MEMO

NATIONAL RISK ASSESSMENT 2018 – DENMARK

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1. Introduction

1.1 Regulation 2017/1938

The risk assessment at national and regional level is an element in complying the security of gas supply Regulation (EU) 2017/1938 (“the Regulation”) – Article 7 Risk assessment and article 5 Infrastructure standard.¹ The Risk Assessment Report is prepared by the Danish Transmission Operator, Energinet, in cooperation with the Competent Authority – the Danish Energy Agency. The purpose of the infrastructure standard is to check whether the gas system is capable of delivering the necessary capacities in case of interruption of the largest infrastructure in order to supply all gas customers on a cold day with exceptionally high demand (with a statistical probability of once in 20 years). This is done indicative with the N – 1 formula. Furthermore, on the basis of the N – 1 formula, the purpose of the risk assessment is to assess all relevant risk factors which may affect the security of gas supply. For the Danish gas system, the basis of the risk assessment is the demand on a cold day with an average temperature of -13°C.

Energinet has prepared the risk assessment for the Danish competent authority, the Danish Energy Agency. The risk assessment must be notified to the Commission by 1 October 2018.

The risk assessment shall be updated at least every four years, i.e. the risk assessment will be updated no later than 1 October 2022. Thus this risk assessment covers the period where the most important source of gas to the Danish and Swedish gas market (the Tyra complex in the North Sea) is shut down due to reconstruction. The reconstruction will take place from November 2019-July 2022 but the supply from the North Sea will gradually start to decrease from March 2019. The risk assessment also covers the coming winter 2018/2019 where the Danish gas market is supplied with gas both from the North Sea and Germany. However, the focus of this risk assessment has been on the reconstruction period. The Risk Assessment focus on descriptions of the tight supply situation as foreseen in the period 01.01.2020 – 31.12.2021. In this period almost no gas will flow from the North Sea, and the simulations has been prepared on the basis of the expected infrastructure and supply situation for that period. As the renovated Tyra complex is planned to come on stream in July 2022 the supply situation is expected to be significant improved with delivering of capacity from to large infrastructures and two gas storage facilities. Furthermore, if investment decision is taken by the end of 2018 the Baltic Pipe-project will deliver significant further capacity to the Danish and Swedish market and access to new gas sources from Norway.

This risk assessment will form the basis of both the preventive action plan including the necessary measures for mitigating the identified risks, cf. Articles 8 and 9, and of the emergency plan, which will include measures to be taken to eliminate or mitigate the consequences of a disruption of the gas supply, cf. Articles 8 and 10.

1.2 Conclusions Danish risk assessment

The single largest infrastructure is identified as Inter Connection Point (IP) Elllund – the single source of supply in the analyzed period. The N – 1 calculation shows that Denmark complies with the infrastructure standard in the period of reconstruction of the Tyra complex when the investment in expansion of the Lille Torup storage facility is completed in 2019 before the shut

down of the Tyra complex: \( N - 1 = 100 \% \), compared to 88 % if the Lille Torup storage facility is not expanded.

The identified main risks during the reconstruction of the Tyra complex are:

1) Incidents that affect the supply to Denmark:
   a. Technical incidents in the northern German transmission system
   b. An EU gas supply crisis

2) Incidents that affect the functioning of the Danish gas system:
   a. The Stenlille storage facility
   b. The Egtved compressor station
   c. The pipeline Egtved to Dragør.
   d. Failure of the Interconnection point Dragør (supplies to Sweden, see Swedish Risk Assessment Plan)

1.3 Conclusions from regional risk groups

1.3.1 Risk Group Denmark (Denmark, Germany, Luxembourg, Netherlands and Sweden)

Denmark and Sweden are facing a period where the supply may be tight in the event of exceptional high demand or in case of a serious technical incident due to the forthcoming reconstruction of the Tyra complex in the Danish North Sea. Denmark and Sweden will from November 2019 to July 2022 be almost fully dependent on gas supplies from Germany via the interconnection point Ellund.

ENTSOG’s SoS simulations (volume incidents, not sudden hydraulic incidents) based on a technical interruption of all supplies from Germany under normal weather conditions indicate that it will be possible to supply the Danish and Swedish market. It is a precondition that the market actors has sufficient gas in storage to handle such a critical situation.

Energinet and Gasunie Deutschland has analyzed a situation where 35 % of the gas supply from Germany is interrupted. Even with reduced supply from Germany it will be possible to supply the Danish and Swedish market for 30 days in cold weather conditions.

The worst case will be a situation with no supplies from Germany due to a technical failure. In such a situation it will not be possible to supply the total Danish and Swedish market and it will be necessary to immediately declare Emergency in Denmark and Sweden in order to reduce the consumption and thereby ensure supplies to the protected marked in Denmark and Sweden.

