that a new supply structure should be considered for Copenhagen and the surrounding area.

While some parts of the country are experiencing higher peak load increases due to the demographic shift, other parts of the country are seeing smaller load increases or even load declines. This means it is possible to avoid or reduce grid improvements in other areas, and thereby ensure renovation and reinvestments in the grid are based on a more accurate peak load forecast.

### 3.3.2 Reinvestments in the transmission grid

Energinet.dk is facing extensive reinvestments because Denmark greatly expanded the grid from the 1960s up until the 1990s. Following, Energinet.dk has initiated extensive work to structure reinvestments in the existing transmission grid using the asset management approach. This work includes:

- A reinvestment strategy and associated strategic initiatives to help fulfil the pledges of high security of supply and an efficient transition,
- Defining reinvestment principles for a common framework and business case for managing and recommending reinvestment projects,
- Introducing the expanded state analysis activity to prepare a holistic overview and qualification of the reinvestment need for a whole substation or section and analyse the potential for extending lifetimes,
- A reinvestment report, including a reinvestment plan.

The reinvestment plan is based on the health matrix and uses components' condition and criticality scores to prioritise between investment projects. This ensures a risk and condition based approach to reinvestment. Energinet.dk will prepare a quarterly reinvestment report.

The reinvestment plan in the report is an important basis for coordinating and combining reinvestment projects with other Energinet.dk projects. This coordination helps optimise planned grid outages and identify project synergies. The reinvestment plan also serves as a tool for advising procurement at Energinet.dk of impending reinvestments.

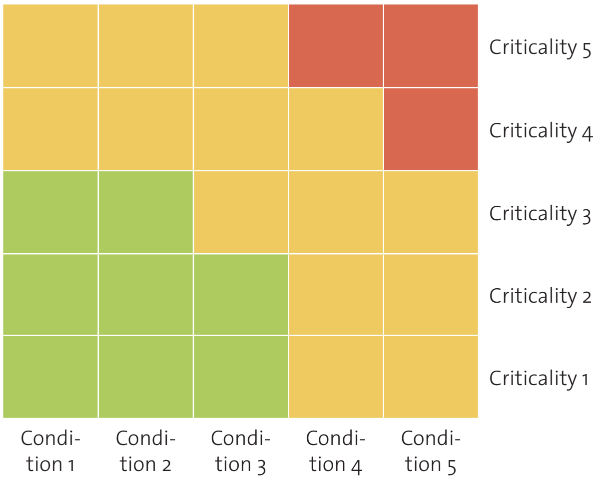



*Figure 16. Illustration of a health matrix, which is used to evaluate all assets on both condition and criticality.*

## 3.4 System security

System security is the electricity system's ability to handle sudden system disturbances. The system has to be robust and able to handle power station and international connection outages, without the total system going out of balance or breaking down (blackout). System security relates to the system's dynamics, at the moment a fault occurs and in the ensuing seconds.

System security is largely an international issue. Western Denmark is part of the synchronous area covering continental Europe. Eastern Denmark is part of the Nordic synchronous area. There are detailed international rules and agreements to ensure system security within the synchronous areas and between synchronous areas. Just as it is important for local disruptions not to spread to all of Denmark, it is important for problems in one country not to spread to the entire synchronous area.

### 3.4.1 Reserves and properties required to maintain power system stability

Ancillary services refers broadly to services that help ensure the grid's functionality. Ancillary services consist of reserves and properties required to maintain power system stability. Reserves are production capacity which can be activated should the need arise.

The need to purchase power plants that can provide the properties required to maintain power system stability is determined based on various parameters. The basic need parameter is fulfilment of the N-1 principle. By extension, any momentary imbalance from a system disturbance must not lead to certain limits being exceeded. Energinet.dk's internal statedependent instruction text contains other requirements, such as limits on the size of voltage jumps during the connection and disconnection of grid components.

The need for properties required to maintain power system stability can be covered by power stations, synchronous condensers and power electronic grid components connected to the transmission grid.

