Identification of the main contributors to the security of supply in a gas transmission network

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Abstract: The paper presents a study of security of gas supply quantification by probabilistic metrics and focuses on identification of the main risk contributors. The paper illustrates the use of probabilistic gas network (ProGasNet) simulation tool on a selected part of EU gas infrastructure. The results show that the whole selected region is well supplied under baseline scenario A when all gas sources are operational. However, complete loss of supply via pipelines (scenario D) is the worst case scenario for the region and further network development projects are needed. The main contributor analysis identifies a short pipeline (3,11) as the most important network element. Other main risk contributors are gas supply sources: Node 19 and Node 10.

Keywords: Gas transmission network, critical infrastructures, security of supply, maximum flow.

1. INTRODUCTION

Energy security remains among the priorities in the EC policy agenda. The EU economy strongly depends on imported natural gas from a few main gas suppliers. Furthermore, the EU Member States have very different natural gas networks, some of them historically connected to receive supply from a single source. The new initiatives of Energy Union, energy security strategy and Connecting Europe Fund are in place to identify weaknesses in the supply routes and propose and implement solutions. The EU regulatory framework is being constantly reviewed and updated. The new EU Regulation 2017/1938 [1] of the security of gas supply which replaces Reg 994/2010 since October 2017 reinforces the solidarity principle among the Member States of the EU to share the available gas supplies in case of emergency situations.

The European Commission Joint Research Centre provides a technical support to policy initiatives by developing models and performing technical analysis of natural gas networks in Europe. Among the models under development, a Probabilistic Gas Network (ProGasNet) simulator is one of the in-house tools used to simulate security of supply problems in gas networks. The approach is based on Monte Carlo simulations and graph theory. The ProGasNet Simulator is being developed as an extended version of GEMFLOW simulation tool [2]. The ProGasNet simulator has already been used for a number of problems, like bottleneck analysis [3], importance analysis, time-dependent storage analysis, effect of new infrastructure. This paper presents for the first time the main contributor analysis to the security of supply in a realistic gas network of several EU Member States. The results can help to prioritize the network development plans, target protection measures or simply raise awareness for the network operators.

2. THE MODEL

The ProGasNet simulator is the JRC in-house developed software tool which is currently in use at the Joint Research Centre of the European Commission. The ProGasNet is applied for security of supply analyses of selected European gas transmission networks. The ProGasNet runs a modified maximum flow algorithm for each network configuration to distribute available gas from supplying nodes to consuming nodes taking into account pipeline capacity constraints and limitations. The model is not running hydraulic gas flow computations, but uses results of hydraulic computations as a set of rules to define flow limitations. The ProGasNet simulates network facility failures (pipeline ruptures, failures of compressor stations, unavailability of LNG terminals and storages) by Monte Carlo method and each different network configuration is evaluated by modified maximum flow algorithm to evaluate available gas for each network consuming node. The statistical results are obtained from 1 million of Monte-Carlo runs. The ProGasNet tool provides probabilistic results of the network ability to meet its demand and such results can be used either as absolute values to compare among different networks or in qualitative terms to choose between better or worse options.

2.1. The ProGasNet model input parameters

The transmission network GIS data are converted into a graph by creating nodes and links (edges). The nodes are:

- Demand nodes (consumers, typically pressure reduction stations of the network to connect to distribution network);
- Compressor stations;
- Supply nodes (storages, LNG terminals, import points at cross-borders)

The network links are typically pipelines. The model explicitly considers two parallel pipelines as two components (double links between nodes) and not a single pipeline of equivalent diameter. The model uses pipeline maximum capacity value to compute the maximum possible flow through each pipeline section between the nodes. The flow direction is determined by the model where bi-directional flow is possible, but in case reverse flow is not possible due to physical constrains, it must be specified in the capacity matrix. The length of each pipeline connection must be provided.

The node data entered in the model depend on the node type. The demand nodes require only daily demand value. This value used in this paper is peak demand value, but it could be also average winter or summer consumption value depending on the purpose of the model. The data were provided by the transmission system operators.

The compressor station node is modelled as working or failed, for each state determining the corresponding capacity of the outgoing pipelines. The capacity reduction due to compressor station failure is normally estimated by hydraulic model computations or expert evaluation.