In order to mitigate the risks the following steps has been taken:

- Investment in increased withdrawal capacity at Lille Torup storage facility to be completed in 2019
- Energinet has been in dialog with Gasunie Deutschland (GUD) on technical issues to increase the firm capacity at Ellund. This resulted in an extra 1 GWh/h offered by GUD in a PRISMA auction in July. The capacity was not booked. However, GUD has decided to increase the capacity, which will be available for the distribution company in Schleswig-Holstein. The capacity available in Ellund to Denmark and Sweden offered by GUD today (2018), continues to be available.
1.3.2 Risk Group Baltic Sea (Austria, Belgium, Czech Republic, Denmark, France, Germany, Italy, Luxembourg, Netherlands, Slovakia and Sweden)

Denmark is solely connected to continental Europe at the Inter Connection Point (IP) Ellund at the German border. In principal Denmark can import H-gas original from either the Netherlands, Germany, Norway or Russia. In the period of renovation of the Tyra complex Denmark (and Sweden) is almost 100% relying on available transport capacity in the German transmissions system and sufficient firm capacity at IP Ellund.

The conclusion of the analyses in Risk Group Baltic Sea is, that the Member States’s infrastructure is well developed and inter connected in the region. The simulations show no effects on the Danish as well as the Swedish market. Various transport routes and gas resources are available to ensure the gas supply in the Risk Group. In addition there is access to a large number of storage facilities with large working gas volume capacities and withdrawal capacity. The available storages capacity is mainly used for seasonal and daily balancing of the system as well as emergency supply.

The German gas infrastructure is an important key to the European gas transport system as the German system can deliver gas in all directions from North to South and East to West. Furthermore, planned investment measures in the gas infrastructure play an important role to further improvement of security of gas supply. The majority of the investment measures in Germany have a direct positive impact at the various IP’s capacities to adjacent Member States. Additional transport capacity creates opportunity for the market actors and allows varying routes and access to sources of supply.

A positive impact on the security of supply has the liquid gas markets in this region. The TTF in the Netherlands as well as the market areas Gaspool and Net Connect Germany are among the trading points with the highest liquidity in Europe.

The region fulfils the N-1 standard. The calculation was performed for two entry points into the region, Greifswald as well as Velke Kapusany. Both calculations show that the region lies well above the 100%. This will in the future even be further improved due to investment in the infrastructure.

The Risk Group did not identify a particular high risk exposure. Of course, risks exist and cannot be excluded with certainty. Especially technological risks can cause several infrastructure failures as recent events in Baumgarten have shown. But at the same time it is important to highlight that significant levels of resilience are built into the region’s infrastructure. In the further analysis representative scenarios and disruption duration have been defined in order to cover a wide bandwidth of potential consequences of risks and failures.

The analysis showed that every Member State of the Risk Group is in a position to handle the effects of these disruptions scenarios with the existing infrastructure and access to alternative sources including access to storage facilities. The capacity reduction would not cause any demand curtailments of customers. The missing capacity can be compensated by other means such as alternative import points, LNG, storages etc. Also, the analysis showed that the Member States could handle these disruption scenarios with their own means. No repercussions on neighboring Member State have been identified.

The resilience of the North-West European gas network is supported by indigenous production, imports and storage, and underpinned by a mature and liquid gas market which has
demonstrated its ability to deliver even during the most extreme combination of infrastructure failure and increased demand.

1.3.3 Risk Group Norway (Belgium, Denmark, France, Germany, Italy, Ireland, Luxembourg, Netherlands, Slovakia and Sweden)

The analyzes demonstrates that gas supply infrastructure is resilient to all and the most unlikely combinations of supply shocks. The upper ends of supply ranges are sufficient to maintain supplies to protected consumers in all scenarios.

Based on the analysis conducted Norwegian gas supplies may be considered as reliable for the foreseeable future. Nevertheless the foreseeable decline of Norwegian production from a current level of 122 bcm to a level of around 90 bcm/y in 2030 may be taken into account when preparing measure related to the future security of gas supply.

This analysis is the first one, and further analysis may benefits from:

- Detailed exchanges with Gassco on impact of an outage of production facilities in Norway and simulation of its impacts of flows;
- More detailed analysis on the impact of a disruption on gas flows within the group;
- Interactions with other risk groups.

To avoid duplications of data from the Baltic Sea Risk Group and Risk Group Norway for further informations about the analyzes in carried out in the groups please see the final reports.
2. The Danish gas system

2.1 Description of the Danish gas system

The Danish gas system (Figure 1) consists of gas production facilities and pipelines in the Danish part of the North Sea, a transmission system, where gas is transported across the country, and a distribution system, where gas is delivered to the gas customers. Moreover, the gas system consists of a gas treatment facility (Nybro), two underground storage facilities (Stenlille aquifer and Lille Torup salt caverns) and a compressor station (Egtved). The compressor station at Egtved has been constructed in order to enable transport of gas from Germany to Denmark.

