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An Embargo of Russian Gas and Security of Supply in Europe

Harald Hecking · Christopher John · Florian Weiser

Abstract This study analyzes the case of a Russian gas export embargo starting in November 2014 and its effects on security of gas supply in Europe. Russian gas exports are crucial for European supply. In 2013, Russia exported more than 160 billion cubic meters of natural gas to Europe (including Turkey, excluding Belarus and the Ukraine), thereby supplying more than 30% of European annual gas demand.

The analysis is conducted on a country level with a special focus on Germany. The study is based on a computer simulation of European pipeline, storage and LNG infrastructure utilization. We simulate different durations of an export embargo, i.e., 1 to 9 months, different availability of LNG on global markets and different use of gas storage. Technical aspects such as pipeline pressure could be another threat for security of gas supply during an embargo, but these are beyond the scope of this paper.

The results found imply that in case of a 3-month embargo supply would be secured in almost all of the European countries except for in Bulgaria, Poland, Turkey and Finland. In case of a 9-month embargo the case is different and gas supplies in Germany, Italy, France and many countries in Eastern Europe would severely be affected. In total 46 bcm of European gas demand could not be served in that case.

Dipl.-Phys. F. Weiser (✉) · Dipl.-Volksw.,
Dipl.-Geoinf. H. Hecking · Dipl.-Phys. C. John
Energiewirtschaftliches Institut an der Universität zu Köln (EWI), Alte Wagenfabrik, Vogelsanger Straße 321a, 50827 Köln, Germany
e-mail: Florian.Weiser@ewi.uni-koeln.de

Ein Embargo auf russisches Erdgas und seine Auswirkungen auf die Versorgungssicherheit in Europa

Zusammenfassung Dieses Papier untersucht die Auswirkungen eines russischen Gasembargos auf die Versorgungssicherheit für Erdgas in Europa. Die Studie hat das Ziel, je nach Land mögliche Lieferengpässe zu quantifizieren. Ein besonderer Fokus wird auf die Situation in Deutschland gelegt. Für die Analyse werden verschiedene Szenarien betrachtet, welche sich in der Dauer des Embargos (ein bis neun Monate), in den Speicherfüllständen für den ersten Winter nach der Krise (d. h. am 1.11.2015) und in verschiedenen Mengen an im Krisenfall zusätzlich verfügbarem Flüssiggas (25, 45, 65 bcm) unterscheiden.

Die vorliegende Untersuchung ist eine Simulationsstudie und wurde mit dem Optimierungsmodell TIGER durchgeführt. TIGER ist ein lineares Modell des Europäischen Gasmarktes und berücksichtigt alle Pipelines des Europäischen Fernleitungsnetzes, die Gasspeicher sowie LNG-Terminals. TIGER errechnet in tagesscharfer Auflösung, wo welche Mengen an Gas produziert, transportiert und importiert werden müssen, um den täglichen Gasbedarf in 58 Nachfrageregionen zu bedienen.

1 Introduction

During the Russian/Ukrainian crisis in 2014, the European Union, the United States and other countries applied sanctions against several sectors of the Russian economy as well as Russian individuals. In turn, the Russian government imposed sanctions on food imports from, among others, the EU a few days later. Given the high level of uncertainty surrounding the future development of the Russian/Ukrainian crisis, other sanctions may be conceivable such as an

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embargo of natural gas—perhaps either an export embargo imposed by Russia or an import embargo by the European Union.

The effects of, say, a Russian gas export ban on the European gas supply are unclear. On the one hand, in 2013, Russia exported more than 160 bcm to Europe (including Turkey, excluding Belarus and the Ukraine), thereby supplying more than 30 % of European gas demand (BP 2014). On the other hand, significant gas production in Western Europe (the Netherlands, Norway, the UK) exists and, furthermore, LNG import terminals are currently underutilized at only one quarter of their capacity (IEA 2014b). Many European countries even have large gas storage capacities. Additionally, the importance of Russian gas varies by country: Whereas the Netherlands, for example, is a big gas producer itself, many Eastern European countries satisfy the majority of their gas demand from Russian gas (e.g., Hungary by 90 % or Poland by 60 %). Germany imports more than a third of its gas demand from Russia.