The data for supply nodes are the maximum daily output values asprovided by transmission system operators. The model in this study uses maximum storage discharge capacity, but equally well smaller discharge capacity values can be analysed corresponding to lower storage availability (time-dependent analysis).

The data for the model are selected to represent the worst winter situation with peak demand situation for a 1-day period. Therefore, the model uses physical capacity values and not contracted (firm) capacity values thus enabling to analyse physically possible supply routes. The model however could be used to analyse average/summer low/ summer high supply regimes with any capacity level of storage or LNG terminal.

2.2. Reliability data

For each network component, failure data must be provided. The following network components are considered for failures: pipelines, compressor stations, storage facilities and LNG terminals. The pipeline import points are not considered as failure-prone elements due to lack of upstream network model, however they are modelled as binary on/off elements in the scenario analysis. It should be noted that the model structure allows to analyse any partial pipeline import capacity availability, not only 0 or max (on/off as indicated above), this choice (e.g. 10, 50 or 80%) depends on the analysis performed. In this study binary on/off approach was used with the primary purpose to evaluate the importance of the most critical supply sources. The model uses annual failure data (probability of failure per year), however when simulations are performed, one month interval is considered. It is assumed that the same peak consumption in the network is constant during this one month period. All multiple failures are assumed to occur at the time, although the sampling is performed during 1-month period thus introducing conservatism (overestimation) to the results. It is common practise that modelling assumptions are chosen conservatively in the risk assessments and similar studies. The reliability estimates are obtained from EGIG pipeline reliability database (for pipelines), reliability studies (for storage facility and compressor stations) or expert estimations (LNG terminal).

2.3. Computational engine

The ProGasNet model estimates consequences by applying a maximum flow (MF) algorithm. This algorithm has been tested on gas transmission networks of several EU countries and the results compared with complex hydraulic calculations. The results match quite well for the network of limited size. The mathematical description of the MF problem is a standard problem in graph theory. More details on the computational engine are given in [4].

2.4. Simulation results and their use

The ProGasNet model results are the following:

- Probability estimate of gas supply of any volume in each network demand node or in selected parts of the network. As cumulative distribution function is computed, we can estimate probability of having less than any volume between 0 and maximum required volume of gas. By default, the model outputs the following probability estimates:
  - Having no gas at all;
  - Having less than 50% of the demanded gas;
  - Having less than 80% of the demanded gas;
  - Having less than demanded gas.
- Information about utilization factor of pipelines and occurrence frequencies during the simulation runs;
- Information failures or their combinations in the network causing the least available gas volumes for supply.

The following types of analysis can be performed by using the above results:

- Analysis to quantify security of supply situation and identify the weakest nodes and links in the network
- Supply disruption analysis
- Evaluation of new facilities or pipeline connections in the network from the security of supply point of view
- Vulnerability analysis
- Bottleneck analysis