**Tendering properties required to maintain power system stability**

During periods where Energinet.dk believes the properties required to maintain power system stability in the grid are insufficient, Energinet.dk may choose to call for tenders. Such a tender might aim to ensure, for example, that central power station units are available during the summer period. In the event of sudden system disturbances or geographic needs, available power plants can be ordered into service.

In 2015, Energinet.dk introduced summer purchases in addition to the annual purchases which can provide the properties required to maintain power system stability. In the tender for the summer period, power plants were purchased for the May-August period to provide properties required to maintain power system stability.

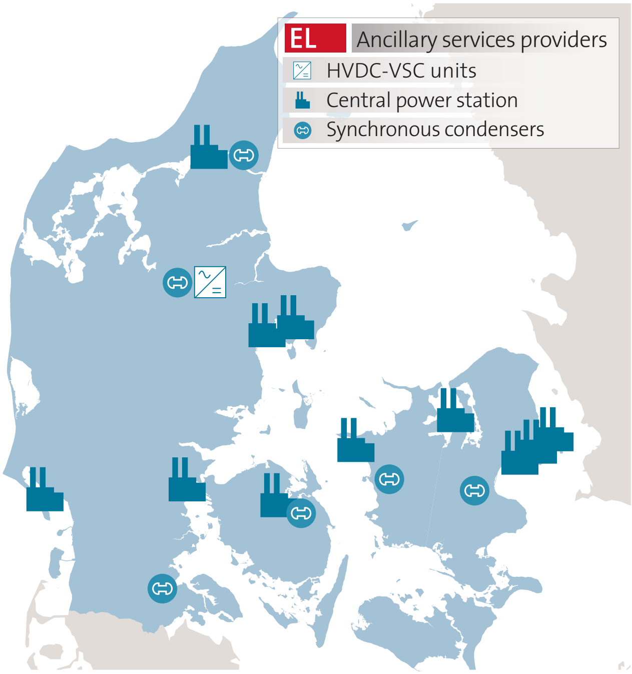



*Figure 17. The location of existing units with properties required to maintain power system stability for Eastern and Western Denmark.*

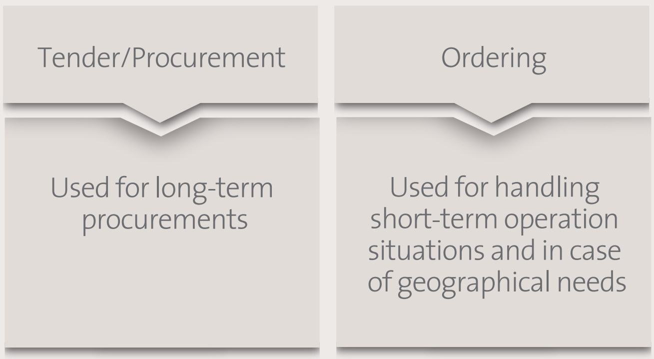



*Figure 18. Illustration of purchases of units that can provide services for maintaining grid stability.*

During the winter months, power plants which can provide the properties required to maintain power system stability are purchased in the periods where this is deemed necessary. As part of the Market Model 2.0 initiatives, Energinet.dk has begun working to clarify the European framework for procuring and paying for properties required to maintain power system stability, with the aim of achieving a predictable market design.

**Future need for properties required to maintain power system stability**

In the past, power stations were located such that production was close to where consumption took place – at the central power station sites. Over time, production has become more distributed in the form of local CHP plants and an increasing number of offshore and onshore wind turbines. This has meant that properties required to maintain power system stability are also needed in other places.

The many new wind turbines and strong international connections in Western Denmark contribute to system stability in a way, where it no longer is depending on power plants during normal operation. This is partly because the new international HVDC connections also provide properties required to maintain power system stability, as a power station or synchronous condenser does.

In autumn 2015 and spring 2016, Energinet.dk conducted extensive analyses of the future need for properties required to maintain power system stability in Western Denmark and presented the results to the suppliers of such properties at a workshop.

The analyses of Western Denmark show that the need for properties required maintaining power system stability, in addition to the system's own contribution, can practically be confined to a need for dynamic voltage control.