Figure 1: The Danish gas system

The Danish gas system has three physical entry/exit points (Nybro, Ellund, Dragor) where gas can be supplied to or from the Danish gas market. Ellund is the only point with physical reverse flow. Furthermore, there are a number of virtual entry/exit points for gas traded within the system (bilateral contracts or gas exchange) and for upgraded biogas (BNG).

From Nybro (landfall of Danish North Sea gas) and Ellund (Germany), the gas is transported to customers in Denmark and Sweden or stored at one of the two underground storage facilities.

The Danish and Swedish gas market is primarily supplied with gas from the Danish part of the North Sea. Since 1987, the Tyra complex has been the most important source of supply for Danish and Swedish gas consumers. The Tyra complex has sunk approx. 5 meters since its establishment and waves are getting higher and more powerful. Therefore, the owners of the Tyra complex DUC (Danish Underground Consortium) has decided to reconstruct the platforms in the period November 2019-July 2022 in order to continue to produce gas in the Danish part of the North Sea in the future.

As a consequence, the Danish and Swedish market will not be supplied with gas from the Tyra complex in the reconstruction period. Only a small amount of gas will be supplied from the South Arne field to Nybro. The main supply source will be gas import from Germany via Ellund. Furthermore, Denmark will also be supplied with indigenous production of BNG.
2.2 Key infrastructure relevant for the security of supply

Key infrastructure in Denmark with Tyra in production:
- North sea production and the Nybro facility (Nybro Entry)
- Stenlille storage facility

Key infrastructure in Denmark without Tyra in production:
- Ellund Entry
- Stenlille storage facility
- Egtved compressor station
- Lille Torup storage facility
- Pipeline Egtved – Dragør

2.2.1 Descriptions of key infrastructure

Today in 2018 most of the gas on the Danish market comes from the Danish gas fields in the North sea. Furthermore, the Nybro facility ensures the right pressure when the gas enters the system. An interruption at the production facilities or the Nybro facility could lead to a curtailment of the main source of gas in normal years with the Tyra complex in production.

ENTSOG has in their Security of Supply Simulation Report from 2017 pointed at Ellund as critical for the supply in Denmark and Sweden during the reconstruction of the Tyra complex. During the reconstruction period Ellund is the only supply source in the region. The point has also been analyzed in the regional risk assessment for Denmark and Sweden where an interruption of the compressors in Quarnstedt (Northern Germany) could lead to reduced capacity at Ellund.

The Stenlille storage facility is critical for the gas supply east of the Egtved compressor station (East Denmark and Sweden) during periods with extraordinary high demand due to an internal bottleneck. If the Stenlille storage facility is interrupted, it might be necessary to reduce the flow to some of the Danish non-protected customers and to Sweden.

The Egtved compressor station ensures the necessary pressure to transport the gas east of the compressor station (East Denmark and Sweden). During the reconstruction of the Tyra complex the Egtved compressor station becomes essential to ensure the gas supply to the customers. An interruption of the Egtved compressor station can lead to the same consequences as an interruption of the Stenlille storage facility.

The Lille Torup storage facility will be expanded in 2019 prior to the reconstruction of the Tyra complex. This means that the Lille Torup storage facility can ensure a larger withdrawal rate during the reconstruction period. The Lille Torup storage facility can therefore improve the integrity of the system if the supply from Germany should fail. An interruption of the Lille Torup storage facility is not expected to lead to a reduced supply to the Danish customers and Sweden.

The pipeline Egtved – Dragør is located east of the Egtved compressor station. A breach on the pipeline can have several consequences for the customers in East Denmark and Sweden. However, the probability of a breach is little as the repair time is estimated to be short and there is two pipelines crossing the belts (Little Belt and Great Belt).
Table 1: Capacities and utilization of the gas transmission system in 2017

<table>
<thead>
<tr>
<th>Point</th>
<th>Capacity mcm/day</th>
<th>Maximum daily flow 2017 mcm/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nybro</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entry</td>
<td>32.4(^1)</td>
<td>14.0</td>
</tr>
<tr>
<td>Ellund</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entry/Exit</td>
<td>10.8(^2)/20.0</td>
<td>4.9/5.2</td>
</tr>
<tr>
<td>Drager Border</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exit</td>
<td>7.2(^3)</td>
<td>4.7</td>
</tr>
<tr>
<td>The Danish Exit zone</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exit</td>
<td>25.5</td>
<td>16.7</td>
</tr>
<tr>
<td>Lille Torup Gas Storage Facility(^4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injection</td>
<td>3.6</td>
<td></td>
</tr>
<tr>
<td>Withdrawal (100 %)</td>
<td>8.0</td>
<td></td>
</tr>
<tr>
<td>Withdrawal (30 %)</td>
<td>8.0</td>
<td></td>
</tr>
<tr>
<td>Injection/Withdrawal</td>
<td>3.8/7.6</td>
<td></td>
</tr>
<tr>
<td>Stenlille Gas Storage Facility(^4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injection</td>
<td>4.8</td>
<td></td>
</tr>
<tr>
<td>Withdrawal (100 %)</td>
<td>8.2</td>
<td></td>
</tr>
<tr>
<td>Withdrawal (30 %)</td>
<td>8.2</td>
<td></td>
</tr>
<tr>
<td>Injection/Withdrawal</td>
<td>4.8/6.3</td>
<td></td>
</tr>
</tbody>
</table>