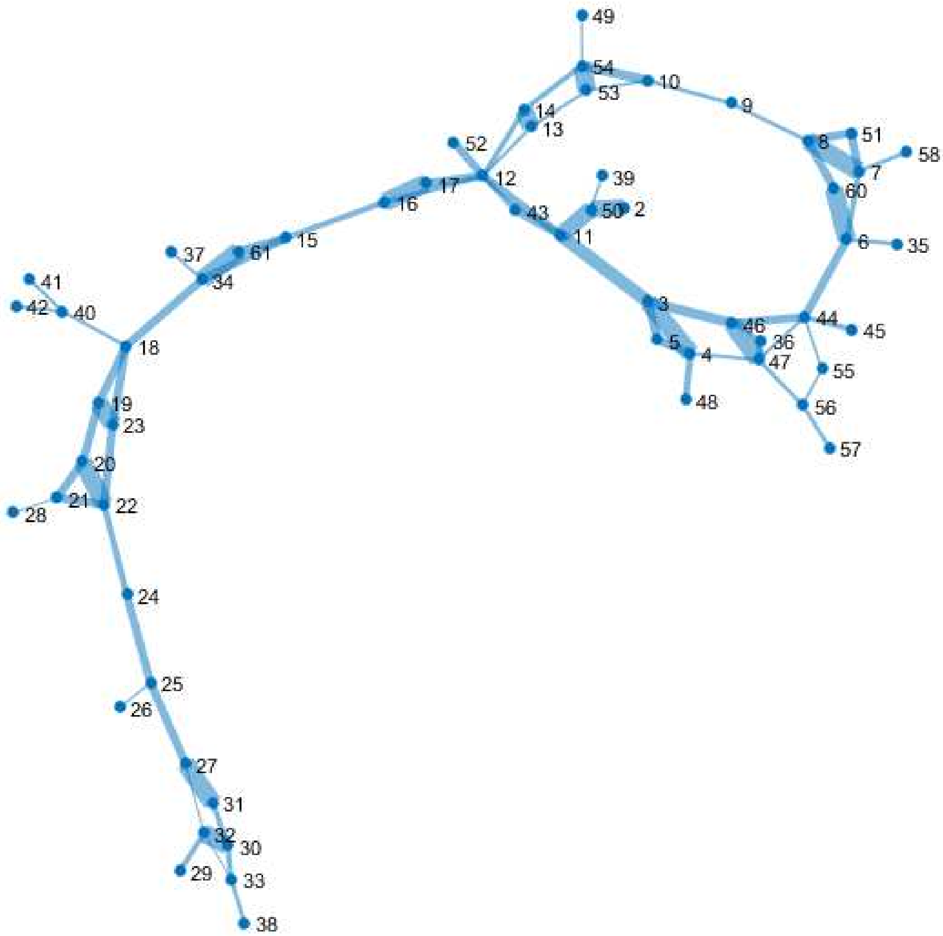
3. STUDY CASE

3.1. Network topology and demand

The network topology is given in Figure 1. It is a gas transmission network of several EU member states that is anonymized due to sensitivity of the information. The gas transmission network was simplified for computational purposes in the ProGasNet model however all major consuming nodes were maintained. The network is under strong development and many new infrastructure development projects were implemented in the last decade. Several very important projects are currently under design and preparation. The network topology reflects the most recent changes in the configuration and the model allows to evaluate the effect of new infrastructure projects and quantify changes in the security of supply situation.

Due to space limitations the numerical network data are not provided in the paper. The data can be found in references [3-4]. The total network demand is estimated to be 41.6 mcm/d (millions of cubic meters per day), 8.4 mcm of which are exported to third countries.

Figure 1: Topology of the gas transmission network. Line thickness is proportional to capacity.



3.2. Network capacity

Table 1 provides capacity data of the network supply sources. The same table gives failure frequency estimates. Note that pipeline sources do not have failure frequencies (N/A) due to reasons discussed in section 2.2, other sources have different frequencies for total loss of supply or partial loss of supply. The Node 19 failure estimate comes from a confidential reliability study of the facility. Node 10 failure estimate is an expert estimation based on available open literature. The total maximum capacity of sources in the network is 73 mcm/d.

Table 2 gives approximation of the pipeline capacity for different diameters [5]. The network has different sizes of pipelines as indicated in Table 2. Note that some pipelines have large capacity, but the connecting supply sources have smaller capacities and therefore the large capacity pipelines cannot be fully utilized.

3.3. Supply scenarios

In total 4 supply scenarios were analysed in this study. The supply scenarios are developed in order to evaluate effect of failure of a single or multiple pipeline sources for which no upstream model is available.

Scenario A: All sources available. Scenario A represents basic scenario when all sources can be used for supply.

Scenario B: All sources available, except Node 2 entry point. Scenario B runs the model with node 2 entry point unavailable. This scenario can test the system when the largest supply source is unavailable.

Scenario C: All sources available, except Nodes 29 and 38 entry points. Scenario C models situation when supply to one specific part of the network is unavailable.

Scenario D: Nodes 2, 29 and 38 are unavailable. Scenario D assumes that all source nodes with pipeline connections are unavailable. This is very unlikely scenario, but used in the study to analyse the resilience of the network to withstand a supply disruption from one single type of supply – via pipelines. In this scenario only LNG and storage supply sources are available.