The conclusion is that during normal operational situations, there is a need for procurement of one readystate unit in the summer period, provided that other grid components are in service. The need is not expected to change significantly up to and including 2018.

Like the Skagerrak 4 connection, the COBRA connection to the Netherlands will also provide voltage control. It is therefore expected that there will be no need to purchase power plants

## Bow-tie method for risk assessment of critical situations

The bow-tie method is a probability based approach to assessing the risk and impacts of potential critical situations which occur very rarely. The bow-tie method consists of four basic elements:

**1. Critical situations:**
- Situations that have a given probability of leading to a brownout or blackout in the electricity grid.

**2. Cause analysis:**
- Identifies factors that may lead to critical situations, such as rare types of simultaneous faults.
- Estimates the probability of critical situations arising.
- Presents the cause analysis in a fault tree, showing combinations of incidents that can lead to critical situations.

**3. Consequence analysis:**
- Assesses and describes possible outcome scenarios. Some scenarios can lead to brownout or blackout. Quantifies the undelivered energy using the method.
- Presents the consequences in a tree structure, showing the probabilities of the various outcomes.

**4. Risk diagram:**
- Presents a bow-tie diagram based on the cause and consequence analysis.
- The critical situations are presented in a risk diagram showing the frequency (number of incidents per year) and
- consequence (expected energy unserved in MWh).

The bow-tie method for risk assessment for system security will be used by Energinet.dk in future as a tool. One of the method's strengths is that the relationship between initiatives and effects can be seen directly in the risk diagram.

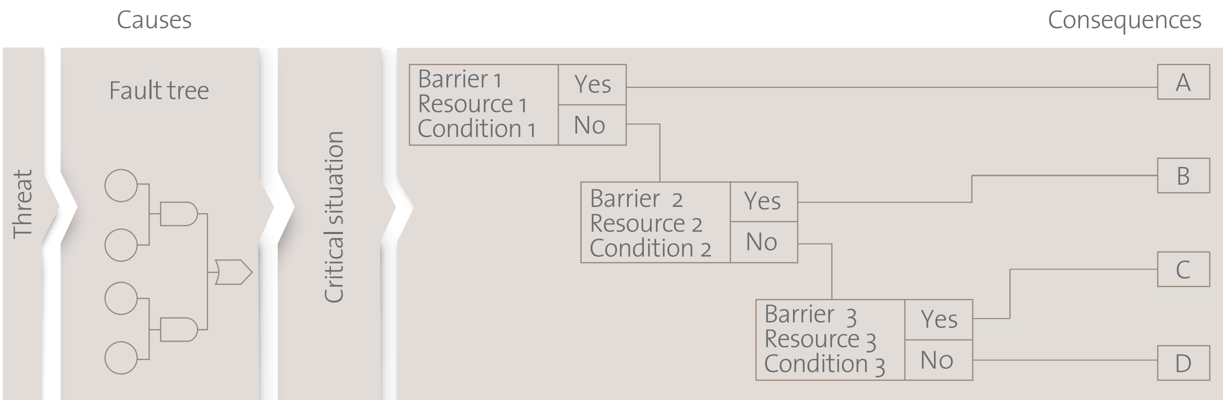



*Figure 19. Illustration for the bow-tie methodology for a critical situation including cause analysis with fault tree and consequence analysis.*

in normal situations, in either the summer or winter period, as long as other grid components are in service.
Energinet.dk is conducting similar analyses for Eastern Denmark. These analyses are expected to be completed in spring 2017.

### 3.4.2 Risk assessment for incidents which could affect system security

We have previously experienced blackouts in Denmark, and it is almost impossible to avoid it happening again. During unfortunate circumstances, there will always be a risk of system breakdown. The key is to prevent and limit the scope when it happens.

Prevention is primarily achieved through continuous improvements to the existing framework for operation of the electricity system, such as effective operating criteria, good management of reserves and properties required to maintain power system stability, rapid restoration following outages, smooth international cooperation and decision support through dynamic analyses and risk assessments.

