Scenario analysis of gas crisis using the European Gas Assessment Model (EUGas)

Nuria Rodriguez-Gomez, Nicola Zaccarelli, Kwabena Pambour, and Ricardo Bolado-Lavin

Institute for Energy and Transport, Joint Research Centre, European Commission, Westerduinweg 3, 1755 LE, Petten, the Netherlands, http://iet.jrc.ec.europa.eu/

**Corresponding Author e-mail:* Nuria.RODRIGUEZ-GOMEZ@ec.europa.eu *Phone:* +31 (0)22456 5212

Abstract

The European Gas Assessment model (EUGas) is a country level model of the European gas transmission pipeline network which is being developed by JRC-IET (Joint Research Centre – Institute for Energy and Transport). The model aims at supporting Directive 2008/114/EC on "the identification and designation of European Critical Infrastructure (ECI)" and Regulation 994/2010 on "measures to safeguard security of gas supply". The hydraulic model of the European gas network is developed using a combination of commercially available software. SynerGee Gas allows solving the steady state condition of a gas network under different load conditions. Within SynerGee Gas, a module based on ESRI ArcGIS Desktop, is able to import GIS data in various formats and specify a suitable geographic coordinate system to carry out the simulation and calculating the geometric parameters. EUGas was originally created in 2008 for 3 countries (Czech Republic, Slovakia and Hungary). Currently EUGas covers 20 country models (Finland, Sweden, Denmark, France, Luxemburg, Belgium, Portugal, the Netherlands, Germany, Poland, Latvia, Estonia, Lithuania, Czech Republic, Slovakia, Hungary, Austria, Romania, Bulgaria, and Greece) and it is an on-going effort of updating and integrating up to the 26 countries with gas systems that comprise the European Union. The model is needed not only to assess national risks but also to better understand cross-border bottlenecks and the regional consequences of a national crisis. The paper presents the scenario analysis carried out for Denmark and Sweden region. The gas networks of these countries are interconnected. Moreover Sweden relies completely on the gas supplied by Denmark; thus, Sweden supplies may be affected in the event of a gas disruption in the Danish network. EUGas model has been used to run scenarios of gas disruption under peak-demand conditions in this region. The paper will show the importance of considering not only the high pressure transmission pipelines but also the medium pressure lines which are proved to provide resilience to the network in the event of gas disruptions.

1. Introduction

Since 2008, the Energy Security, Systems and Market Unit, Institute for Energy and Transport - Joint Research Centre, has been actively involved in the development of an integrated environment for modelling national natural gas transmission systems (NNGTSs) of EU Member States. An integrated European model of the gas transmission network is needed to properly evaluate the national risk assessments of the Member States. The main benefit of using a European model, rather than 26 individual ones[1], is that the regional implications of a national gas disruption can be assess to better understand cross-border bottlenecks and the regional consequences of a national crisis. Therefore the "European Gas Assessment" (EUGas) model is being designed:

- to test the resilience of gas transmission networks under different scenarios of stress, crisis or disruption;
- to support the application of Directive 2008/114/EC on "the identification and designation of European Critical Infrastructure (ECI)";
- to provide numerical tools to assess "Risk Assessment" (RA) (art. 9) and standards (art. 6 and 8) of Regulation (EU) No 994/2010 of the European Parliament and of the Council of 20 October 2010.

[1] From 28 Member States, all are natural gas consumers but Malta and Cyprus.

The development of EUGas is carried out by the integration of three different modules: a Geographic Information System (GIS) module, a scenario creation module and a hydraulic network module. All three modules can exchange data in a way to ensure "feature consistency" and "topology consistency" (Zaccarelli et al. 2013). The first module, implemented by ArcGIS Desktop version 10.1©(ESRI, 2012), performs all necessary data pre-processing in order to have a topologically correct network composed of nodes (i.e., entry and exit points of gas) and branch lines. The scenario creation module is a database composed of spreadsheets for each Member State, where data concerning the demand/supply are stored, managed and processed based on specific rules for gas allocation to nodes. The last module is the hydraulic numerical solver engine based on SynerGee Gas© version 4.7.1 (GL Noble Denton, 2013). The module creates an explicit 3D hydraulic model and solves the steady state condition of the gas network under different load and environmental conditions (passed by the scenario creation module). A detailed description of EUGas is provided by Zaccarelli et al. of the proceedings of this Conference.