Table 1: Gas sources, capacities and failure frequencies

Node	Capacity C, mcm/d	Failure frequency, yr^{-1}
2	31	N/A
19	26	f(C=0)=4.6E-02 f(C=15)=6.25E-02
29	4	N/A
10	10	f(C=0)=8.3E-02 f(C=5)=0.125
38	2	N/A

Table 2: The relationship between capacity and diameter

Pipeline diameter, mm	Capacity, mcm/d
1200	49.2
1000	30.6
800	17.1
700	12.1
600	8.1
500	5.1
400	2.8
350	2.0
300	1.3
250	0.83
200	0.47

3.3. ProGasNet model validation with hydraulic model

The ProGasNet model was undergoing validation process by using SynerGEE natural gas model. For the validation exercise, 10 different scenarios were tested and computed by using SynerGEE natural gas model.

In overall view, the results from SynerGEE model and from ProGasNet show similar lack of supply volumes. The main differences arise from the fact that ProGasNet is not able to check the pressure in the system and to detect when the pressure drops below the required level although the flow is sufficient to supply the gas. From this validation exercise it can be concluded that apart from some exceptional and rare cases, ProGasNet simulates the network rather well, however from this validation study no quantitative measure of the model accuracy could be derived.

4. THE RESULTS

The ProGasNet model is run for 1 million times and probabilistic estimates gas supply in the network are obtained. The same results can be presented in different ways: we provide probability table and empirical cumulative distribution function (CDF) plots in the section. Both types of the results are obtained from the same statistical sample, but given in different format.

The model results reflect the supply situation computed over a period of one month. For this time period, peak demand is considered to be stable as it would happen during severe winter. However, this assumption is considered to be conservative. The network elements (pipelines, facilities), once failed, no repairs are considered. All failures are considered to occur during a period of one month, although they might not occur at the same moment. This is another conservative assumption.

4.1. Security of supply estimation

Below in the tables and figures of this section the probabilistic results of the risk assessment study are displayed. Each table provides the following results: number of the country or region (groups of countries), estimated probabilities to have no gas at all (column P(X=0)), less than 20% of the demanded gas volume (column P(X<0.2D)), less than 50% of the demanded gas volume (column P(X<0.5D)), less than 80% of the demanded gas volume (column P(X<0.8D)) and in the last column probability of less than the demanded gas volume D (P(X<D)). Country 1 consumes about 45 % of the total demand, Country 2 consumes about 35% and Country 3 consumes about 20%.

The values provided in the tables can be obtained directly from the CDF plots. The interpretation of the empirical CDF plots is as follows: for any given gas volume in horizontal axis, the CDF function line provides a probability estimate in a vertical axis of having less than given gas volume. By definition, the CDF plot value at the peak demand gas volume CDF(D) is always 1, meaning that probability that available gas volume is peak demand or less is one by definition of the CDF plot. All CDF plots displayed are empirical, i.e. the plots are made from points coming from 1 million Monte-Carlo simulations and for some scenarios the simulation results are not available for very low probabilistic level, usually at the level of 1E-05 or below. Therefore when CDF plot does not start at zero (like scenarios A and C in Figure 2), the interpretation should be as if a vertical line should be added to the plot meaning that the model was not able to simulate situation of lower gas supply and thus the probability to have less than that volume of gas is zero.

Table 3 shows the probabilistic results for the scenario A, Table 4 shows the results for the scenario D. The average volumes of gas not supplied are presented in Table 5.

Figure 2 shows the CDF plot for the whole network, Figure 3 shows the CDF plot for the Country 1. The tables and plots are available for all regions and even nodes of interest, but due to large number of the results only selected part is shown in the paper.

Table 3: Probabilistic results for scenario A – all sources are available

Region	P(X=0)	P(X<0.2D)	P(X<0.5D)	P(X<0.8D)	P(X<D)
All Network	0	0	3.6E-05	4.4E-03	1.6E-02

Country 1	0	1.0E-06	4.2E-03	4.3E-03	5.2E-03
Country 2	0	0	1.4E-05	3.9E-03	5.8E-03
Country 3	0	0	1.0E-05	1.0E-05	2.9E-04
Exports	8.7E-05	8.6E-03	8.7E-03	8.7E-03	8.9E-03
Sum Country 1-3	0	0	1.4E-05	4.3E-03	1.1E-02

Table 4: Probabilistic results for scenario D: supply sources 2, 29 and 38 are unavailable

