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Development of an evaluation tool to assess correlated risks and regional vulnerabilities

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"TECHNICAL ASSISTANCE, ANALYSIS AND INPUT TO SUPPORT THE IMPLEMENTATION OF CERTAIN PROVISIONS OF THE REGULATION ON SECURITY OF GAS SUPPLY"

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1. Introduction

According to Regulation 994/2010 [1], the Competent Authorities of each EU Member State shall make a risk assessment of the security of gas supply "*by taking into account all relevant national and regional circumstances, in particular market size, network configuration, actual flows, including outflows from the Member State concerned, the possibility of physical gas flows in both directions including the potential need for consequent reinforcement of the transmission system, the presence of production and storage and the role of gas in the energy mix, in particular with respect to district heating and electricity generation and for the operation of industries, and safety and gas quality considerations*" (Reg. 994/2010, article 9(1.b).

With only few exceptions (Baltic states, Finland, Sweden), the European gas transmission network is well interconnected and could be viewed as a single gas infrastructure system. For historical reasons, the gas transmission networks were better developed inside each Member State and less attention was given for cross-border connections between Member States. National risk assessments of gas supply will be limited to geographical borders of each Member State and analyse only part of the whole gas infrastructure system. The risk assessment results of each country might not be complete or accurate enough due to the effects of interconnections between Member States. Therefore, Article 9 (1.d) requests to take into account "*the interaction and correlation of risks with other Member States, including, inter alia, as regards interconnections, cross-border supplies, cross-border access to storage facilities and bi-directional capacity*".

This report presents an approach to assess cross-border and regional risks, here called 'correlated risks'. It discusses the concept of correlated risk, the methods for hazard identification and screening, and the potential use of a European gas transmission network model.

2. Concept of correlated risk

2.1 Historical development of risk definition

Since the first comprehensive risk assessment study for five US nuclear power plants, better known as WASH-1400 study [2], risk assessment became a very widespread requirement across many different industries and sciences, including economics, finance and even project management. Naturally, many definitions of risk were developed, targeted for specific activity or purpose.

Risk can be viewed both quantitatively and qualitatively. Qualitatively, when there is a source of danger (e.g. loss of gas import, fire in LNG terminal, pipeline leak) and there are no safeguards or existing are unavailable or they are not adequate against exposure of the hazard; then there is a possibility of accident, loss or injury. This possibility is referred as *risk*. Risk can be formally defined as the potential of loss in rather wide sense (e.g. human, environment, economic or financial) and assessed in a qualitative scale: very likely, likely, unlikely, very unlikely etc.

From the quantitative point of view, the fundamental questions in risk analysis are the following [3]:

1. What can go wrong that could lead to an outcome of hazard exposure?
2. How likely is this to happen?
3. If it happens, what consequences are expected?

To answer question 1, a list of outcomes (scenarios of events leading to the outcome) should be defined. The likelihood of these scenarios should be estimated (question 2) and the consequences of each scenario should be assessed (question 3). Therefore, quantitatively risk can be defined as the following set of triplets:

$$R=<S_i,P_i,C_i>,\ i=1,\dots,n. \quad (1)$$

where S_i - scenario of events that lead to hazard exposure,

P_i - likelihood of scenario,

C_i - consequence of scenario (e.g. measure of the degree of damage),

n - number of scenarios.

In case of technical systems, triplet risk definition (1) is the most widespread and used.

2.2 Correlated risk

The classical risk assessment theory [4-6] does not define the concept of correlated risk for technical systems. Therefore it is important to characterize the term as accurately as possible within the frame of the gas infrastructure network.

The concept of correlated risk term has been employed in financial investment theory: correlation risk is defined as a change of portfolio due to correlation of assets. This definition is hardly applicable to technical systems. Another example of related terminology can be found in the Seveso II directive [7], where the concept of *Domino effect* is defined and applied. Its primary purpose is to identify scenarios when hazardous events in a specific facility may affect other nearby facilities. Correlation of risk is also applicable in the case of collapse of upstream hydro-power dam which causes collapses of other downstream hydro-power dams in the same river.

An important attribute in the risk assessment of the European gas network is the fact that each Member State provides risk assessment for a single country and network cross-border connections are analysed from their local perspective rather than by investigating the whole network globally. To compensate for this drawback, Regulation 994/2010 requires each Member State to perform a full risk assessment by (Article 9, par. 1d) *"identifying the interaction and correlation of risks with other Member States, including, inter alia, as regards interconnections, cross-border supplies, cross-border access to storage facilities and bi-directional capacity".* This paragraph is the only place in the regulation where the *correlation of risks* term appears.

The more direct interpretation of correlation of risk in the case of European gas infrastructure, which is divided into interconnected subsystems bounded by the geographical borders of Member States, is the likelihood of an event or series of events having undesired consequences (disruption of gas supply) in more than one Member State. Three types of such events and combination of them can be considered:

1. **Disruption of imports** (pipeline, country, region) causing disruption of gas supply in more than one Member State;
2. **External hazards** affecting one or several countries and causing disruption of gas supply in more than one Member State;
3. **Internal hazards** (component failures) causing disruption of gas supply in more than one Member State;

The first type of events (e.g. disruption of import supply routes or single large transmission pipelines) can be studied with the GEMFLOW model [8], developed at the JRC. The GEMFLOW tool enables analysis to be performed for a single supply country or regions in case of complete or partial loss of supply from different areas (Russia, North Sea, Mediterranean Sea), specific pipelines (North Stream, Yamal, Medgaz, Transmed, Brotherhood etc.) or LNG terminals. The effect of loss of supply can be studied for a specific country or all EU countries.

The second type of events are mainly due to natural hazards (also called area events, because they affect large geographical areas and possibly several countries simultaneously). In addition, other events like terrorist attacks, airplane crashes can be included. A full list of external hazards is described in section 4.2. These events can be better studied with a detailed network model (Section 0). Some scenarios can be also studied with GEMFLOW, e.g. extremely low temperatures for a long period in a number of Member States and the associated high gas demand.

The third type of events, related to internal gas network hazards, can be better studied by employing a detailed network model (Section 0). However, hazardous events happening at cross-border points or connections can be studied by GEMFLOW (e. g. UK Interconnector, UK-Ireland interconnector, CH-IT Griespass connection etc.).

Table 1 provides an overview and comparison of the capabilities of different tools for the analysis of correlated risks.

Table 1: Modeling capabilities for different type of hazards.

Type of hazard	***GEMFLOW (existing)***	***Detailed model (extended GEMFLOW)***
Type 1: Disruption of imports	All scenarios	All scenarios
Type 2: External hazards	Only specific scenarios linked to particular Member States, e.g. high gas demand due to extremely cold weather	All scenarios
Type 3: Internal hazards	Only cross-border points/connections	All scenarios

3. Analysis of disruption of imports: GEMFLOW

Disruption of import supply routes or single large transmission pipelines can be studied with the GEMFLOW model [8], developed at the JRC and being an improved version of the MC-GENERCIS tool [9]. The GEMFLOW tool enables analysis to be performed for a single supply country or regions in case of complete or partial loss of supply from different areas, specific pipelines or LNG terminals. The effect of loss of supply can be studied for a specific country or all EU countries. Some scenarios, linked to external hazards can also be studied with GEMFLOW, e.g. extremely low temperatures for a long period in a number of Member States and the associated stress to the system due to high gas demand simultaneously in a number of countries.