Given the importance of Russian gas imports for Europe, a potential export embargo by Russia could have severe short-term effects on security of gas supply in Europe. Therefore, the study aims at extensively analyzing European gas supplies under a Russian export embargo. In particular, we focus on the following questions:

- How would the European gas market counteract a Russian gas embargo?
- Which countries would suffer from supply shortfalls?
- How would Germany be affected by a Russian embargo?
- Could LNG fully compensate a Russian embargo and how much LNG would be needed?
- What is the role of storages during an embargo?
- What would be the effects of a cold spell during the embargo?
- How much revenue would Russian gas exporter Gazprom lose during an embargo?

This analysis is conducted by applying the European gas market simulation model TIGER. TIGER has been applied, for example, by (Bettzüge and Lochner 2009) to simulate the gas market effects of the Ukraine gas crisis in 2009.

The following section provides a brief introduction to previous work on the European gas supply situation and the Russian and Ukrainian gas crisis in 2009 as well as to publications using the TIGER model. Section 3 gives an introduction to EWI's TIGER gas market model and describes the optimization constraints. The model assumptions are presented in Sect. 4 before we state our results in Sect. 5. Finally, we would like to offer some concluding remarks and give our thanks in Sect. 6 and 7.

2 Literature

There is a wide literature concerned with Russian gas exports and the security of European gas supply. Spanjer (2007) and Sagen and Tsygankova (2008) analyze the energy relationship between Russia and the European Union and especially focus on the issue of unified pricing. Goldthau (2008) investigates the geopolitical threats that Russia could impose by using gas a political weapon. He comes to the conclusion that Russia could have difficulties to fulfill the growing European gas demand in the future and identifies a lack of investment in the Russian upstream sector as a risk for the European gas supply.

An event that gained much interest of the scientific community as well as the general public was the Russian-Ukrainian gas dispute in January 2009. Because Russia and the Ukraine did not agree on gas prices, the transit for Russian gas to Western Europe through Ukraine was disrupted for 2 weeks. Pirani et al. (2009) assess the political implications of the crisis. In comparison to this contribution, Bettzüge and Lochner (2009) and Lochner (2011) pursue a more quantitative approach to investigate the Russian-Ukrainian gas dispute by using the TIGER model. Bettzüge and Lochner (2009) come to the conclusion that the European gas infrastructure operators reacted in the best possible way during the crisis. The Russian-Ukrainian gas dispute motivated Morbee and Proost (2010) to research the impact of Russian reliability on European gas markets. They argue that it is more attractive for Europe to buy gas from reliable sources at higher prices than relying on unsecure, cheaper sources and building storage capacity.

Dieckhöner (2010) uses the TIGER model to analyze the security of supply effects of the proposed pipeline projects South Stream and Nabucco. Another application of the TIGER model that is not directly related to EU-Russia relations, but also focuses on security of supply issues is Lochner and Dieckhöner (2012). It analyzes the risks for natural gas supply by the political uprising in Libya in 2011.

Henderson and Heather (2012) assess the situation in January 2012 when Russia was not able to export the agreed gas volumes to Europe because of increased domestic demand caused by a cold spell.

Richter and Holz (2014) focus on different disruption scenarios within the context of the Ukrainian crisis in 2014. They use a global gas market model with 5 years steps. In comparison to that, our contribution focuses on the specifity of the European gas infrastructure and smaller time scales.

3 Methodology

3.1 The European Gas Infrastructure Model TIGER

In order to quantify the effects of a disruption of Russian gas flows on the European gas market, we apply the gas market simulation model TIGER.

The TIGER (Transport Infrastructure for Gas with Enhanced Resolution) model is a highly-detailed European infrastructure and dispatch model that is able to simulate gas production, LNG imports, storage operations and pipeline flows. The model minimizes the total cost for serving European gas demand with a given infrastructure and supply structure. TIGER simulates the gas market on a daily basis in order to assess short-term changes in the infrastructure utilization. The high degree of both spatial and temporal resolution enables a detailed analysis of a potential outage of Russian gas supplies to Europe.