Region	P(X=0)	P(X<0.2D)	P(X<0.5D)	P(X<0.8D)	P(X<D)
All Network	3.0E-05	7.6E-05	4.0E-03	3.5E-02	1
Country 1	3.1E-05	7.4E-05	1.5E-02	3.2E-02	3.6E-02
Country 2	7.4E-05	7.6E-05	3.9E-03	3.9E-03	5.8E-03
Country 3	4.7E-03	5.2E-03	1.0E-02	1.1E-02	1.1E-02
Exports	7.4E-03	1	1	1	1
Sum Country 1-3	3.0E-05	7.6E-05	4.0E-03	2.0E-02	4.0E-02

Table 5: An average volume of the gas unserved (mcm/d) for all scenarios

Region	A	B	C	D
All Network	0.14	7.77	0.16	7.83
Country 1	0.042	0.22	0.042	0.23
Country 2	0.026	0.033	0.026	0.033
Country 3	5.9E-05	6.5E-05	0.027	0.042
Exports	0.068	7.52	0.068	7.52

Figure 2: CDF plot for the whole network demand including exports

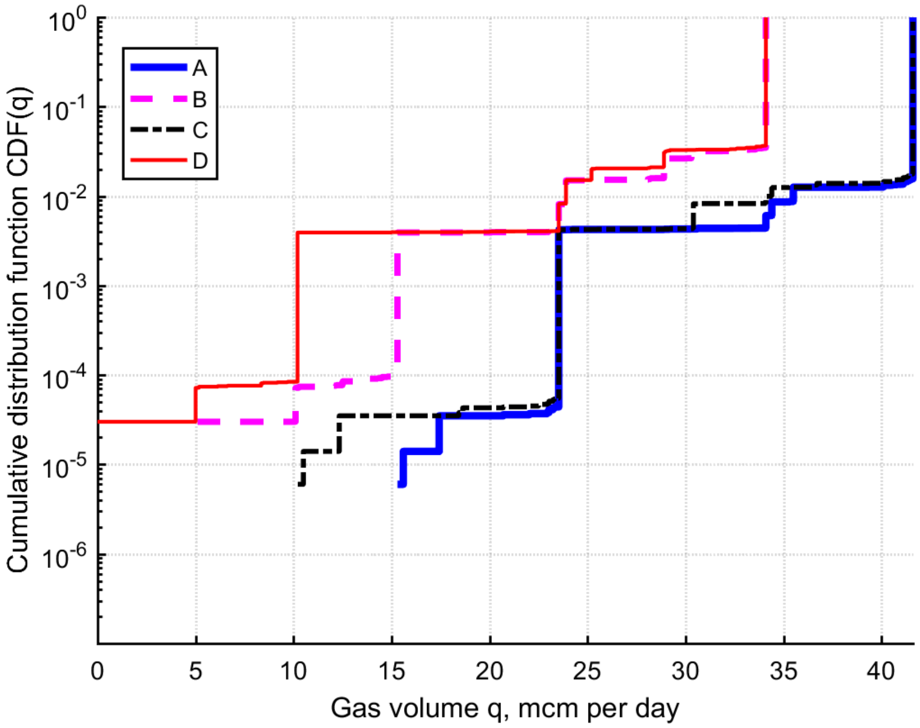
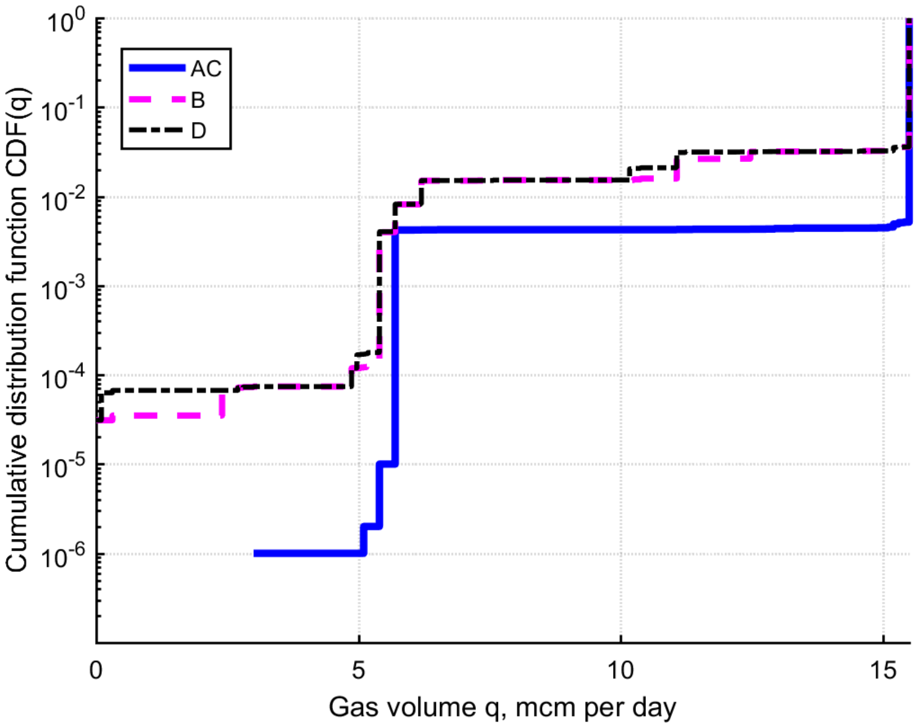