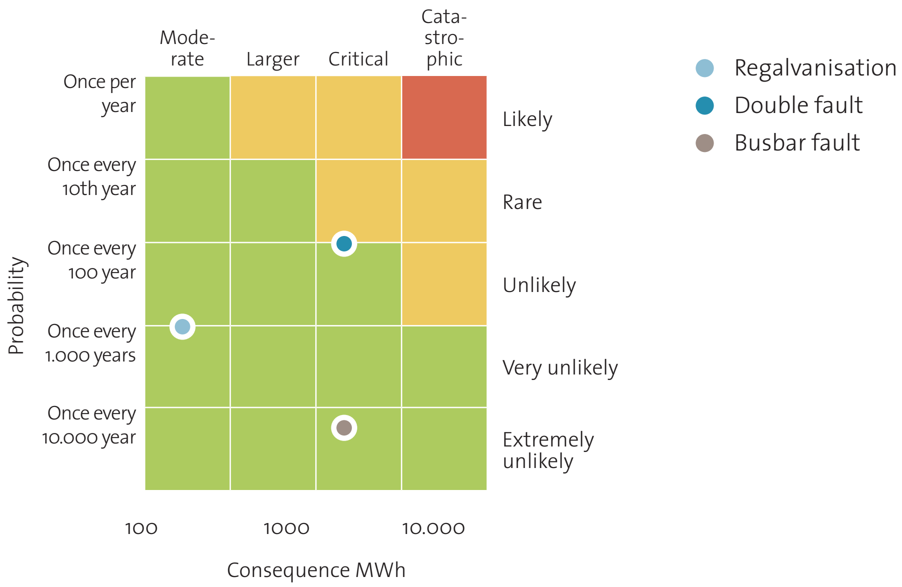



*Figure 20. Risk evaluation for each of the three critical situations for system security.*

Risk assessment for system security is based on broad analyses and selected critical situations. There is an endless number of critical situations that could lead to power outages. However, these situations are very unlikely and/or only lead to minor outages.

To assess the risk of rare incidents with major consequences, Energinet.dk uses a risk diagram in which critical situations are placed according to probability and consequence.

The risk assessments are based on three specific critical situations:

- A double fault.
- A busbar fault.
- A regalvanisation project.

The position of each situation in the risk diagram depends on the probability of the critical situation and its outcome. The analyses calculate the probability of a critical situation leading to a blackout etc.

Overall, the results show that the risk of the three situations ranges from low to medium. Previous analyses have not identified situations with a high risk. On this basis, system security in Denmark is considered to be good.

**Critical situation – 'double fault'**
This critical situation has been assessed as medium risk. The risk of this situation arising will be reduced within a few years by completing:

- A major maintenance project, being carried out for other reasons.
- A minor system protection initiative effected based on the risk assessment for system security.

**Critical situation – 'busbar fault'**
This situation has been assessed as low risk. The low risk is the result of initiatives implemented in recent years. Given the low risk, no further measures are deemed necessary.

**Critical situation – 'regalvanisation'**
The third situation analysed addresses the system security risk of a maintenance project involving regalvanisation of a series of towers.

The analysis considers a situation in which other projects are not occurring concurrently, reflecting coordination between projects. The project therefore does not impact on overall system security to the same extent as it would otherwise. This is because the maintenance period only covers a small portion of the year, and the system will be brought into a safe state before work commences. Coordinated planning of all necessary projects is thus essential for the sake of system security. Although the project has not been found to have a high system security risk, it increases the overall security of supply risk, as it involves limits on the Øresund connections, thereby increasing risk of a power shortage.

## 3.5 Outage planning

Daily operation of the electricity system must ensure that elec-

tricity generation and electricity consumption balance at all times. This requires that forecasts and operating plans be regularly updated in the leadup to each delivery hour. Part of this work involves outage planning for transmission and production facilities over 25 MW. This planning must ensure maintenance is scheduled in a way that allows operation to be maintained with sufficient security.

Energinet.dk has to approve outage periods for transmission and production facilities larger than 25 MW. Energinet.dk can change submitted maintenance and outage period requests prior to approval if they are deemed to threaten security of supply or impact on the functioning of the market unacceptably.

The system operator coordinates outage planning with international partners with respect to production facilities and grid maintenance in their regions.