The TIGER model is a linear network flow model with nodes and edges. The edges represent European pipelines. The nodes represent production sites, demand regions, LNG terminals, storages, connections between pipelines or exit and entry points to the grid. In total, more than 600 nodes and more than 900 pipeline sections are included in TIGER, allowing for a very high spatial resolution of the infrastructure.

TIGER includes 58 European demand regions. Germany, for example, is subdivided into 8 demand regions. In each region, shares of the total demand are assigned to 3 sectors: power generation, household and industry. Different demand sectors exhibit different seasonal demand patterns. Household gas demand is mainly driven by heating. Therefore, there are substantial differences in demand over the course of a year, which are derived from historic data. On the contrary, industrial gas demand is rather constant. Besides the seasonal effects, gas demand also differs on a daily basis. Therefore, the model accounts for differences in demand conditions on weekdays and weekends, which are relevant in all of the three sectors.

Gas supply is represented by 22 production regions in and around Europe. These production regions include the big gas exporting countries Russia, Norway, Algeria and the Netherlands as well as countries with smaller gas production such as Germany and Denmark. The model accounts for production flexibility. For example, the Groningen field in the Netherlands is characterized by high production flexibility due to its geological conditions. Additionally, long-term contracts both for LNG and pipelines are included in the model.

The infrastructure elements are modeled according to a wide range of technical details. A pipeline is characterized by its length, capacity, availability and flow direction. The flow direction is of particular importance in this analysis since reverse flows from Western Europe to Eastern Europe can become relevant given a Russian supply outage. Concerning storages, TIGER includes three different types of storages with different injection and depletion profiles: depleted oil or gas fields, salt or rock caverns and aquifers. In addition to the storage type, the injection rate, withdrawal rate and working gas volume determine the technical features of the storages. More than 200 storages, i.e. all relevant storages in Europe, are modelled in TIGER. LNG terminals are characterized by import capacity (hourly and yearly), LNG storage capacity and regasification capacity. TIGER accounts for all of the European LNG terminals.

3.2 Constraints for the Cost Minimization

To model the European natural gas market in a realistic way, the model accounts for the following constraints:

- **Node Balance Constraint:** In each node at every simulated day, the sum of inflows has to equal the sum of outflows. That is, production, pipeline inflow and storage withdrawal have to meet pipeline outflow, storage injection and the gas demand. In every node, the gas volumes transported into (or out), the production injected and the gas regasified has to equal the demand, the storage flows and the volumes used for compressor usage during storage injection or withdrawal.
- **Capacity Constraints:** To model not only the topology of the European gas infrastructure but also its physical constraints, the TIGER model accounts for maximum pipeline capacities, maximum storage volumes, injection and withdrawal rates as well as maximum LNG regasification capacities.
- **Production Constraints:** The production is constrained by an annual production capacity and, to account for production flexibility of certain gas fields, also by a daily production capacity (e.g. the Groningen gas field). The daily gas production, aggregated over one year is however restricted by the annual production capacity. Additionally, the TIGER model accounts for the ramping of field production.
- **Storage Constraints:** To simulate decreasing injection (or withdrawal) rates with rising (or declining) storage volume the storage in (or out) flow cannot exceed the maximum in (or out) flow rate multiplied by a factor depending on storage type and stored volume.

There are several limitations of the chosen modelling approach that will be discussed in the following.

TIGER is a cost minimizing model, thereby implicitly assuming a perfectly competitive market. Since a major part of European gas demand is supplied by a few (state-owned) gas exporters, there are concerns that the market is indeed perfectly competitive. Potential strategic behavior is however not modelled within TIGER.

Furthermore, a fixed demand is assumed, i.e. a demand reaction in response to a change in prices is not modelled. In reality, there is at least some price elasticity of demand in the gas market. For instance, gas and oil are substitutes for some industrial applications. In the power sector, a fuel switch can take place and the power system can adjust to supply electricity with less gas fired power plants. In the household sector, it would be possible that consumers slightly reduce their indoor temperature level and therefore demand less gas. To model these demand reactions, a detailed analysis on the price elasticities of gas demand would be required for each sector.