One of the main challenges when building EUGas is finding and aggregating reliable data. The contribution from the Transmission System Operators (TSO) is surely needed when details of the actual operational regime are crucial in order to evaluate the risk associated to a disruption. For instance, knowing the existence of duplicated infrastructure, the availability of back-up fuel in compressor stations or the operational pressure limits of the gas network, is essential to solve a crisis scenario with the simulation tools.

The EUGas is a country level model of the European gas transmission pipeline network which was originally created for 3 countries (Czech Republic, Slovakia and Hungary) in 2008 (pride, 2008). Up to now it is composed of approximately 5.000 nodes and 6.500 pipelines, and it covers 20 Member States (i.e., Finland, Sweden, Denmark, The Netherlands, Germany, Poland, Latvia, Estonia, Lithuania, Czech Republic, Slovakia, Hungary, Austria, Romania, Bulgaria, Greece, France, Belgium, Luxemburg and Portugal). At the end of 2014 it will be extended up to the 26 countries with a high pressure gas grid that comprise the European Union.

2. Disruption scenarios based on the Danish and Swedish gas transmission network

The Danish and Swedish gas transmission network has been used to illustrate how the EUGas model developed can be used to simulate disruptions of the gas network. The Danish natural gas network consists of approximately 860 km of 80 bar pipelines, two entry points (i.e., Ellund and Nybro), two underground storage facilities (i.e., Lille Torup in the North and Stenlille in the East), forty-two and 42 measuring and regulator stations. The main entry point is in the upstream pipelines in the Danish part of the North Sea that deliver gas to Nybro in the West coast of the country. From Nybro, gas can be sent to national consumers, stored in Denmark or exported to Germany or Sweden. All the natural gas consumed in Sweden comes via Denmark through a pipeline that stretches Denmark and Sweden at Dragør cross border point (Figure 1).

Figure 1. ENTSO-G map of the gas transmission network of Denmark and Sweden (Source: ENTSOG 2014).

Table 1. Gas production, consumption, import and export data for 2012.

Country	Production (mcm)	Consumption (mcm)		Import (mcm)	Exports (mcm)
		Total	Consumption for power generation		
Denmark	6416	3899	1727	255	2985
Sweden	-	1130	544	1130	-

Source: IEA (2014b)

The Swedish transmission grid consists of 620 km pipelines, 41 measuring and regulator stations and 6 gas metering stations located in the southwest part of Sweden. It is to the Danish gas system with a maximum cross border capacity of 73 GWh/day. The pipeline interconnection is from Dragör in Denmark to Klagshamn in Sweden. The transmission system is connected to an UGS, Skallen storage facility, located in the west coast close to Halmstad. The storage has a volume of 10 mcm which corresponds to 120 GWh. The size of the storage does not allow seasonal storage but is limited to peak shaving services (Figure 1).

In Denmark the demand for natural gas decreased from 4.2 bcm to 3.2 bcm from 2011 to 2012, with the bulk of gas consumption (42%) used for power generation in the transformation sector. Industry made up the second largest group, representing 19% of gas use, while the energy sector, where gas is used for oil extraction, represented another 16% (IEA, 2014a; Energinet.dk, 2014).

Three gas fired power plants are directly fed with gas from the high pressure grid (e.g., Avedøre Power Station, H.C.Ørstedsværket Power Plant and Skærbækværket). In 2013, a compressor station in Egtved and a new pipeline from Egtved to Ellund have been put in place, so to increase the flow to East during winter and to the South during summer.

In Sweden, nearly 55% of all gas is used by 9 cogeneration plants (CHP and district heating), while only around 2% is for smaller consumers (i.e., households), considered as protected costumers (IEA, 2014a). Table 1 provides a general description of the demand/supply of natural gas for the region.