Figure 3: CDF plot for the Country 1



The probabilistic results could be analysed from different points of view and this analysis is not straightforward in some cases as the aggregated results may hide the causes of high or low values and more detailed statistical results are needed. Below we present some observations that are obvious from the results presented in the tables and CDF plots.

Note that each CDF curve represent better security of supply situation if it shifted towards the lower right corner of the plot, and worse security of supply situation if it is shifted towards the upper left corner of the plot. As example, in Figure 2 scenario A represents the best supply situation (not surprisingly, because it assumes all sources to be operational) and scenario D represents the worse supply situation (3 sources are assumed to be unavailable). The probabilistic results and the CDFs provide an easy way to compare security of supply situations in different scenarios and for different countries, regions and nodes.

When all supply sources are available (scenario A) none of the countries look to be in particular difficult situation. From the whole network point of view, probability to have less than 80% of the peak demand volume is 4.4E-03 per 1 peak demand winter month, which is rather low. If we could assume that during one year there is only one month of such peak demand (real peak demand period could be longer or shorter), the estimate converts into once in about 230 years value which is fairly unlikely. The estimate for having less than demanded gas volumes is 1.6E-02 per month, which corresponds to once in 62.5 years on average.

In case of pipeline supply crisis (scenario D), the Countries 1-3 are more vulnerable, which is expected. The network experiences gas insufficiency with probability of 4E-02 which is almost 3 times higher compared to scenario A (1.6E-02). Further network development by expanding internal pipelines and adding new sources could further minimise impact of scenario D. The results also indicate that Country 3 has the highest risk of supply disruption, followed by Country 1. Country 2 is in the best supply situation under this scenario. This result is obtained because Node 19 is considered to be fully available at the maximum supply level. In case of low supply level, situation could get worse for Countries 2 and 3 in particular.

4.2. Main contributor analysis

This section provides tables of the main risk contributors obtained by the ProGasNet simulations. The main contributors are typical the most important result obtained from risk assessment exercise. Even in presence of uncertainty in the estimation of events probabilities, the main risk contributors point to the weakest parts of the network, i.e. those components whose failure contributes the most to the system failure.

In case of network analysis, this task is complicated by the fact the main contributors are different for different supply levels and different regions. This inflates the number of results to be analysed. For this reason we provide only for selected demand levels and only two cases: all network without exports and Country 1 as the biggest consumer in the network.

Looking at the results (Table 6) probability of zero gas in the network under scenario D can be obtained only in a simultaneous complete failure of both Node 10 and storage facilities (estimated to be 3E-05 per severe winter month). Note that LNG or storage facilities can fail in several modes. Unfortunately this version of ProGasNet does not display the failure mode and it should be guessed by the reader based on available supply in the network.

An important result is provided by Table 7. The pipeline (3,11) dominates among the main contributors for supply level below 80%, scoring first for scenarios A and C, second for scenario B and third for scenario D. The other main contributors are Nodes 19 and 10 which are source nodes.

Table 6: Main risk contributors of the whole network for supply X=0 and X<0.2D=6.64 mcm/d.