The model is based on aggregated graph approach. The European Gas Transmission Network is simulated at the level of countries: each country is represented by a node and each pair of countries connected via gas transmission pipelines is connected via a virtual branch with the properties (maximum technical capacity, actual flows) of all the pipelines connecting both countries (Figure 1). Gas production, gas consumption, storage capacity, gas withdrawal from storage, cross-border flows and LNG supply is also modelled in aggregated way, i.e. assuming there is only one 'virtual' facility per country with the aggregated capacity, flow, or any other pertinent magnitude of interest. The GEMFLOW model has 31 nodes (all EU countries, except Malta and Cyprus; Bosnia and Herzegovina, Switzerland, Croatia, FYROM, Serbia and Turkey).

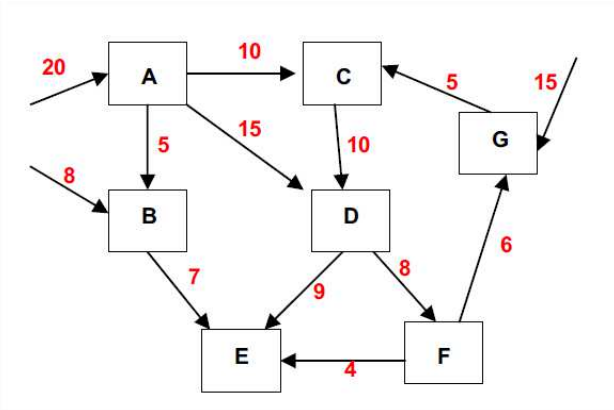

Figure 1: Graph approach in GEMFLOW [9].

The time step is one day gas supply and consumption. The supply from storages, flows from neighbouring countries and consumption level can be randomized (by using Monte Carlo simulations) or change in a predefined way in order to get the balance in the whole gas network.

The objective of GEMFLOW is to compute demand-supply balances in all the nodes (countries) and display the results in terms of the imbalanced countries and timing of the imbalance to appear after the disruption scenario starts. Various disruption scenarios can be run, including complete or partial loss of supply from different areas (Russia, North Sea, Mediterranean Sea), specific pipelines (North Stream, Yamal, Medgaz, Transmed, Brotherhood etc.) or LNG terminals.

4. Identification of hazards

This section presents a list of potential hazards that can potentially threaten the gas infrastructure.

Hazard identification is the first step of any risk assessment process. Standard ISO 31000 [10] calls this the risk identification step, although the meaning of 'risk' is that of 'hazard' for technical systems. Several methods have been proposed in the literature for hazard identification, such as checklists, Hazard Indices (Dow and Mond), What If Analysis, Failure Modes and Effects Analysis (FMEA) and Hazard and Operability Analysis (HAZOP) or Master Logic Diagram (MLD).

Hazard is defined as a potential to cause disruption or undesired consequences. It is different from risk because depending on system configuration, safety systems available, geographical and other circumstances it may turn or not into actual risk. For example, earthquake is a big hazard to any infrastructure, but in a particular geographical location or country, its probability can be very small, meaning that earthquake risk is negligible. After hazards are identified, screening analysis and further risk analysis can identify which hazards are actually risks and what is their magnitude.

For the gas infrastructure, the hazards can be grouped into 3 different categories:

1. **Disruption of imports**
2. **External hazards**
3. **Internal hazards** (component failures)

In the following, each of the categories will be described in detail.

4.1 Disruption of imports

This category comprises all type of hazardous events that can happen outside the EU and that might cause supply disruption to the EU Member States. The type of possible events is very numerous, including natural hazards, technical failures, terrorist attacks, political crisis, sabotage or civil wars that can happen in the exporting or transit countries. Due to the large number and very diverse origins of possible disruption, disruptions of imports should be studied as specific scenarios without attempt to estimate their frequency of occurrence. It should be a "What-If" type of analysis.

Three levels of scenarios are proposed to study in detail:

- Individual pipeline level for any pipeline arriving at the EU external border (TransMED, MedGAZ, Brotherhood, Yamal etc.) and at LNG import terminals;
- Exporting/transit country level (Algeria, Norway, Ukraine, Belarus, Turkey, Qatar, Egypt etc.) for all imports either through pipelines or LNG ships.
- Regional level (North Sea, Mediterranean Sea, Atlantic Ocean, Black Sea, North Africa, Russia etc.) for all gas flows through that region.

4.2 External hazards

External hazards are normally grouped into natural events and man-made events. Natural events form a large group of events that can threaten any infrastructure in Europe, but with local specificities. The following natural hazards should be studied in order to evaluate their consequences to gas supply in a number of Member States:

1. Seismic events. They might affect large areas and a number of countries damaging infrastructure and supply routes;
2. Extreme floods (from tides, tsunamis, storm surges, precipitation, waterspouts, dam forming and dam failures, snow/ice melt, landslides into water bodies);
3. Extreme precipitation: rain, hail or snow. It might damage infrastructure and/or limit or block accessibility for repairs or maintenance;
4. Hurricane, tornado, extreme wind;
5. External fire (forest, nearby facility);
6. Extremely cold temperatures and ice (of different duration and different size of area);
7. Electro-magnetic impact (lightning, solar flare);
8. Direct impact from ground (volcano, landslide, avalanche);
9. Air contamination (salt storm, sand storm);
10. Extreme humidity (mist, white frost, drought);

Relevant combinations of natural hazards should be studied as well, like seismic events and tsunami, extremely cold temperatures and heavy snowfall etc.

The following man-made external events should be studied in order to evaluate their consequences to gas supply in a number of Member States:

11. Loss of electricity supply in large area (one of several Member States). It might affect gas transportation if compressors are electrically driven, as well as repair/maintenance activities.
12. Explosions (deflagrations and detonations) with or without fire, originated from external sources, like storage of hazardous materials, transformers, high energy rotating equipment.
13. Direct impact from air: airplane crash. It has to be taken in consideration when any important gas infrastructure is nearby airports;
14. Air contamination (chemical release from nearby facility, transportation accident)
15. Ground impact: excavation works;
16. Coast pollution (ship accident/release; oil platform accident);
17. Internal missiles (from explosions, ruptures, collapses, high energy rotating machinery).
18. Terrorist threats and targeted attacks.

4.3 Internal system hazards

This group of events is linked mostly to gas system components and their failures or malfunctioning. The following hazards should be studied for the main gas infrastructure facilities in order to investigate their impact on gas supply to several Member States:

19. Partial or complete failure of compressor station;
20. Pipeline ruptures due to loss of structural integrity: mechanical damage, corrosion, overpressure etc;
21. Failures of LNG degasification plants;
22. LNG cargo accidents;
23. Failures to extract gas from storages;
24. Failures to extract gas from gas fields (inside the EU);

More detailed list of events should be developed by studying each gas facility and applying standard hazard identification techniques: FMEA, FMECA, HAZOP, MLD or others.