The EUGas hydraulic model consists of the following facilities: 184 pipes (42 of which are medium-pressure pipes), 23 regulators and 1 compressor station. The beginning and the end of a facility is delimited by a node. The nodes in the model can be nodes of positive flow, negative or zero. A zero flow node means that no gas exits nor enters in the network through that node. A positive flow indicates that certain volume of gas is entering through that node which means the node is a source node. If a node has a negative flow it means the node is a demand node and therefore gas is exiting the network via that point.

Two different scenarios have been simulated with EUGas. The first scenario simulates the normal operation of the network of Denmark and Sweden under peak-demand conditions, by using only the high pressure grid of the region. The second scenario simulates the case of the disruption of a gas pipeline in the Danish network that may have implications for Sweden, by showing the role of the medium pressure grid. Allocation of demand to the off-take points is based on the peak daily demand for the gas year 2010-2011 (data kindly provided by Energinet.dk) for Denmark, while for Sweden values are estimated proportionally to the main features of the Municipalities served by the grid (i.e., power and heating facilities, population and industry). As values used refer to the gas year 2011-2012, the compressor station in Etgved, and the new pipeline from Ellund are disabled in the EUGas model.

3. Results

In this first scenario the medium-pressure pipelines have been ignored. There are 5 supply sources of this scenario: Nybro entry point, Ellund cross border point and the three storage facilities of the region. The supply sources are represented with a green circle in Figure 2.

The volume of gas that flows at the cross border points and storages of the region may vary and be dependent on the seasonal demand. EUGas uses maximum capacity figures at cross-border points as constraints for the model (i.e., no feasible solution is considered when the gas flow values are higher than the ones declared). Values are obtained the ENTSOG "Transmission Capacity map" for the year 2012 (ENTSOG, 2012), and the GSE "Gas storage 2012" map (GSE, 2012). In this scenario gas flows from Germany to Denmark through Ellund cross border point. In other scenarios gas flows reverse from Denmark to Germany. The total demand of the region was 28.5 mcm/d (21.1 mcm/d are consumed in Denmark and 7.4 mcm/d in Sweden). Table 2 provides the values obtained for some reference points along their constraints.

The second scenario simulates the disruption of a high pressure gas pipe between Køge and Karslunde, before the metropolitan area of Copenhagen (Figure 3). The event has been simulated firstly looking only at the high pressure transmission network, and from this it is obvious that the disruption leads to an isolation of the Eastern area from the rest of the network (see Figure 3). The supply sources of the isolated area are the Stenlille underground storage in Denmark and the small Skallen storage in Sweden. The maximum withdrawal capacity of these is not enough to ensure the demand of the area when the disruption occurs in a peak day. EUGas model has been used to estimate that 6.5 mcm/d would not be satisfied in case the disruption of Figure 3 occurs.

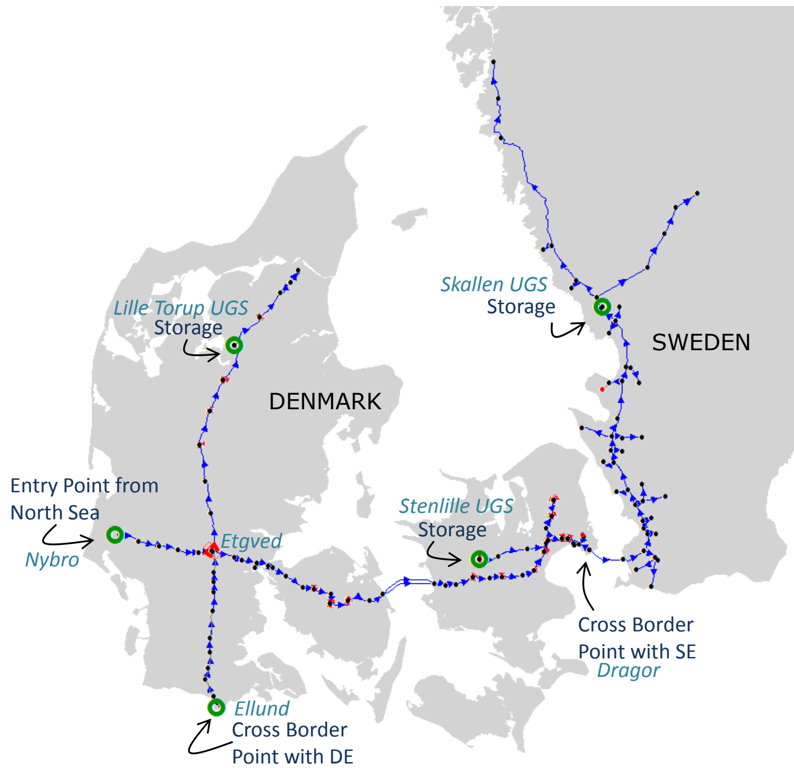

Figure 2. Gas network model of Denmark and Sweden built in SynerGee© Gas software.