Note 1: Total capacity of the receiving terminals at Nybro. The potential supplies are smaller today as the Tyra-Nybro pipeline is subject to a capacity constraint of approx. 26 million Nm\(^3\)/day, and large volumes cannot be supplied from the Syd Arne pipeline.

Note 2: At a calorific value of 11.2 kWh/Nm\(^3\).

Note 3: The Swedish system is not designed to receive the firm capacity at the assumed minimum pressure at Dragør of 44 barg in normal operation (Interconnection agreement).

Note 4: The Danish storage company dimensions the commercial injection capacity conservatively in relation to the pressure in the gas transmission grid. When the pressure occasionally increases, it is possible to inject more gas into the storage facilities than the specified injection capacity.

2.3 The role of the Danish gas storage facilities

The storage facilities are usually filled up during the summer when gas consumption is low. When it gets colder and consumption exceeds the daily gas deliveries from the North Sea, the deliveries are supplemented by gas from the storage facilities. In addition to seasonal leveling, trading in gas may have an effect on gas export and import and consequently on withdrawal from and injection into the storage facilities. The storage facilities are also used for emergency supply.

The withdrawal capacities of the Stenlille and Lille Torup gas storage facilities are today 8.2 mcm/d and 8.0 mcm/d respectively (Table 1) in situations with both full storage levels (100 %) and low storage levels (30 %). The total volume of working gas in the storage facilities is approx. 890 mcm. In 2020 the working volume will be reduced by approx. 12% as the storage facilities are filled with gas from Germany with a lower heat value.

Reconstruction of the Tyra complex 2019-2022

In April 2016, Maersk (today TOTAL) announced that the Tyra complex is sinking and that a solution is to be found which either involved permanent or temporary shutdown to secure Danish gas production for many years to come. DUC (Danish Underground Consortium) and the Danish Government concluded an agreement on 22 March 2017 enabling a reconstruction of the Tyra complex in the North Sea. TOTAL has subsequently announced that Danish gas production will be reduced considerably in the period 2019-2022 during which the reconstruc-
tion will take place. The reconstruction will imply considerably reduced production since 90 per cent of Danish gas production passes through the Tyra complex.

During the reconstruction of the Tyra complex, Denmark and Sweden will depend on gas imported from Germany and on supplies from the two Danish gas storage facilities. To secure the supply of gas to the Danish and Swedish consumers it is necessary that the market actors make optimal use of the import and storage volume capacity.

The Danish and Swedish gas consumers will continue to be supplied during the reconstruction of the Tyra complex. Nevertheless, the gas system will get more vulnerable and less flexible if the demand becomes unusually high or a technical incident occurs that may reduce the supply to the consumers.

Different measures to improve the supply situation has been analyzed. The analysis has lead to the decision to increase the withdrawal capacity from 8.0 mcm/d to 10.3 mcm/d at the Lille Torup storage facility in 2019 before the start of reconstruction of the Tyra complex.

Further measures will be increased information to and dialogue with the market actors, for instance by regularly publishing system information for them to act on and by facilitating incentive regulating market initiatives.

2.4 Gas consumption

Gas is consumed by a number of different sectors in Denmark: households, industry (including service industries), district heating and electricity generation. Furthermore, gas is consumed in oil and gas production in the Danish North Sea. In 2016, the total gas consumption including the gas used for production in the North Sea was approx. 3.1 bcm.

[All figures should be updated with new data.]

Figure 2: Gas consumption by sector, 2016

Source: Energinet based on data from the Danish Energy Agency.

The natural gas consumption in Denmark, excluding oil and gas production, in 2017 was 2.5 bcm. After having declined for many years, the Danish annual gas consumption has been relatively stable the last couple of years.
Figure 3: Total Danish gas consumption, 2014-2017

Source: Energinet based on data from Energinet and the Danish Energy Agency.

The total natural gas and BNG consumption in Denmark (Figure 4) is expected to fall to about 1.7 bcm in 2030. The natural gas consumption is expected to fall to about 1.3 bcm in 2030. Consumption of biogas and bio natural gas is expected to grow from the present level of approx. 0.3 bcm to approx. 0.4 bcm in 2030.

Figure 4: Forecasted demand and supply, 2018-2040

Source: Energinet based on data from the Danish Energy Agency.