5. Screening of external hazards

Section 4.2 provides a list of possible events that in the next step of the analysis must be screened out according to a number of criteria. Two main screening criteria are proposed: relevance and impact. The relevancy screening is essentially based on likelihood of occurrence of the hazard, either in quantitative or in qualitative terms. The impact screening is the next step screening for those hazards that remained in the shortlist after performing relevancy screening. The impact screening is essentially a consequence based screening, selecting only those hazards that are posing significant threat to the infrastructure.

After performing both screenings, the selected hazards are both likely to happen and can pose a significant damage to the infrastructure. A detail risk study should be performed for the selected hazards to estimate risk.

5.1 Relevancy screening

The purpose of this task is to screen out those potential external events, either single or combined, which are not relevant to the selected gas infrastructure. This means that they cannot occur in its surroundings or their frequency of occurrence is below a predefined threshold or that their strength is evidently too low.

Each event must be analysed independently for each important gas facility of the transmission network (compressor station, junction, LNG terminal, cross-border connection, major pipeline segment).

Figure 2 shows an earthquake hazard map [11] that can be utilised in order to determine likelihood of earthquake in different locations. Obviously, white/green areas are not earthquake prone areas and seismic hazard could be screened out, but attention should be given to the gas infrastructure in red areas.

The ESPON report [12] provides many hazard maps regarding various natural events and technological activities. Figure 3 presents a flood hazard map that can be used to identify flood prone areas. The report also provides hazard maps for the following natural hazards: avalanches, drought, earthquakes, extreme temperatures, floods, forest fires, landslides, storm surges, tsunamis, volcanic eruptions, winter storm. These hazard maps presented here are only examples of how to deal with relevance screening procedure. They are purely illustrative and their data quality should be carefully checked in real applications.

At the end of the relevancy screening procedure, a list of relevant hazards to each gas infrastructure facilities and pipeline segments should be produced.

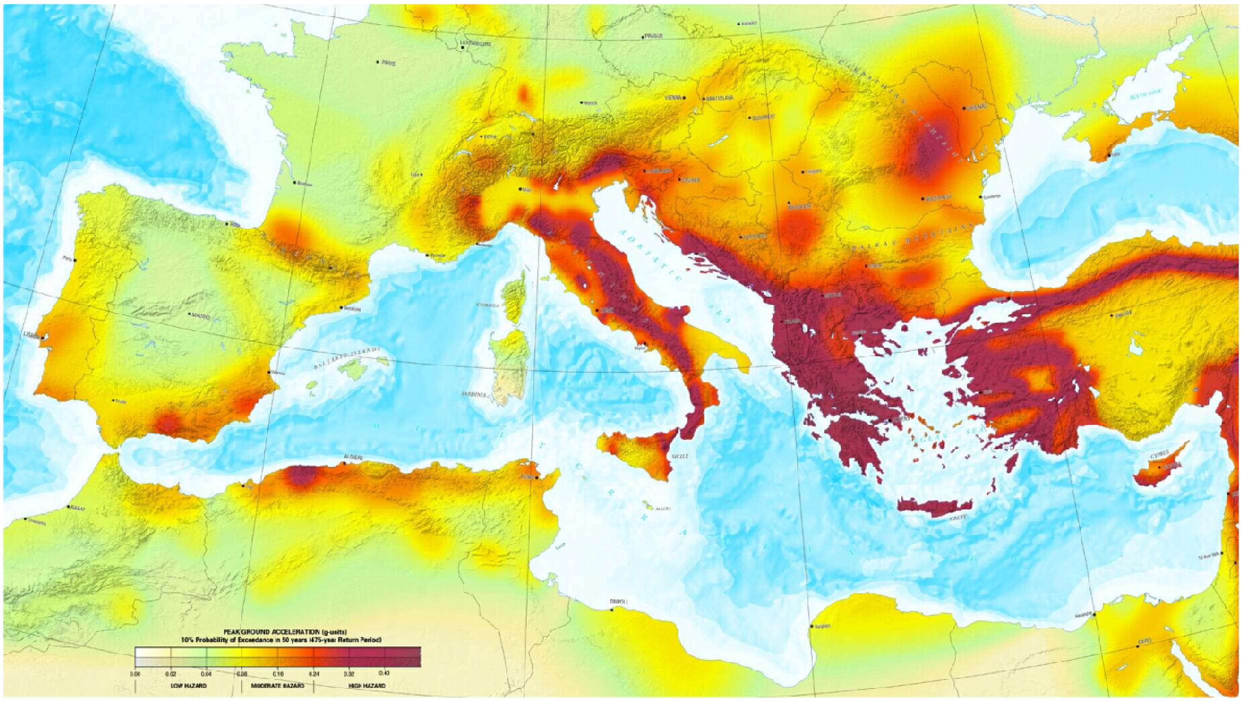

Figure 2: Peak ground acceleration map of South Europe/Mediterranean area (probability 0.1 of exceedance in 50 years) [11].

5.2 Impact screening

The purpose of this screening is to filter those external events, either single or combined, which are not relevant to the selected gas infrastructure. This means that no relevant impact to selected gas infrastructure can be identified. The impact screening exercise will screen out hazards in many obvious cases, like flood, lightning, forest fire or extreme wind events for underground pipeline segments, however in a number of cases the impact will not be easy to assess.

By judging an impact, conservative approach should be used and unclear cases left for the more detailed study. By evaluating possible impact, all protection measures available at the given facility should be taken into account, i.e. flood barriers, earthquake resistant design etc.

Impact screening should be performed after the relevancy screening and should result in a final list of hazards for the detailed analysis of their correlated risks.