The Danish electricity system, which is getting on in years, is currently being expanded with renewable energy. This means there will be a larger pool of grid and power station maintenance and renovation projects, at the same time as there are fewer power stations online in the electricity system. As a consequence, there is less flexibility in the timing of maintenance for transmission and production facilities. This heightens the importance of outage planning in the years ahead.

Outage planning is most extensive for the summer period, as most maintenance is requested at this time of year. CHP plants have compulsory heat production during the winter, and renovation is easier during the summer when outdoor working conditions are better.

Outage planning is carried out for:

- **2-6-year plan:** Long-term outage planning.
- **1-year plan:** Annual plan and plans closer to the day of operation.

**2-6-year plan**

Long-term outage is planned based on long-term plans for transmission and production facilities. The plan must ensure that known major maintenance work on transmission and production facilities which is mutually dependent is not planned to be carried out within the same year, but spread over several years. The plan also helps ensure maintenance plans are coordinated among TSOs.

The long-term plan does not show the complete picture, as it is not possible to know all maintenance needs so far in advance. The long-term plans are not binding and Energinet.dk cannot compensate for rescheduling of outage in relation to the long-term plan.

**1-year plan**

1-year planning is carried out twice a year for the coming year. The plan must ensure that more grid and production facilities is not taken out of operation than allows security of supply to be maintained. Where maintenance is rescheduled in relation to the 1-year plan, the player affected must be compensated. In addition to the long-term planning, the power stations sub-

## Projects of significance to maintenance planning in 2018

**Øresund 132 kV:** The project involves replacement of 132 kV cables across Øresund to Sweden, installed in the 1950s, which are in need of replacement. New cables are planned to become operational in early 2018. A brief outage period is expected during commissioning, as the new cables are being installed in parallel with the existing cables.

**Øresund 400 kV:** The project involves replacement of the four oldest 400 kV cables from 1973 across Øresund to Sweden. The original cables have reached the end of their technical service life due to corrosion. The Øresund 400 kV project will be organised by Svenska Kraftnät.

During replacement, original cables will first be removed, and then new cables installed. Energinet.dk therefore expects an outage period of approx. 2 months. The duration of the outage period is a key criterion in the impending call for tenders for delivery and installation of the cable, as the cable plays a key role in security of supply.

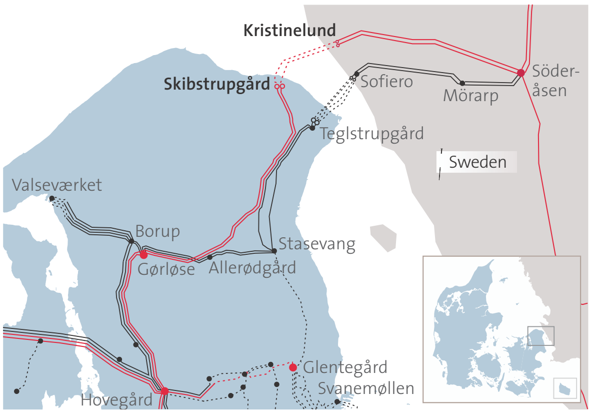


*Figure 21. Map of the power grid in Northern Zealand and the cables from Zealand to Sweden.*

This project is particularly important in relation to the power situation in Eastern Denmark. A delay in replacement of the cables will mean a longer period of operation in a weaker state, and thus a greater risk of unexpected faults and longer outage times. A long outage time significantly increases risk of outage for consumers on Zealand.

mit 4-week plans. Within 24 hours of the day of operation, forecasts for wind and solar power and local production are known, and the day's power balance can be estimated.
As part of its handling of the challenge, Energinet.dk is preparing a more detailed long-term maintenance plan than in the past to identify particularly challenging periods. The maintenance plan will then be adjusted to reduce the risk to the electricity system. At the same time, the already major focus on maintenance planning across borders will be maintained, so the outage plan also takes into account production and grid facilities maintenance in neighbouring regions.

In order to better prioritise between various maintenance projects which cannot all occur in the same period, Energinet.dk has begun formulating prioritisation principles based on economic criteria. The criteria must take into account the coming EU regulation on maintenance (GL SO) and market and supply-related aspects.