TIGER assumes perfect markets. In reality, there may be actors that are not purely guided by economic reasoning. In a crisis situation, political interventions would be possible. For instance, a country could forbid exports of gas to ensure its own security of supply for a longer period of time.

TIGER is a perfect foresight model. This is especially crucial for the storage operation, since the storages can adapt their depletion in an optimal way to the crisis. In reality, the length of an embargo would not be known. Therefore, the storage operators may be reluctant to empty their storages at an early phase of the embargo or do the opposite: extensively using the stored gas at the beginning of a crisis.

Since the focus of this study is on economic rather than technical modeling, the TIGER simulation model does not consider pipeline pressure. If gas exports from Russia are missing from the pipeline grid, many countries could have difficulties to transport, e.g., storage gas through the pipeline since a minimal pressure would be required. Therefore, supply issues could be aggravated. A detailed technical analysis of the European pipeline grid would be needed to precisely answer this question on a country level.

Another shortcoming of this analysis could arise from the daily time resolution. An hourly resolution could identify supply problems within a day, e. g. emerging from a morning peak in gas demand.

4 Main Assumptions

4.1 Main Assumptions

4.1.1 Gas Demand

We assume that the annual gas demand for each country is identical to the 2013 gas demand according to the IEA (IEA 2014b). Since this study does not include a gas demand forecast—neither for the power nor the industry or the residential sectors—it is reasonable to assume that gas demand remains at the 2013 level: Concerning gas demand for residential heating, we find by evaluating heating degree days from (EC Energy 2014) that apart from the exceptionally cold month of March, heating degree days in the EU between January and June 2013 are close to the long-term average. For Germany, in particular, we see a similar picture (Arbeitskreis Energiebilanzen 2013b). Although 2013 overall was slightly colder than the average, both a colder and warmer winter in 2014/15 is conceivable. Additionally, we eliminate outliers such as the exceptionally cold March 2013 by deriving monthly gas demand based on historical monthly demand patterns.

4.1.2 Gas Production

For most countries, we assume gas production to be identical to the output in 2013 (IEA 2014b) with two exceptions: For Norway, we assume an additional production during an embargo of 5 bcm per year, which is in line with the IEA (IEA 2014a). For the Netherlands, we assume that the output of Europe's largest gas production site, the Groningen field (53 bcm in 2013), will decrease in accordance with current legislation: The Dutch government recently imposed a maximal production rate of 42.5 bcm per year. Nonetheless, we account for the high production flexibility of the Groningen field.

However, the Groningen field can hardly compensate for the disrupted Russian gas flows during an embargo for two reasons: Even during a normal winter without an embargo, the field alters production according to the demand. Therefore, there is little remaining potential to further increase the output during an embargo situation. Furthermore, the gas produced in the Groningen field is L-Gas (i.e., low calorific gas), whereas Russian gas is of high caloric value (H-Gas). Many appliances (heaters, pipelines) that require H-Gas cannot be run using L-Gas for technical reasons and the blending capacity to transform L-Gas to H-Gas is scarce. Therefore, Groningen gas cannot easily substitute Russian gas.

4.1.3 Storage

Because of, e.g., the mild winter during 2013/14, storage volumes in many European countries were almost entirely filled by August 2014. This is a rare situation which has not been observed before. Hence, we assume a storage level of 100 % on November 1st, 2014, the first day of the embargo. For the time between November 2nd, 2014 and October 31st, 2015, storage operation is optimized within the model.

Another crucial assumption to make is the storage level one year after the crisis, i.e., on November 1st 2015: Each cubic meter of gas that does not need to be refilled in the storage until that day will help to compensate for the unavailable Russian gas. However, storage volumes must be sufficient to secure supply during the winter of 2015/16, especially in extreme events such as a cold spell or further trade disruptions. Therefore, we fix the storage levels to a level of 85 % on November 1st 2015. This is in line with historical values (2011–2013) from the Gas Infrastructure Europe (GIE) transparency platform (GIE 2014), which indicates that European storages remain, on average, between 84 and 94 %. However, it is highly speculative how markets will react and which storage levels will actually be realized by then. Therefore, we consider a sensitivity analysis with storage levels on November 1st 2015 between 70 and 100 %.