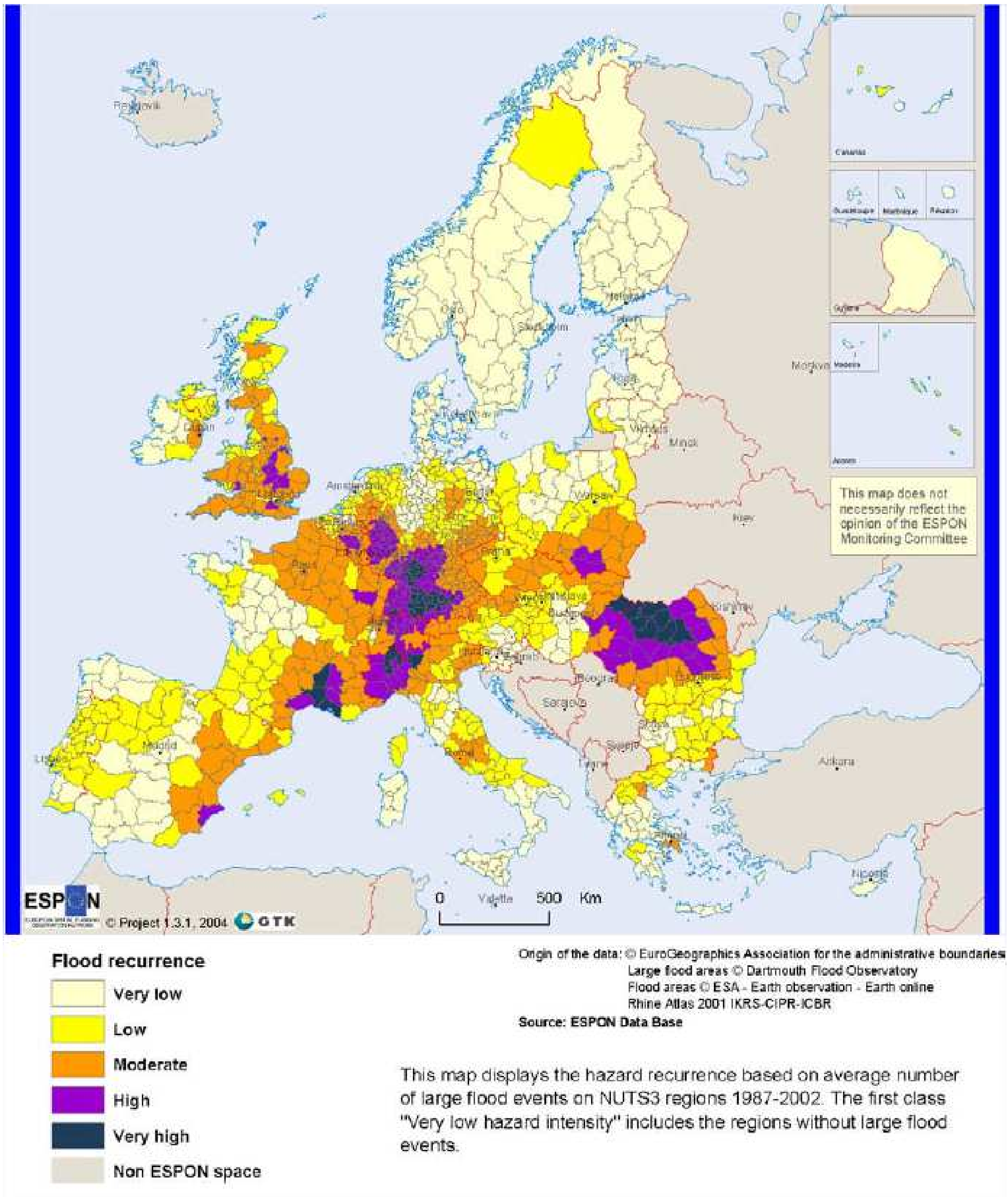

Figure 3: Flood hazard map in Europe [12].

6. Interdependence between gas and electricity networks

An important impact in view of correlated risks can be observed due to interdependence between gas and electricity networks. Although in different countries the impact can be significantly different, the links between both networks must be systematically studied and analysed. The interdependence can be studied from a number of perspectives:

- Loss of gas supply propagates to power network affecting gas fired power plants (either conventional gas power plants or combined cycle gas turbines - CCGT) that may result in reduced electricity generation. This situation is especially important in the countries producing a lot of electricity from gas, e.g. Italy produces ~50% of its electricity from gas powered turbines; in case of Ireland which produces even 80% of electricity from gas, the loss of gas supply can be critical. The situation may turn especially severe when there is simultaneous scarcity or lack (interaction) of renewables and gas. In a growing number of countries gas is used as a backup for renewables regarding the generation of electricity. Simultaneous lack of both sources of energy may pull down the electricity grid heading to a blackout.

- Having loss of gas supply in a country that is highly dependent on electricity production from gas fired power plants, this event might trigger electricity blackout that in turn might again affect the remaining gas supply system. However, this type of spiral propagation of failures is rather unlikely and should be addressed only in specific countries with significant electricity generation from gas and lack of international power connections.

- All types of infrastructures, and the gas transmission network among them, rely more and more on electricity driven components. An electricity grid blackout in a large area may affect the gas network in a number of ways either direct or indirect: electricity driven gas compression stations stop working, remote network control rooms are disabled, functioning of storages is affected, a lot of gas consuming equipment either industrial or household, does not function properly without electricity (e.g. electrical pump operated heating systems).

As this report considers correlated risks in terms of failures of gas infrastructure in one country affecting another country, the latter perspective constitute a reasonable risks to be taken into account in the analysis of correlated risks.

A number of historic power grid blackouts observed in Europe and worldwide did not produce any significant effect to the gas infrastructure and gas consumption. In some cases the explanation comes from the low level of electrification of infrastructures in some countries, although as already mentioned the global tendency goes towards an increasing level of electrification. For example, the most severe Italian blackout in 2003 had insignificant consequences on the gas network, among other reasons because all Italian compressor stations are gas driven. Another factor that helps mitigating the effect of electricity grid blackouts is that the gas network is rather inertial due to large amount of gas contained within the pipelines (wise use of linepack may help a lot) and that power grid blackout are usually short in terms of time (<1-2 day). However, this does not prove the fact that interdependence cannot be very strong producing severe consequences if a number of circumstances in terms of timing, extreme weather conditions, geographical area affected, network topology or cascading events badly interact. Therefore, gas and electricity interdependence must be studied in detail and in all perspectives.

The risk assessment reports that Members States submitted according to the Regulation 994/2010 hardly address this issue. Only occasionally some countries (Belgium, Estonia, France) mentioned the problem, but no systematic analysis was performed.

7. Qualitative assessment of correlated risks

Assessment of correlated risks can be best performed by applying the European Gas Transmission network model that is described in Section 9. As the model is not yet developed, a qualitative assessment can be performed based on risk assessment reports of each Member State.

The suggested approach relies on risk overview tables that can be compiled for each Member State. The template of a risk overview table is shown in Table 2.

7.1 Risk overview table

The risk overview table contains information from risk assessment reports of each Member State in following five columns of the Table 2:

- *Event analysed:* it is either disruption of import route/pipeline/LNG terminal or internal/external hazard;
- *Type of event analysis performed:* can be grouped into the following categories:
  - ***Descriptive:*** postulated event with no or limited analysis of the root causes;
  - ***Detailed:*** well analysed root causes;
- *Quantification of likelihood:* can be quantitative (frequency or probability) or qualitative (relative measure);
- *Evaluation of consequences:* can be grouped into the following categories:
  - ***Descriptive:*** general assumptions with no or limited analysis;
  - ***Detailed:*** well analysed consequences of the hazard event;
- *Risk evaluation:* how the event is rated in terms or likelihood and consequences;

The next columns of the Table 2 qualitatively analyse the information provided in the report and try to assess its possible consequences to other Member States:

- *Can transit flow or supply to another MS be affected:* Yes or No; The answer is based on the information provided in the report or other sources;
- *Which country is affected:* List of countries affected by the event;
- *Value of N-1x criterion for the affected countries:* The criterion N-1 is applied to all affected countries, but not for the largest infrastructure (as required by [1]), but for the loss of supply route triggered by the analysed event in the MS for which risk overview is performed. In order to highlight the differences between N-1 criteria, the N-1x notation is used.