2.5 Gas production, import and export

The Danish gas production (Figure 5) is an important part of the Danish and Swedish gas market since it covers the gas demand most of the year. Denmark and Sweden used to be dependent on gas supplied from the North Sea but investments in the Danish gas system have enabled import of large amounts of gas from Germany. This has made the Danish and Swedish gas market less dependent on the Danish gas production.
The Danish gas production has decreased significantly since its peak (9-10 bcm annually 2005-2007). The system is therefore capable of transporting large amounts of gas to the Danish market. The capacity at the entry point for the gas production at Nybro is 32.4 mcm/day. However, the maximum daily flow was 14 mcm/day in 2017.

**Figure 5: Forecasted Danish North Sea gas production**

Source: Energinet based on data from the Danish Energy Agency.

The total reserves in the North Sea are forecasted by the Danish Energy Agency. The total reserves have been generally increased from 2022, due to changed resource assessments on ongoing recovery and several expected developments of existing fields and new discoveries. The expected reserves have been significantly increased but contribution from technological reserves and prospective reserves has been reduced.

The Danish annual production still exceeds the annual Danish and Swedish consumption (except the period of renovation of the Tyra complex). Denmark thus continues to be a net exporter of gas on an annually basis. The Danish production is either exported directly to the Netherlands or transported to Denmark where it is consumed by Danish customers, stored in storages and exported to Sweden and Germany.

**Figure 6: Annual net production distributed on flow, 2014-2017**
2.6 The role of gas in the electricity production

About a quarter of all thermal power plants in Denmark use natural gas or biogas as the main type of fuel (Figure 7). Several of these units are combined units which can use different kinds of fuel. The actual use of fuel is determined by current fuel prices, electricity prices and also the current taxation scheme. Based on the possibility of gas consumption about 35% of installed capacity is capable of using gas for production of power.

Figure 7: Thermal power Installed capacity per main fuel type

Source: Danish Energy Agency statistics, Energiproducenttællingen

Almost all gas fired power plants are cogeneration units producing power and heat for either district heating or industry. About half the installed gas fired capacity is based on a small scale combined heat and power plants (CHP) producing heat for local communities. There are approximately 460 units with an average size of 2.9 MW.

Figure 8: Power plants which can use natural gas in DK

Source: Danish Energy Agency statistics, Energiproducenttællingen

All gas fired power plants, except for some industrial and very small units sell the electricity production on the day-ahead electricity spot market. Power prices vary through the day and the year depending on electricity demand, availability of renewable energy and many other factors.
parameters. The gas fired power plants optimize revenue by mainly producing electricity when prices are above a certain level. Small scale CHP units use a large heat accumulator in order to produce electricity independent of demand for heat. The small CHP units are able to start, stop and regulate power production very quickly. In addition to a heat accumulator, the large CHP units are also equipped with a condensation turbine which allows them to produce electricity without heat production. This gives the large units a larger degree of flexibility compared to the smaller CHP units. However, the larger units are slower to regulate and start and stop production compared to the small scale CHP units.

The current outlook for the gas fired capacity is a reduction in capacity. The larger units are being supplemented or converted to biomass. The capacity to use gas as a fuel will remain, but the expectation is a reduced demand for natural gas. A large share of the small scale CHP units are expected to be shut down and replaced with other heat producing units: mainly biomass, heat pumps and solar heating. The capacity for producing electricity using gas is thus expected to decline significantly the next years. The drivers for this development are: low electricity prices and a relative higher taxation on heat based on fossil fuels compared to heat from biomass or electricity. This is a general trend in the Danish electricity system, power plant capacity is expected to be reduced and other sources of flexibility are used to balance load and production. The role for power plants gas fired and others is expected to decrease significantly
3. Infrastructure standard

3.1 N – 1 formula

Each Member State shall according to the Regulation ensure that in the event of a disruption of the single largest infrastructure the necessary measures are taken in order to continue to supply the gas market. This is the infrastructure criteria. The impact of a disruption on supply is determined by the N – 1 formula:

According to the Regulation\(^2\), “the N – 1 formula describes the ability of the technical capacity of the gas infrastructure to satisfy total gas demand in the calculated area in the event of disruption of the single largest gas infrastructure during a day of exceptionally high gas demand occurring with a statistical probability of once in 20 years.”

The N – 1 formula

\[
N - 1[\%] = \frac{EP_m + P_m + S_m + LN_{m} + I_m}{D_{\text{max}}} \cdot 100, N - 1 \geq 100 \%
\]

\(D_{\text{max}}\) The total daily gas demand of the calculated area (Danish market) during a day of exceptionally high gas demand (20 year incidence)

\(EP_m\) Total technical capacity of all entry points that can supply the calculated area, excluding production, storage and LNG facilities

\(P_m\) Maximum technical production capacity that can supply the calculated area

\(S_m\) Maximum technical withdrawal capacity from storage facilities in the calculated area

\(LN_{m}\) Maximum technical send-out capacity at all LNG facilities in the calculated area

\(I_m\) Technical capacity of the single largest infrastructure with the highest capacity to supply the calculated area

3.1.1 The single largest infrastructure

This national risk assessment covers a period, where the main source of gas in Denmark, the Tyra complex, will be reconstructed and the gas supply capacity to Denmark will therefore be significantly reduced.