Table 2. Summary of results of Scenario 1 (normal operation under peak-demand conditions)

Cross Border Point	Entry Point from	To	Pressure (bar)	Flow (mcm/d)	Max. Capacity – July 2012 (mcm/d)*
Nybro	North Sea	DK	80.0	19.2	32.4
Ellund	DK	DE		-	3.40
	DE	DK	72.0	1.6	2.36
Dragor	DK	SE	59.8	6.7	8.67
	Storage				Maximum withdrawal capacity (mcm/d)**
Stenlille	DK		62.4	5.4	8.2
Lille Torup	DK		66.8	1.6	8.0
Skallen	SE		53.9	0.7	0.9

*** Source: ENTSOG map (2012**)   ** Gas Storage Europe (2012)

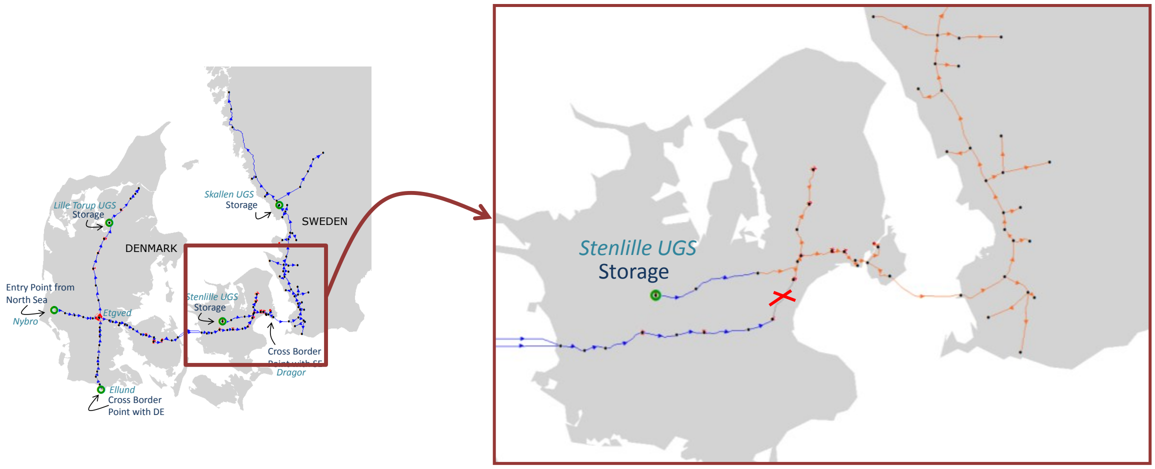

Figure 3. Scenario 2: disruption of a pipeline in a highly populated

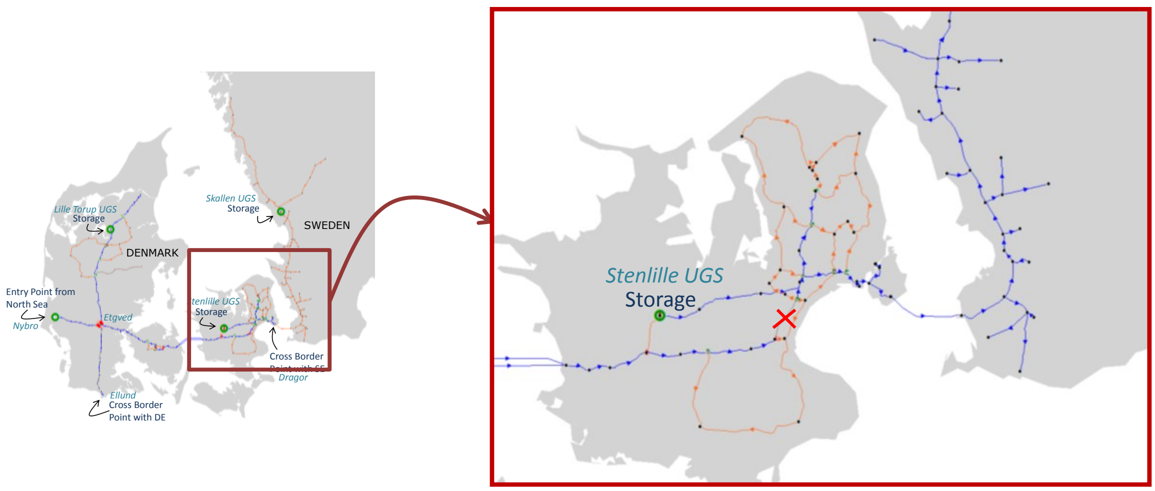

Figure 4. Scenario 2: disruption of a pipeline in a highly populated when the medium pressure lines (in orange) and included in the model.

Table 3. Summary of results of Scenario 2 (disruption of a high pressure pipe under peak-demand conditions)

Cross Border Point	Entry Point from	To	Pressure (bar)	Flow (mcm/d)	Max. Capacity – July 2012 (mcm/d)*
Nybro	North Sea	DK	80.0	16.7	32.4
Ellund	DK	DE		-	3.40
	DE	DK	74.0	1.5	2.36
Dragor	DK	SE	32.0	6.5	8.67
	Storage				Maximum withdrawal capacity (mcm/d)**
Stenlille	DK		43.0	7.7	8.2
Lille Torup	DK		65.8	1.6	8.0
Skallen	SE		21.1	0.9	0.9

* Source: ENTSOG map (2012) ** Gas Storage Europe (2012)

However, we will be overestimating the consequences of such a disruption by only taking into consideration the high pressure lines of the Danish gas transmission network. A gas network is comprised of transmission and distribution pipelines. Transmission pipelines transport natural gas across long distances, usually from production wells and storage facilities to a distribution centre. Distribution pipelines are the middle step between high pressure transmission lines and low pressure service lines that deliver natural gas to individual customers. In some gas networks, transmission pipelines can be divided into high pressure pipelines and medium pressure pipelines. In these cases, it is essential no to ignore the medium pressure lines when building a hydraulic model of the gas transmission network since this grid of pipelines may have enough capacity to transport the needed gas to solve a crisis event.