Although the input data for the analysis of correlated risks obtained from risk overview tables is rather preliminary and descriptive, the results can be used to indicate specific scenarios for more detailed study to be performed. Value obtained by computing N-1x criterion can be used to prioritise the actions to be taken to mitigate the risks. The N-1x criterion is described in detail in the next subsection.

7.2 N-1x criterion

The proposed method to compute N-1x value is very similar to the N-1 formula given in the Regulation 994/2010:

$$N - 1[\%] = \frac{EP_m + P_m + S_m + LNG_m - I_m}{D_{max}} \times 100,\ N - 1 \geq 100\,\%$$

Definitions of the parameters of the N – 1 formula:

'Calculated area' means a geographical area for which the N – 1 formula is calculated, as determined by the Competent Authority.

Demand-side definition

'D_{max}' means the total daily gas demand (in mcm/d) of the calculated area during a day of exceptionally high gas demand occurring with a statistical probability of once in 20 years.

Supply-side definitions

'EP_m': technical capacity of entry points (in mcm/d), other than production, LNG and storage facilities covered by P_m, S_m and LNG_m, means the sum of the technical capacity of all border entry points capable of supplying gas to the calculated area.

'P_m': maximal technical production capability (in mcm/d) means the sum of the maximal technical daily production capability of all gas production facilities which can be delivered to the entry points in the calculated area.

'S_m': maximal technical storage deliverability (in mcm/d) means the sum of the maximal technical daily withdrawal capacity of all storage facilities which can be delivered to the entry points of the calculated area, taking into account their respective physical characteristics.

'LNG_m': maximal technical LNG facility capacity (in mcm/d) means the sum of the maximal technical daily send-out capacities at all LNG facilities in the calculated area, taking into account critical elements like offloading, ancillary services, temporary storage and re-gasification of LNG as well as technical send-out capacity to the system.

'I_m' means the technical capacity of the single largest gas infrastructure (in mcm/d) with the highest capacity to supply the calculated area. When several gas infrastructures are connected to a common upstream or downstream gas infrastructure and cannot be separately operated, they shall be considered as one single gas infrastructure.

The N-1x criterion proposed in this report affect only one variable in the above formula of N-1 criterion: I_m. This variable in the above formula means technical capacity of the single largest infrastructure (in mcm/d) with the highest capacity to supply the calculated area. In the newly proposed N-1x formula, I_m variable is replaced by I_x variable which means technical capacity of the infrastructure in the neighbouring country (mcm/d) with the largest possible capacity to supply the affected country. All other variables in the formula of N-1x are as in the Regulation 994/2010:

$$N-1x[\%]=\frac{EP_m+P_m+S_m+LNG_m-I_x}{D_{\max}}\times 100\%$$

Where:
I_x means technical capacity of the infrastructure in the neighbouring country (mcm/d) with the largest possible capacity to supply the affected country.

In some cases, especially where several MSs are dependent on a single transit pipeline, I_x can be equal to I_m meaning that correlated risks are also associated with the largest gas infrastructure. However, such coincidence of $I_x= I_m$ is dependent only on topology of the gas infrastructure.

The N-1x criterion should be computed not only for a single largest import infrastructure, but for all identified loss of supply risks in the neighbouring countries or import points. The value of the criterion provides a qualitative ranking of the correlated risks, the lower value meaning more severe consequences to the affected country.

Table 2: A template for a risk overview table.

COUNTRY – Risk overview table							
Event analysed	Type of event analysis performed	Quantification of likelihood	Evaluation of consequences	Risk evaluation	Can transit flow or supply to another MS be affected?	Which country is affected?	Value of N-1x criterion for the affected countries
Type I: Disruption of imports							
Type II: External hazards							
Type III: Internal hazards							

8. Examples of qualitative assessment of correlated risks

8.1 Baltic States: Estonia, Latvia, Lithuania

As an example, a risk overview table was developed for the 3 Baltic States: Estonia, Latvia and Lithuania. All the information is strictly and only obtained from the national risk assessment reports. The risk overview table for Lithuania is shown in Table 5, Latvia - Table 6 and Estonia - Table 7.

The gas infrastructure of the Baltic countries is shown in Figure 4.

Figure 4: Natural gas supply system of the Baltic States.

From the risk overview tables it is clear that the following hazards should be studied in the correlated risk study, all of them being identified by screening the Latvian and Estonian risk assessment reports:

- Inčukalns UGS unable to supply sufficient volume of gas
- Inčukalns UGS temporarily unable to supply gas
- Accident in TGP Izborsk-Inčukalns UGS (winter)
- Accident in TGP Izborsk-Inčukalns UGS (summer)
- Accident in TGP Vireši-Tallinn

The identified hazards (Table 3) should be further analysed and only the most important selected for more detailed analysis.

Table 3: Correlated risk table for the Baltic states.

Country Report	Event analysed	Which country is affected?	Value of N-1x criterion for the affected countries
Latvia	Inčukalns UGS unable to supply sufficient volume of gas	Estonia	>60%
Latvia	Inčukalns UGS temporarily unable to supply gas	Estonia	60%
Latvia	Accident in TGP Izborsk-Inčukalns UGS (winter)	Estonia	60%
Latvia	Accident in TGP Izborsk-Inčukalns UGS (summer)	Estonia	>100%
Latvia	Accident in TGP Vireši-Tallinn	Estonia	60%

Screening of the correlated risks

Table 3 provides a list of hazards that may pose correlated risks. Further screening of the identified hazards must be performed in order to identify the most important events. One of the criteria proposed here is so called N-1x criterion. It helps to identify those hazards that are not very important for the other MSs: when N-1x criterion gives value significantly higher than 100%.

In case of the Baltic States, the following event: Accident in TGP Izborsk-Inčukalns UGS (summer) can be skipped from further analysis as it has little effect on Estonia, because during summer demand is low and another pipeline from Izborsk will supply enough gas to Estonia.

Another event: 'Inčukalns UGS unable to supply sufficient volume of gas' is not well defined in the Latvian report, but its consequences in terms of correlated risks should be significantly lower, therefore this event is not included in the final list of correlated risks.

The following events are the most important as they pose the highest correlated risks:

Table 4: The most significant correlated risks for the Baltic States.

Country Report	Event analysed	Which country is affected?	Value of N-1x criterion for the affected countries
Latvia	Inčukalns UGS temporarily unable to supply gas	Estonia	60%
Latvia	Accident in TGP Izborsk-Inčukalns UGS (winter)	Estonia	60%
Latvia	Accident in TGP Vireši-Tallinn	Estonia	60%

8.2 UK and Ireland

Republic of Ireland imports about 95% of gas from via single connection point at Moffat (UK). The connection is twinned for most of its route, but there is a single pipeline of about 50km. In this case single failure in the UK infrastructure would have severe consequences on the Irish side.

The N-1x criterion in case of blockage of Moffat entry point, is equivalent to N-1 criterion for Ireland, because the Moffat connection is at the same time also the largest infrastructure of the Irish gas network. The UK risk assessment report does not explicitly provide possible failure modes for Moffat gas infrastructure, therefore as a general case the event is specified as 'Total loss of gas supply from the UK at Moffat". For this event, the corresponding criterion N-1x = N-1 = 15%.