The main gas source during the reconstruction period is imported gas from Germany. The single largest infrastructure for Denmark is therefore the Ellund entry point.

3.1.2 Calculation of the N-1 formula for Denmark

Energinet is currently looking at different initiatives that can be implemented in order to strengthen the system and increase flexibility during the reconstruction of Tyra. One of these initiatives is an increase of the storage withdrawal capacity at Lille Torup storage facility which has been initiated.

The calculation of N – 1 for Denmark has therefore been done both with the current capacities and with the increased storage withdrawal capacity.

\(^2\) Annex II Calculation of the N – 1 formula
The calculation of \( N - 1 \) should according to the Regulation be based on two different storage volume levels: 100 \% and 30 \%. However, the Danish gas storage facilities are able to yield the same withdrawal capacity irrespective of these storage volume levels.

Energinet reserves strategic volumes for Emergency (less than 30\% of the maximum storage volume) both for short and long term incidents, in order to ensure that the necessary withdrawal capacity to handle an Emergency incident is available at all times.

The parameter values based on the current capacities are shown in the table below.

### Table 2: Demand and capacities before realization of initiatives

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mcm/d</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( D_{\text{max}} )</td>
<td>19.5</td>
<td>Total daily gas demand on an exceptional cold day (20 year-incidence with an average temperature of -13(^{\circ})C). The Danish gas demand is expected to be 19.5 Mcm/d (including BNG).</td>
</tr>
<tr>
<td>( E_{\text{P,m}} )</td>
<td>10.3</td>
<td>Total technical capacity for all entry points that can supply the calculated area, excluding production, storage and LNG facilities. The value of this parameter is equal to the entry capacity at the Danish side of the Ellund point based on the maximum existing capacity at the German side (the capacity at the Danish side is much higher).</td>
</tr>
<tr>
<td>( P_{\text{m}} )</td>
<td>1.0</td>
<td>Maximum technical production capacity. The forecast for the gas production in the Danish part of the North Sea is used instead of the maximum technical production capacity. In the period 2020-2022 the value of this parameter is expected to decrease significantly from 10.1 Mcm/d to 0.5 Mcm/d. Furthermore, ( P_{\text{m}} ) includes the Danish biogas production, which is expected to be 0.5 Mcm/d in 2020 (BNG).</td>
</tr>
<tr>
<td>( S_{\text{m}} )</td>
<td>16.2</td>
<td>Maximum existing technical withdrawal capacity from all storage facilities. The value of this parameter is the sum of the withdrawal capacity at the two Danish storage facilities: Stenlille 8.2 Mcm/d and Lille Torup 8.0 Mcm/d. The withdrawal capacities for the two storages are the same irrespective of a storage level of either 30 % or 100 % of the maximum working volume.</td>
</tr>
<tr>
<td>( \text{LNG}_{\text{m}} )</td>
<td>-</td>
<td>Maximum technical capacity at all LNG facilities. There are no LNG facilities connected to the gas grid in Denmark.</td>
</tr>
<tr>
<td>( I_{\text{m}} )</td>
<td>10.3</td>
<td>Technical capacity of the single largest infrastructure. Danish Ellund Entry point.</td>
</tr>
</tbody>
</table>

### Calculation of \( N - 1 \)

\[
N - 1[\%] = \frac{10.3 \text{ mcm/d} + 1 \text{ mcm/d} + 16.2 \text{ mcm/d} + 0 - 10.3 \text{ mcm/d}}{19.5 \text{ Mcm/d}} \cdot 100 = 88\%
\]

The parameter value for the increased storage withdrawal capacity (\( S_{\text{m}} \)) is shown in the table below.

### Table 3: Storage withdrawal capacity after expansion of Ll. Torup storage facility

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mcm/d</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( S_{\text{m}} )</td>
<td>18.5</td>
<td>Maximum existing technical withdrawal capacity from all storage facilities. The value of this parameter is the sum of the withdrawal capacity at the two Danish storage facilities: Stenlille 8.2 Mcm/d and Lille Torup 10.3 Mcm/d. The withdrawal capacities for the two storages are the same irrespective of a storage level of either 30 % or 100 % of the maximum working volume.</td>
</tr>
</tbody>
</table>
Calculation of N – 1 with increased storage withdrawal capacity:

\[ N - 1[\%] = \frac{10.3 \text{ mcm/d} + 1 \text{ mcm/d} + 18.5 \text{ mcm/d} + 0 \text{ mcm/d}}{19.5 \text{ mcm/d}} \cdot 100 = 100\% \]

A summary of the results from the calculations of N – 1 are shown in the table below.