**Outage planning in 2018**
There is some construction work scheduled for 2018 which will have a major influence on security of supply. Replacement of the Øresund cables is particularly important, as this affects imports from Sweden. In addition, planned projects involving connection of a biomass-fired unit at the Amager Power Station, reinvestment in the Avedøre Power Station and cable laying operations will also impact on the security of supply risk.

Construction projects in Western Denmark may indirectly affect the power situation in Eastern Denmark via limitations on the Great Belt Power Link. This applies, for example, to the 400 kV east coast project in Western Denmark. Close coordination between projects in the east and west is therefore also an important part of outage planning, in order to avoid power shortages in Eastern Denmark.

**New framework for outage planning and its coordination**
There is a major focus on the coordination of maintenance planning in the coming EU regulation on system operation (GL SO). The regulation sets out a framework particularly for coordination between TSOs, and between players and TSOs.

Under the regulation, coordination must occur in future on an annual and weekly basis as a minimum. Planning by individual

## Joint Nordic office in Copenhagen

The new Nordic office is handling task within coordination of capacity calculations, outage planning and security analysis, as well as development of common grid models and short and medium term adequacy forecasts across the four countries.

The office will be fully operational by staffed with employees for the four Nordic transmission system operators.

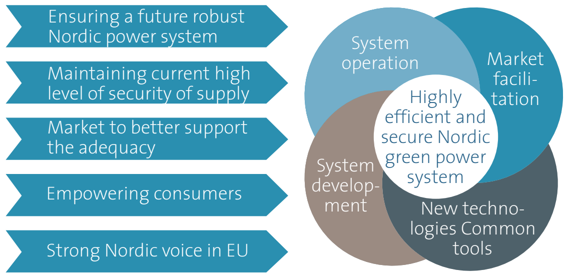



*Figure 22. Illustrations of the strategic collaboration areas between the Nordic TSOs.*

TSOs must commence up to two years prior to the annual coordination, by formulating indicative maintenance plans and identifying potential incompatibilities.

The more detailed principles for coordinating outage planning will be formulated for each coordination region jointly by players, TSOs and authorities. This process is expected to take place during second half of 2016.

## 3.6 Operational cooperation across borders

Denmark is becoming increasingly dependent on electricity imports from abroad and therefore benefits greatly from smooth operational cooperation across borders. Operational cooperation between the European TSOs is based on a common agreement framework. The agreement describes how to manage the operation of facilities and services.

The operation agreements are regularly refined to match changing market conditions, technological development, expansion of the electricity grid, changes in regulations, and experience from operating incidents.

Energinet.dk currently has operating agreements at Nordic level, with central European TSC, and bilaterally with all of Denmark's neighbouring countries. The Norwegian, Swedish, Finnish and Danish transmission companies' cooperation has become more formalised, most recently with the decision to establish a joint office in Copenhagen. The office is also in response to coming EU regulations which will require the establishment of Regional Security Cooperation Initiatives (RSCI) in the area of transmission.

In the European context, the coming network codes provide the foundation for ongoing operational cooperation. The network codes for operational cooperation have been gathered in 'Guideline System Operation' (GL SO).

**Guideline System Operation**
GL SO sets the framework for operation and operational cooperation in line with contents of existing system operational agreements. In GL SO, the system operator is responsible for maintaining security of supply during the operations phase. This means that in future Energinet.dk must maintain security of supply using tools which are based to a greater extent on European regulations. This will ensure more uniform tools for the European TSOs.

GL SO covers reserve scope criteria and the authority to determine the need for the various types of reserves, including properties required to maintain power system stability, in regional cooperation. GL SO also defines a number of information requirements related to status and operation which producers must submit to the TSO.

GL SO was adopted in the Cross Border Committee on 4 May. The GL SO must be approved by the European Parliament and will then enter into force in form of an EU regulation in late 2016.

It can also be expected that future European regulations will increase focus on the consumer in relation to security of supply. This applies in relation to incorporating consumer flexibility, setting objectives, and specifically, how consumers will be disconnected in crisis situations.