The Irish risk assessment report provides information that Corrib gas field is under construction and Shannon LNG is being planned. This might significantly affect Irish N-1 value and correspondingly N-1x. New entry points would also mean increasing number of scenarios for which N-1x can be computed.

8.3 Bulgaria and Romania

Bulgaria is a gas transit country depending on a single supplier (Russia) via Romania, Moldova and Ukraine. This means that any accident or failure in the upstream transit country could have severe consequences for the downstream consumers. In case of Bulgaria, as all of its gas is supplied via single gas pipeline from Romania, computation of the criterion N-1x is equivalent to N-1 criterion, because there is no other import supply points from other countries and the existing one is the largest infrastructure.

Currently, Romanian risk assessment report is not available, therefore it is difficult to specify the events that might initiate loss of supply to Bulgaria. As an general case the event is specified as 'Total loss of gas supply from Romania at Negru Voda border point". For this event, the corresponding criterion N-1x = N-1 = 60% (for 2011).

As Bulgaria plans to expand its gas network and construct more border connections, the N-1x criterion might change in the near future, also leading to increased number of scenarios.

8.4 Other areas vulnerable to correlated risks

This report provides examples of several cases, where events in the gas system of one country might provoke severe consequences in another country or even groups of countries. This effect is in particular important when countries have single or few supply points. Systematic analysis of all Member States is necessary in order to identify the most vulnerable areas.

As evident from the topology of the European Transmission network, a number of areas can be severely exposed to correlated risks, among them (the list is not complete):

- Slovakia, Hungary, Austria and Czech Republic;
- Slovenia and Austria;
- Sweden and Denmark;
- Greece and Bulgaria;
- Belgium and Netherlands (only L-gas network);

The proposed N-1x criterion provides only an indicative measure to assess consequences of correlated risks, but has very limited capability to find and evaluate cost-effective mitigation measures or security upgrades. The next section describes development of European gas transmission network model which is primarily focused to identify network vulnerability to all types of risks including correlated risks as defined in this report.

9. Development of the European Gas Transmission Network model

The currently available European gas network model GEMFLOW uses aggregated cross-country connection capacities and is based on mass-balance approach. The GEMFLOW gas network model consists of one node per country and is able to provide general estimates of gas volumes available for each Member State. Table 1 provides an overview of the GEMFLOW modelling capabilities regarding correlated risk analysis. The main GEMFLOW limitations are:

- Aggregation of capacity and flows of all gas facilities in each Member State: LNG terminals, storages, cross-border connections, gas production, import routes;
- Modelling is performed under normal operational conditions, i.e. no reliability aspects are considered;
- No possibility to explicitly model most of external and internal hazards, except if they are affecting cross-border connections;

In order to overcome these limitations a more detailed network model must be developed, which can be then used to model much larger set of disruption scenarios compared to GEMFLOW.

9.1 Scope of the analysis

The model should consider the European gas network as a single system, having entry points at the EU borders or LNG terminals. The network of major transmission pipelines and compressor stations is shown in Figure 5. Local distribution networks should not be analysed as this will enormously complicate the study.

The time scale can be set to one day as a minimum time interval and 30 days as maximum. Taking into account inertia in the gas system, one day could be chosen as a reasonable time step to follow system dynamics. In fact, similar time considerations were implemented in the current GEMFLOW model.

The following major gas facilities should be explicitly modelled:

- Major transmission pipelines (only interconnected, not branches for local distribution networks);
- LNG terminals and regasification facilities (Figure 6);
- Gas storages;
- Gas production fields (domestic EU production);
- Gas compression stations;

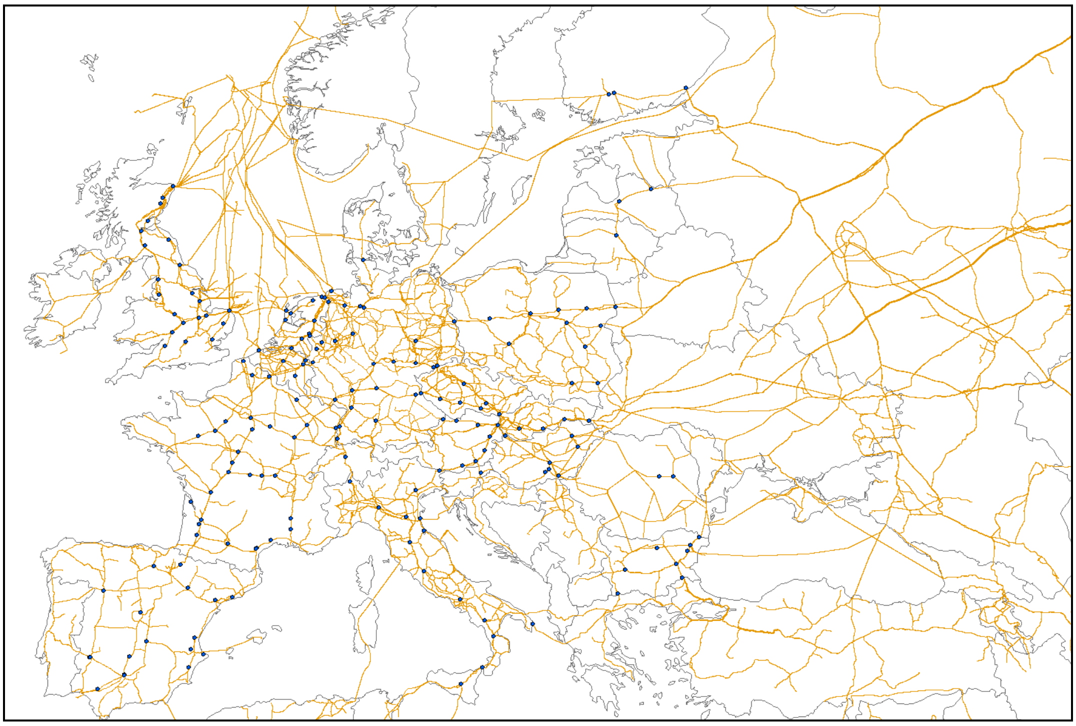

Figure 5: Major European Gas Transmission pipelines and compressor stations.