### Table 4: Results

<table>
<thead>
<tr>
<th>Largest infrastructure: Ellund</th>
<th>( I_m ) (mcm/d)</th>
<th>N – 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>N – 1 without expansion of the Lille Torup storage facility</td>
<td>10.3</td>
<td>88 %</td>
</tr>
<tr>
<td>N – 1 with expansion of the Lille Torup storage facility</td>
<td>10.3</td>
<td>100 %</td>
</tr>
</tbody>
</table>

The calculation of N – 1 for Denmark shows that \( N - 1 < 100 \% \) in the scenario without expansion of the withdrawal capacity at the Lille Torup storage facility but \( N – 1 \) become \( \geq 100 \% \) in the scenario where the withdrawal capacity has been expanded in 2019. Therefore, when the withdrawal capacity is increased Denmark will comply with article 5 (Infrastructure standard) of the Regulation during the period of reduced Danish national production due to the reconstruction of the Tyra complex.

#### 3.1.3 Basic assumptions for hydraulic simulations of the Danish gas transmission system

The Danish gas transmission system is connected to the German and Swedish gas transmission systems via interconnection points (IP) Ellund and IP Dragør. The hydraulic dynamic in the Danish transmission system is dependent on the hydraulic situation in both the German and Swedish system. In order to simulate the robustness of the Danish system it is necessary to make some basic assumptions regarding flows and pressure at these two IP’s. The flow assumption in the analysis is based on the expected off take at different points in the system on a cold day with exceptionally high demand. Thus the flow in the simulation mirrors an extreme situation and might be different from a “real life” situation.

The hydraulic simulation of the N – 1 calculation estimates the “survival time” of the Danish transmission system, which is the period until the system reaches minimum specifications for the pressure at different points in order to supply all customers and fulfill the required pressures.

#### 3.1.4 Hydraulic simulations of sudden incidents

Simulations of the N – 1 calculations above for Denmark have been done in a hydraulic model. Furthermore, a number of other simulations for different scenarios of sudden interruption have been done. All scenarios have been simulated both with the current withdrawal capacity at the Lille Torup storage facility (“no expansion”) and with the expected increased withdrawal capacity (“with expansion”). This section presents the results of the simulation of the following scenarios:

1. 0 % flow from IP Ellund, no expansion of the Lille Torup storage facility
   a. 24 hours simulation of the N – 1 calculation (0 % flow from IP Ellund)
   b. 72 hours simulation of 0 % flow from IP Ellund
2. 0 % flow from IP Ellund, with expansion of the Lille Torup storage facility
   a. 24 hours simulation of the N – 1 calculation (0 % flow from IP Ellund)
   b. 72 hours simulation of 0 % flow from IP Ellund
3. Reduced flow at IP Ellund (expected minimum 65 % of the firm capacity), no expansion of the Lille Torup storage facility
4. Reduced flow at IP Ellund (expected minimum 65 % of the firm capacity), with expansion of the Lille Torup storage facility
5. 24 hours with 0 % flow from the Stenlille storage facility, no expansion of the Lille Torup storage facility
6. 24 hours with 0 % flow from of the Stenlille storage facility, with expansion of the Lille Torup storage facility

The following assumptions have been made:

- In all scenarios the flow to IP Dragør is at least 0.2 mcm/d, which corresponds to the expected consumption of the protected customers in the Swedish gas system. Flow to IP Dragør is set to 0.2 mcm/d after 5 hours.
- In the case with 0 % flow from Stenlille the flow from IP Ellund is increased to 100 % of the firm capacity after 3 hours.
- Flow from storage is set to maximum withdrawal capacity 3 hours after flow from IP Ellund or the Stenlille storage facility is set to 0 %
- The simulations run over 24 and 72 hours respectively
- The model applies estimated off take at the various points during a day with exceptional high demand (the one in twenty years incident with -13°C)