This is the case of the Danish gas transmission network. When considering the gas transmission network of Denmark the most usual picture of the gas network is the given in Figure 1 and Figure 2. However it is unarguable that the medium pressure transmission pipelines in Denmark give the system greater flexibility, especially in scenarios as the simulated in Figure 3.

Figure 4 demonstrate the effect of taking into account the presence of the medium pressure grid for scenario 2. The pipelines in orange transport gas at a pressure between (maximum) 50 and 25 bar, and they highly increase the connectivity of the network, providing alternative path for the gas.

The model is able to find a feasible solution that satisfied the total demand in Denmark (21.1 mcm/d) and strongly support Sweden (7.4 mcm/d), though with a consistent drop in the pressure (from 59.8 bar to 32.0 from scenario 1 to 2) which can affect some off-take points. The role of the medium pressure pipelines is central to transport gas from West Denmark to the East and still provide gas to Sweden. The results obtained with EUGas model has been summarized in Table 3.

4. Conclusions

A hydraulic model of the 26 gas countries of the European Union is being developed by JRC-IET. The model considers the gas transmission network of high and medium pressure to analyse the impact of gas crisis at national and at regional level. Using as an example the gas network of Denmark and Sweden, it has been shown the importance of the medium pressure pipelines to solve successfully gas disruption events. The omission of these pipelines in the model will yield to an overestimation of the consequences of a crisis.

Disclaimer note

DG-JRC does not endorse any commercial software mentioned in the paper. The opinions express by the Authors in this document are theirs alone and do not necessarily represent those of the DG-JRC, nor of other EU Institutions.

5. References

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