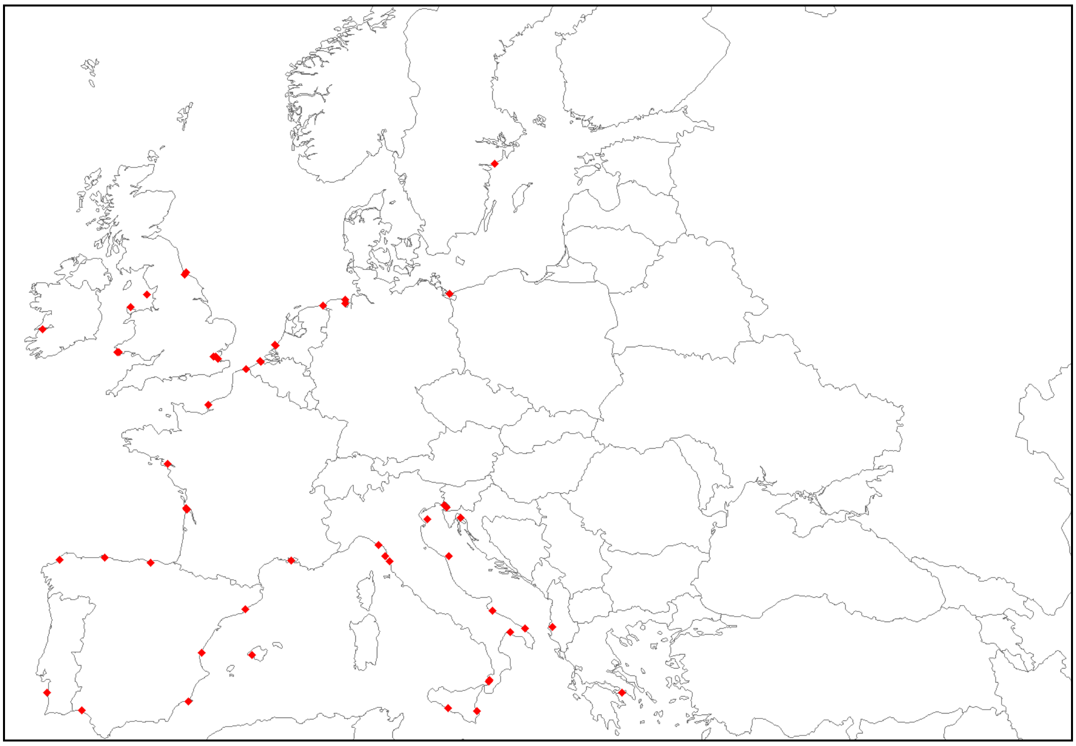

Figure 6: LNG regasification terminal points in Europe.

9.2 Input data and sources

The model should comprise the following technical data about the system components:

- Transmission pipelines:
    - Maximum available capacity (mcm/day);
    - Nominal capacity (normally used; mcm/day);
    - Direction of nominal flow;
    - Maximum available reverse flow capacity (mcm/day);
    - Time needed for reverse flow implementation (hours);
    - Diameter of a single pipeline (cm, optional);
    - Number of redundant pipelines on the same route;
- LNG terminals and regasification facilities:
    - Maximum design capacity (mcm/day);
    - Nominal capacity (mcm/day);
    - Time needed to get extra shipment (days);
    - Capacity of extra shipment (n days x mcm/day);
- Gas storages:
    - Working gas storage capacity (mcm);
    - Maximum and dynamics of withdrawal capacity (mcm/day);
    - Nominal capacity (mcm/day) during winter peak demand period;
- Gas production fields (domestic EU production):
    - Maximum withdrawal capacity (mcm/day);
    - Nominal withdrawal capacity (mcm/day);
- Gas compression stations;
    - Number of compressors and redundancy level;
    - Working pressure (bar/atm);

In addition to technical data, reliability data must collected either at single component level or at facility level. These would include information about mainly internal system hazards regarding (the list of not complete):

- Pipeline ruptures due to leakage, corrosion or overpressure;
- LNG supply disruptions due to failures in regasification system or LNG vessel accidents;
- Failures to withdraw gas from storages;
- Failures to withdraw gas from gas production fields;
- Failures (partial or complete) of compression stations;

The above listed data collection is a very time-consuming work that also heavily depends on data availability and accessibility. The network topology and basic technical parameters can be obtained from commercially available Platts and IHS databases, reliability information can be obtained from many reliability handbooks or specific reliability databases (e.g. EGIG report).

Any cooperation from the Member States in supplying or reviewing the data, network topology would be welcome and certainly improve the validity of the modelling output.

9.3 Methods

A number of techniques are currently under investigation:

- Monte-Carlo based stochastic models;
- Event/Fault tree models;
- Topological network analysis.

Automatic scan of all network components to determine their importance and contribution to risk will be performed when running the model.

9.4 Output results

The aim of the model is to investigate a number of predefined disruption scenarios due to:

- Import supply blockage or reduction;
- External and Internal hazards;

For each predefined disruption scenario or hazard, the following results are obtained:

- Determine the most important components, in terms of highest risk;
- Determine the most important disruption scenarios or hazards, in terms of highest risk;
- Which countries are affected, when and for how long;
- What alternatives are available and how effective they are to compensate for shortage;
- Quantitative evaluation of the effect of network development plans;

The modelling tool can be further upgraded by adding user-friendly interface and making an explicit link to GIS software, which could provide a useful platform for both selecting a disruption scenario for a study and displaying the results.

10. Conclusions

This report presents an approach to assess cross-border and regional risks, here called 'correlated risks'. It discusses the concept of correlated risk, the methods for hazard identification and screening, and the development of a European gas transmission network model.

This report presents the following tools to assess correlated risks of gas supply in the EU:

- GEMFLOW model for assessing import disruptions;
- A check list of hazards that can potentially affect more than one Member State;
- A risk overview table template to be used to summarise information from each country report and identify potential correlated risks.

The report also presents a case study of the 3 Baltic States to identify correlated risks by using risk overview table. Other two pairs of countries were discussed as well: Romania and Bulgaria; Ireland and UK. A systematic study is needed to identify all correlated risks in the European gas transmission network.

A conceptual framework of European gas network model development is presented that will be a powerful tool to assess all type of risks in the gas infrastructure.

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Appendix 1. Risk overview tables for the Baltic States.

Table 5: Risk overview table for Lithuania.

LITHUANIA – Risk overview table							
Event analysed	Type of event analysis performed	Quantification of likelihood	Evaluation of consequences	Risk evaluation	Can transit flow or supply to another MS be affected?	Which country is affected?	Value of N-1x criterion for the affected countries
Type I: Disruption of imports							
Minsk-Vilnius pipeline disruption due to political crisis or contract with Gazprom expiration in 2015	Descriptive	Qualitative: low	Descriptive: Tangible	n/a	No	n/a	n/a
Minsk-Vilnius pipeline disruption due to political/commercial disputes between suppliers (Gazprom) and transit country (Belorussia)	Descriptive	n/a	n/a	n/a	No	n/a	n/a
Type II: External hazards							
Terrorist attack	Descriptive	Qualitative: low	Descriptive: tangible	n/a	No	n/a	n/a
Natural hazards (earthquake)	Descriptive	Qualitative: negligible	n/a	n/a	No	n/a	n/a
Type III: Internal hazards							

Minsk-Vilnius pipeline failure	Descriptive	Qualitative: low	Descriptive: Substantial, loss of > 11M EUR	n/a	No	n/a	n/a
Vilnius-Riga pipeline failure	Descriptive	Qualitative: low	Descriptive: negligible	n/a	No	n/a	n/a

Table 6: Risk overview table for Latvia.