### Table 5: Summary of the hydraulic simulations of the 6 scenarios defined above

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
<th>24 hours</th>
<th>72 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The calculation of the national N – 1 = 88 %. The survival time of the gas system is 21 hours.</td>
<td>The flow to the Danish customers has to be reduced to 87 % of the base case flow. After 5 hours the flow at IP Dragør is set to 0.2 mcm/d (equal to the supply to the protected costumers in Sweden).</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>The calculation of the national N – 1 = 100 %. The survival time of the gas system is 25 hours. (N – 1 is fulfilled nationally.)</td>
<td>In this scenario it is possible to supply Danish consumption when the withdrawal capacity at the Lille Torup storage facility is expanded. The possible flow at IP Dragør after 5 hours is 4 % of the base case flow in IP Dragør (0.3 mcm/d).</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>If the flow in IP Ellund is set to 65 % of firm capacity (which is the expected minimum flow at IP Ellund) it will be possible to supply Danish consumption. The possible flow at IP Dragør is 78 % of the base case flow in IP Dragør (5.2 mcm).</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>If the flow in IP Ellund is increased to 65 % of firm capacity (which is the expected minimum flow at IP Ellund) it will be possible to supply Danish consumption and maintain the flow in IP Dragør.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Supply from the Stenlille storage facility is interrupted for a period of 24 hours</td>
<td>In this scenario it is possible to supply Danish consumption. However, to keep the pressure within the specifications for 3 days the flow at IP Dragør is reduced after 5 hours to 39 % of the base case flow in IP Dragør. After 19 hours the base case flow is fully restored (24 hours after the 0 % flow from the Stenlille storage facility).</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Supply from the Stenlille storage facility is</td>
<td>In this scenario it is possible to supply Danish consumption. However, to keep the pressure within the specifications for 3 days the flow at IP Dragør is reduced after 5 hours to 39 % of the base case flow in IP Dragør. After 19 hours the base case flow is fully restored (24 hours after the 0 % flow from the Stenlille storage facility).</td>
<td></td>
</tr>
</tbody>
</table>
interrupted for a period of 24 hours. However, to keep the pressure within the specifications for 3 days the flow at IP Dragør is reduced after 5 hours to 66 % of the base case flow in IP Dragør. After 19 hours the base case flow is fully restored (24 hours after the 0 % flow from the Stenlille storage facility).

### Table 6: Results of simulations over 72 hours

<table>
<thead>
<tr>
<th>Scenarios – flow compared to base case flow (%)</th>
<th>Supply DK exit</th>
<th>Supply IP Dragør</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 % curtailment at Ellund, no Ll. Torup expansion</td>
<td>87 %</td>
<td>3 %</td>
</tr>
<tr>
<td>100 % curtailment at Ellund, with Ll. Torup expansion</td>
<td>100 %</td>
<td>4 %</td>
</tr>
<tr>
<td>65% supply from Ellund, no Ll. Torup expansion</td>
<td>100 %</td>
<td>78 %</td>
</tr>
<tr>
<td>65% supply from Ellund, with Ll. Torup expansion</td>
<td>100 %</td>
<td>100 %</td>
</tr>
<tr>
<td>24 hours interruption of Stenlille, no Ll. Torup expansion</td>
<td>100 %</td>
<td>39 %</td>
</tr>
<tr>
<td>24 hours interruption of Stenlille, with Ll. Torup expansion</td>
<td>100 %</td>
<td>66 %</td>
</tr>
</tbody>
</table>

#### 3.2 Bi-directional capacity

##### 3.2.1 Bi-directional capacity Denmark-Germany

Bi-directional capacity is established between the Danish and the German gas system in Ellund. In both directions the capacity is restricted by the capacity in the German system. From Denmark to Germany the firm capacity is 8.2 mcm/day. From Germany to Denmark the firm capacity is 10.3 mcm/day.

##### 3.2.2 Bi-directional capacity Denmark-Sweden

Sweden is only supplied with gas from IP Dragør, with no physical reverse flow possibilities from Sweden to Denmark established. The technical capacity from Denmark to Sweden is 8.6 mcm/day whereof 7.2 mcm/day is firm capacity.

In the interconnection agreement between Energinet and Swedegas a minimum pressure of 44 barg is assumed at Dragør where the Swedish transmission system can receive less than the firm capacity.
4. Identification of risks and risk assessment

A number of risk scenarios for the Danish gas system has been identified and analyzed. The period analyzed is the period with significant reduced flow from the North Sea due to the reconstruction of the Tyra complex.

As regards scenarios which can be identified as critical disruptions of the gas supply may be caused from one of the four entry points. The expected consequences of the scenarios and the probability of them occurring have been described. The results of this analysis can be found in Annex A (confidential).

The risks can be summarized as follows:

1) Incidents that affect the supply to Denmark: Import from Ellund.
   a. Technical incidents (sudden incident): An example of an incident that may affect the flow in Ellund is an interruption of the German Quarnstedt compressor station which might reduce the capacity in Ellund or cause a breach of the transmission pipelines.
   b. EU supply crisis: There is also a risk that the supply in Denmark will decrease due to gas shortage. An EU gas supply crisis could lead to a reduced flow of gas from Germany. This scenario may have a higher impact on the Danish gas market during the reconstruction of the Tyra complex compared to the situation today.

2) Incidents that affect the functioning of the Danish gas system (sudden incidents): The transmission system including the Egtved compressor station and the two storage facilities. Due to an internal bottleneck in the system the gas supply to the eastern part of Denmark and Sweden are more vulnerable. Examples of incidents that may affect the supply to the eastern part of Denmark and Sweden are an interruption of the Stenlille storage facility, the Egtved compressor station or the pipeline Egtved to Dragør.