Consumer disconnection is mentioned in several network codes as a tool for maintaining security of supply. There is a focus on activating consumer flexibility in the markets in order to avoid involuntary consumer disconnections as far as possible. The rules governing how consumers are disconnected are specified in the NC DCC network codes for demand connection.

## 3.7 Information security

Greater use of information technology and information has created major development opportunities in the electricity sector, both in terms of business and technology. Their use is one of the key prerequisites for integrating large quantities of renewable energy into the European electricity system.
This stronger dependence on information technology also means greater vulnerability is built into the electricity system.

It is therefore relevant to expand the concept of system security to explicitly cover information security. A modern electricity system must be designed to prevent and withstand malicious data attacks, which could lead to a critical situation for electricity supply.

The three overall goals for information security are to ensure availability, integrity and confidentiality:

- **Availability:** Systems, data and information must be available when needed.
- **Integrity:** Data and information is complete and reliable and has not been distorted by unintended changes.
- **Confidentiality:** Data and information may be confidential and require protection from unauthorised access.

Historically, information security breaches have not had serious impacts on Danish electricity supply.

Energinet.dk has had a focus for several years on securing IT systems and training in contingency situations where systems are unavailable. Various system tests, controlled hacker attacks and information campaigns have been regularly conducted internally at Energinet.dk.

Energinet.dk believes there is a need for an even greater focus on information security throughout the entire value chain. This is because information technology is now vital to the operation of energy systems, and the threat situation has changed in recent years. This greater focus covers everything from system and server operation to culture and awareness among the

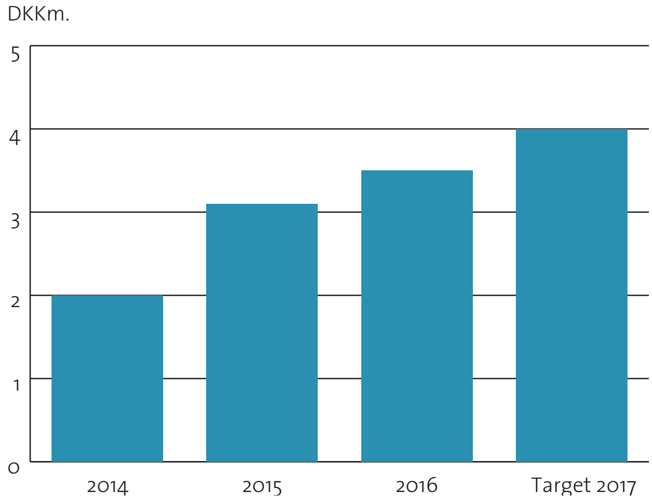



*Figure 23. Level of process maturity for IT security for 2014 and 2015, and targets for 2016 and 2017.*

companies' employees. The key to increasing information security is to understand that information security is anchored in and flows from management of the companies.

A few years ago there was a focus on protecting companies' IT systems through antivirus software. Additional and more complex information is now being shared, and much of the defence has been advanced to the other side of the companies' firewalls. It is therefore necessary to increase information security requirements for all players involved in the sector.

**Initiatives for supply-critical IT**
The Danish strategy for cyber and information security has kicked off a number of initiatives aimed at improving supply-critical IT. In the electricity sector this has resulted in:
- workshops being held to identify players' mutual dependencies
- the initiation of preliminary legislative work aimed at amending the Danish Electricity Supply Act
- work on amending Danish Executive Order no. 1024 of 21 August 2007 on preparedness, to have a greater focus on supply-critical IT.

There are initiatives at the European level aimed at harmonising and simplifying the rules of communication among players in the electricity market – both nationally and internationally. These initiatives focus to a major extent on improving supply-critical IT.

**ISO 27001**
Energinet.dk measures IT security based on the ISO 27001 IT security standard. Energinet.dk had the goal that maturity at Energinet.dk should be above aver-age by the end of 2015.

At the end of 2015, it was PWC's assessment that:
- Energinet.dk reached its goal for 2015.
- Energinet.dk is in a good position to reach the ongoing maturity goal for 2016 of 3.5.

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