LATVIA – Risk overview table							
Event analysed	Type of event analysis performed	Quantification of likelihood	Evaluation of consequences	Risk evaluation	Can transit flow or supply to another MS be affected?	Which country is affected?	Value of N-1x criterion for the affected countries
Type I: Disruption of imports							
Pskov – Riga pipeline supply disruption due to commercial disputes with single supplier Gazprom	Descriptive	n/a	n/a	n/a	n/a	n/a	n/a
Type II: External hazards							
Terrorist attack	Descriptive	n/a	n/a	n/a	n/a	n/a	n/a
Type III: Internal hazards							
Inčukalns UGS unable to supply sufficient volume of gas	Descriptive, qualitative FT used	Qualitative: medium	Descriptive: medium	Qualitative scale: Medium risk	Yes	Estonia	>60%
Inčukalns UGS temporarily unable to supply gas	Descriptive, qualitative FT used	Qualitative: very low	Descriptive: very severe	Qualitative scale: Insignificant risk	Yes	Estonia	60%
Accident in TGP Iecava-Liepāja	Descriptive, qualitative FT used	Qualitative: medium	Descriptive: severe	Qualitative scale: Medium risk	No	n/a	n/a
Interruption of gas	Descriptive,	Qualitative:	Descriptive: very	Qualitative scale:	No	n/a	n/a

supply to Riga	qualitative FT used	medium	severe	Medium risk			
Accident in TGP Izborsk-Inčukalns UGS (winter)	Descriptive, qualitative FT used	Qualitative: low	Descriptive: significant	Qualitative scale: Significant risk	Yes	Estonia	60%
Accident in TGP Pskov-Riga (winter)	Descriptive, qualitative FT used	Qualitative: low	Descriptive: significant	Qualitative scale: Significant risk	No	n/a	n/a
Accident in TGP Riga-Daugavpils	Descriptive, qualitative FT used	Qualitative: low	Descriptive: medium	Qualitative scale: Significant risk	No	n/a	n/a
Accident in TGP Izborsk-Inčukalns UGS (summer)	Descriptive, qualitative FT used	Qualitative: low	Descriptive: severe	Qualitative scale: Significant risk	Yes	Estonia	>100%
Accident in TGP Pskov-Riga (summer)	Descriptive, qualitative FT used	Qualitative: low	Descriptive: severe	Qualitative scale: Significant risk	No	n/a	n/a
Accident in TGP Vireši-Tallinn	Descriptive, qualitative FT used	Qualitative: low	Descriptive: very severe	Qualitative scale: Significant risk	Yes	Estonia	60%
Accident in TGP Preiļi-Rēzekne, accident in TGP Riga-*Panevėžys*	Descriptive, qualitative FT used	Qualitative: very low	Descriptive: significant	Qualitative scale: Insignificant risk	No	n/a	n/a
Accident in line I of TGP Riga-Inčukalns UGS, accident in line II of TGP Riga-Inčukalns UGS	Descriptive, qualitative FT used	Qualitative: very low	Descriptive: medium	Qualitative scale: Insignificant risk	No	n/a	n/a

Qualitative scale of consequences and likelihood in the Latvian risk assessment:

Losses\Evaluation of consequences	***Insignificant***	***Significant***	***Medium***	***Severe***	***Very severe Consequences***
Direct losses (LVL)	Less than 10,000	0.01-0.1 million	0.1-1 million	1-10 million	More than 10 million
Number of users left without gas	Less than 5%	5-10%	10-30%	30-60%	More than 60%

Likelihood qualitative scale and range	***Very low***	***Low***	***Medium***	***High***	***Very high***
Range of frequency of occurence	Less than once in 100 years	Once in 51-100 years	Once in 16-50 years	Once in 1-15 years	Once per year or more often

Table 7: Risk overview table for Estonia.

ESTONIA – Risk overview table							
Event analysed	Type of event analysis performed	Quantification of likelihood	Evaluation of consequences	Risk evaluation	Can transit flow or supply to another MS be affected?	Which country is affected?	Value of N-1x criterion for the affected countries
Type I: Disruption of imports							
Accident in Russia, Izborsk – Tartu–Rakvere section of the transmission pipeline before the Värska GMS	Descriptive	Qualitative: low	Descriptive: low	minor	No	n/a	n/a
Accident in Latvia, Inčukalns –Vireši–Tallinn section of the transmission pipeline before the Karksi GMS	Descriptive	Qualitative: low	Descriptive: severe	acceptable	No	n/a	n/a
Simultaneous accidents in Russia and Latvia, transmission pipelines Izborsk–Värska GMS and Inčukalns – Karksi GMS	Descriptive	Qualitative: very low	Descriptive: severe	minor	No	n/a	n/a
Type II: External hazards							
Loss of electricity supply	Descriptive	Qualitative: very low	Descriptive: minor	minor	No	n/a	n/a

Type III: Internal hazards							
Värska GMS– Tartu – Rakvere pipeline rupture	Descriptive	Qualitative: low	Descriptive: low	acceptable	No	n/a	n/a
Tallinn – Rakvere – Jõhvi – Narva pipeline rupture	Descriptive	Qualitative: low	Descriptive: low	minor	No	n/a	n/a
Karksi GMS – Tallinn pipeline rupture	Descriptive	Qualitative: low	Descriptive: severe	acceptable	No	n/a	n/a

Qualitative scale of consequences and likelihood in the Estonian risk assessment:

Area	Severity level				
Vital sectors	A	B	C	D	E
	Minor	Low	Severe	Very severe	Catastrophic
	Short-term disturbance of sector activity. No direct consequences to other sectors.	Temporary disturbance of national gas supply. Consequences are eliminated by efforts of EGV alone. Impact of consequences of disturbance of gas supply on other sectors (heat supply) are negligible or low.	Gas supply disruption to the area for up to 72 hours. Necessary use of back-up systems or alternative measures. Impact of consequences of disruptions of gas supply to other sectors are severe.	Gas supply disruption to the area for longer than 72 hours. Necessary implementation of emergency measures. Impact of consequences of disruptions of gas supply to other sectors are very severe.	Long-term efforts required for restoration of gas supply. Impact on other sectors can be catastrophic.

Qualitative scale of the frequency of occurrence:

Probability level	Probability	Average frequency of occurrence
1	Very low	Less than once in 25 years
2	Low	Once in 25 years
3	Medium	Once in 5 years
4	High	Once a year
5	Very high	More often than once a month

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Abstract

With only few exceptions (Baltic states, Finland, Sweden), the European gas transmission network is well interconnected and could be viewed as a single gas infrastructure system. For historical reasons, the gas transmission networks were better developed inside each Member State and less attention was given for cross-border connections between Member States. National risk assessments of gas supply will be limited to geographical borders of each Member State and analyse only part of the whole gas infrastructure system. The risk assessment results of each country might not be complete or accurate enough due to the effects of interconnections between Member States. Therefore, Article 9 (1.d) requests to take into account "*the interaction and correlation of risks with other Member States, including, inter alia, as regards interconnections, cross-border supplies, cross-border access to storage facilities and bi-directional capacity*".

This report presents an approach to assess cross-border and regional risks, here called 'correlated risks'. It discusses the concept of correlated risk, the methods for hazard identification and screening, and the potential use of a European gas transmission network model.

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