Supply (mcm/d)	Frequency	Scenario D: Contributors of P(X=0)=3.00e-05
0	3.00E-05	Node(10) Node(19)
Supply (mcm/d)	**Frequency**	**Scenario B: Contributors of P(X<0.2D)=3.00e-05**
5.1	3.00E-05	Node(10) Node(19)
Supply (mcm/d)	**Frequency**	**Scenario D: Contributors of P(X<0.2D)=7.60e-05**
4.87	3.90E-05	Node(10) Node(19)
0	3.00E-05	Node(10) Node(19)
5.04	2.00E-06	Node(19) Line(10, 54)
4.87	1.00E-06	Node(10) Node(19) Line(3, 11)
6	1.00E-06	Node(19) Line(14, 54)
4.87	1.00E-06	Node(10) Node(19) Line(19, 20)
4.87	1.00E-06	Node(10) Node(19) Line(11, 43)
6.5	1.00E-06	Node(19) Line(12, 14)

Table 7: Main risk contributors of the whole network for supply X<0.8D=26.56 mcm/d.

Supply (mcm/d)	Frequency	Scenario A: Contributors of P(X<0.8D)=4.26e-03
23.4	3.90E-03	Line(3, 11)
23.4	7.80E-05	Node(12) Line(3, 11)
23.4	4.20E-05	Node(10) Line(3, 11)
23.4	3.40E-05	Node(11) Line(3, 11)
23.4	2.80E-05	Node(10) Line(3, 11)
17.3	1.80E-05	Node(19) Line(3, 11)
24.2	1.70E-05	Node(10) Line(11, 50)
23.4	1.50E-05	Node(19) Line(3, 11)
23.9	1.20E-05	Node(10) Line(2, 50)
23.4	8.00E-06	Line(3, 11) Line(29, 32)

Supply (mcm/d)	Frequency	Scenario B: Contributors of P(X<0.8D)=1.53e-02
23.9	6.56E-03	Node(10)
23.4	3.90E-03	Line(3, 11)
15.2	3.64E-03	Node(19)
25.3	1.74E-04	Line(18, 34)
23.9	1.43E-04	Node(10) Node(12)
15.2	8.20E-05	Node(12) Node(19)
23.4	7.80E-05	Node(12) Line(3, 11)
23.9	6.20E-05	Node(10) Node(11)
25	4.40E-05	Node(10) Node(19)
23.4	4.20E-05	Node(10) Line(3, 11)
Supply (mcm/d)	**Frequency**	**Scenario C: Contributors of P(X<0.8D)=8.16e-03**
23.4	3.90E-03	Line(3, 11)
22	3.64E-03	Node(19)
22	8.20E-05	Node(12) Node(19)
23.4	7.80E-05	Node(12) Line(3, 11)
23.4	4.20E-05	Node(10) Line(3, 11)
22	3.90E-05	Node(10) Node(19)
22	3.90E-05	Node(11) Node(19)
23.4	3.40E-05	Node(11) Line(3, 11)
22	3.00E-05	Node(10) Node(19)
23.4	2.80E-05	Node(10) Line(3, 11)
Supply (mcm/d)	**Frequency**	**Scenario D: Contributors of P(X<0.8D)=2.04e-02**
23.9	6.56E-03	Node(10)
25.1	4.89E-03	Node(19)
23.4	3.90E-03	Line(3, 11)
10.1	3.64E-03	Node(19)
25.3	1.74E-04	Line(18, 34)
23.9	1.43E-04	Node(10) Node(12)
25.1	1.00E-04	Node(12) Node(19)
10.1	8.20E-05	Node(12) Node(19)
23.4	7.80E-05	Node(12) Line(3, 11)
23.9	6.20E-05	Node(10) Node(11)

Table 8: Main risk contributors of Country 1 for supply X<0.5D=7.75 mcm/d.

Supply (mcm/d)	Frequency	Contribution impact (%)	Scenario A: Contributors of P(X<0.5D)=4.24e-03
5.7	3.90E-03	92	Line(3, 11)
5.7	7.80E-05	2	Node(12) Line(3, 11)
5.7	4.20E-05	1	Node(10) Line(3, 11)
5.7	3.40E-05	1	Node(11) Line(3, 11)
5.7	2.80E-05	1	Node(10) Line(3, 11)
5.7	1.80E-05	0	Node(19) Line(3, 11)
6.5	1.70E-05	0	Node(10) Line(11, 50)
5.7	1.50E-05	0	Node(19) Line(3, 11)
6.2	1.20E-05	0	Node(10) Line(2, 50)
5.7	8.00E-06	0	Line(3, 11) Line(29, 32)
Supply (mcm/d)	**Frequency**	**Contribution impact (%)**	**Scenario B: Contributors of P(X<0.5D)=1.53e-02**
6.2	6.56E-03	43	Node(10)
5.7	3.90E-03	26	Line(3, 11)
5.4	3.64E-03	24	Node(19)
7.57	1.74E-04	1	Line(18, 34)
6.2	1.43E-04	1	Node(10) Node(12)
5.4	8.20E-05	1	Node(12) Node(19)

5.7	7.80E-05	1	Node(12) Line(3, 11)
6.2	6.20E-05	0	Node(10) Node(11)
7.27	4.40E-05	0	Node(10) Node(19)
5.7	4.20E-05	0	Node(10) Line(3, 11)
Supply (mcm/d)	**Frequency**	**Contribution impact (%)**	**Scenario C: Contributors of P(X<0.5D)=4.24e-03**
5.7	3.90E-03	92	Line(3, 11)
5.7	7.80E-05	2	Node(12) Line(3, 11)
5.7	4.20E-05	1	Node(10) Line(3, 11)
5.7	3.40E-05	1	Node(11) Line(3, 11)
5.7	2.80E-05	1	Node(10) Line(3, 11)
5.7	1.80E-05	0	Node(19) Line(3, 11)
6.5	1.70E-05	0	Node(10) Line(11, 50)
5.7	1.50E-05	0	Node(19) Line(3, 11)
6.2	1.20E-05	0	Node(10) Line(2, 50)
5.7	8.00E-06	0	Line(3, 11) Line(29, 32)
Supply (mcm/d)	**Frequency**	**Contribution impact (%)**	**Scenario D: Contributors of P(X<0.5D)=1.53e-02**
6.2	6.56E-03	43	Node(10)
5.7	3.90E-03	26	Line(3, 11)
5.4	3.64E-03	24	Node(19)
7.57	1.74E-04	1	Line(18, 34)
6.2	1.43E-04	1	Node(10) Node(12)
5.4	8.20E-05	1	Node(12) Node(19)
5.7	7.80E-05	1	Node(12) Line(3, 11)
6.2	6.20E-05	0	Node(10) Node(11)
4.97	4.40E-05	0	Node(10) Node(19)
5.7	4.20E-05	0	Node(10) Line(3, 11)

For 50% or lower supply level in Country 1 (Table 8), the pipeline (3,11) again dominates the list of contributors, together with Node 10 and in case of scenario B together with Node 19 failure. Similar situation is observed in other supply levels (the numeric results are not provided in the paper).

Although further importance measures need to be developed and further researched, already from these preliminary results it is obvious that pipeline (3,11) is among the most important network elements. The pipeline (3,11) is a short distance pipeline connecting compressor station (Node 11) to many large demand nodes. It is a pipeline which makes only less than 1% of the total length of the network and is the first candidate to be protected or parallelized. If (3,11) is unavailable, large consumer nodes are cut-off from the supply sources and supply is possible only through a small diameter pipeline which has low capacity.

5. CONCLUSION

The paper presents a risk assessment study performed on security of supply situation in the EU region using probabilistic gas network simulator ProGasNet. The simulations were run for the peak demand situation that was assumed to last for a period of one month. All probabilistic estimates are computed for the same period of one month. In total 4 supply scenarios were analysed, all with the purpose to analyse long-term risk of security of supply situation in the region.

The risk assessments results show that in general all countries are relatively well supplied under scenario A when all sources are assumed to operate. However, complete loss of pipeline supply (scenario D) is the worst case scenario for the whole region and further network development plans are needed.

The main contributor analysis study identifies pipeline (3,11) as the most important network element. The other main risk contributors are the gas supply sources: Node 19 and Node 10.

The model validation should be further extended and developed and this is in particular important for modelling of large networks with ProGasNet approach.

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