4.1.4 LNG Volumes Available to the European Market

Beside storages, the main supply sources to offset a Russian embargo are LNG imports. Europe and Turkey currently have LNG import capacities of about 200 bcm per year. However, it is highly uncertain how much LNG Europe could import during an embargo.

Approximately 75 % of global LNG is sold on the basis of long-term contracts (LTC). According to (IEA 2014a), only 87 bcm of global LNG was sold via medium and short-term contracts (duration below 4 years), re-exports (6 bcm) and flexible spot volumes. We estimate fully flexible LNG volumes to achieve a maximum of 25 bcm. Moreover, a part of the LNG volumes contracted by European importers is currently not delivered to Europe but is instead sold to world regions where LNG demand and prices are higher, such as Asia. In the case of an embargo, European buyers would have the right to purchase these volumes. However, determining the overall amount of potential LNG to be imported into Europe is highly speculative and depends on the price that European importers are willing to pay. The higher the price is, the more LNG that will find its way into Europe. In the end, European LNG prices will have to compete with those in Asia.

We assume total additional LNG, which European importers can purchase, at around 45 bcm per year, i.e. more than 90 bcm in total. Because of the crucial importance of that parameter, we consider sensitivities, i.e. 25 bcm and 65 bcm of additional imports per year.

4.1.5 Infrastructure and Reverse Flows

The computer simulation TIGER determines gas flows within the model accounting for the main European gas infrastructure, i.e. pipelines, LNG terminals and storages. TIGER includes a database which is continuously updated with data from the web portal of Gas Infrastructure Europe as well as data provided by infrastructure operators.

In particular, TIGER accounts for the possibility of reverse flows to Eastern European countries. Nonetheless, the potential to balance gas volumes between the European countries is limited: Long-term contracts and infrastructure restrictions limit the potential offsetting of shortfalls within Europe during an embargo. For instance, Spain has the ability to import large amounts of LNG. The options to export gas to France, however, are limited due to pipeline capacity constraints.

4.2 Scenario Outline

This study assesses a disruption of Russian gas exports to Europe and its effects on the gas supplies of European countries.[1] The analysis focuses on one year, i.e., the time range between November 1st, 2014 and October 31st, 2015.

In order to obtain a complete overview of the economic effects of a Russian embargo in a complex system such as the European gas infrastructure, we evaluate different scenarios with respect to:

- the duration of an embargo, i.e.: 1 to 9 months,
- the amount of additional LNG that can be imported to Europe, i.e., 25, 45 or 65 bcm and
- the amount of gas, withdrawn from storages during the crisis but not re-injected after the crisis, i.e. 15, 30 or 50 % of the European storage volume.

Additionally, we assess the ability of the gas infrastructure to withstand a cold spell: In the main analysis, we generally assume average temperature patterns, i.e. neither a very cold nor a very mild winter. However, an additional part of this analysis is to specifically model a week of very cold temperatures in order to simulate a stress situation for the gas infrastructure. The respective peak demand week in February 2015 is derived from the 14-days average scenario by the Ten-Year Network Development Plan 2013-22 (ENTSO-G 2013).

5 Results

5.1 How Would the European Gas Market Counteract a Russian Gas Embargo?

The upper map in Fig. 1 shows the pipeline flows, storage withdrawals and LNG imports in Europe aggregated for the time period between November 1st 2014 and April 30th 2015 for the case of **no embargo** of Russian gas flows. The map indicates the importance of Russian gas flows, in particular, for Central and Eastern Europe as well as Turkey.

Additionally, the bottom map in Fig. 1 shows how a **6-month embargo** of Russian gas exports affects infrastructure utilization in Europe. The map shows how the Euro-

[1] These countries include the EU−28, Switzerland, Norway, Bosnia/Herzegovina, Serbia, Montenegro and Macedonia. Turkey is also included because of its membership in the NATO. Ukraine and Belarus are only transit countries in this analysis, but not modelled as demand countries, therefore not part of this analysis.

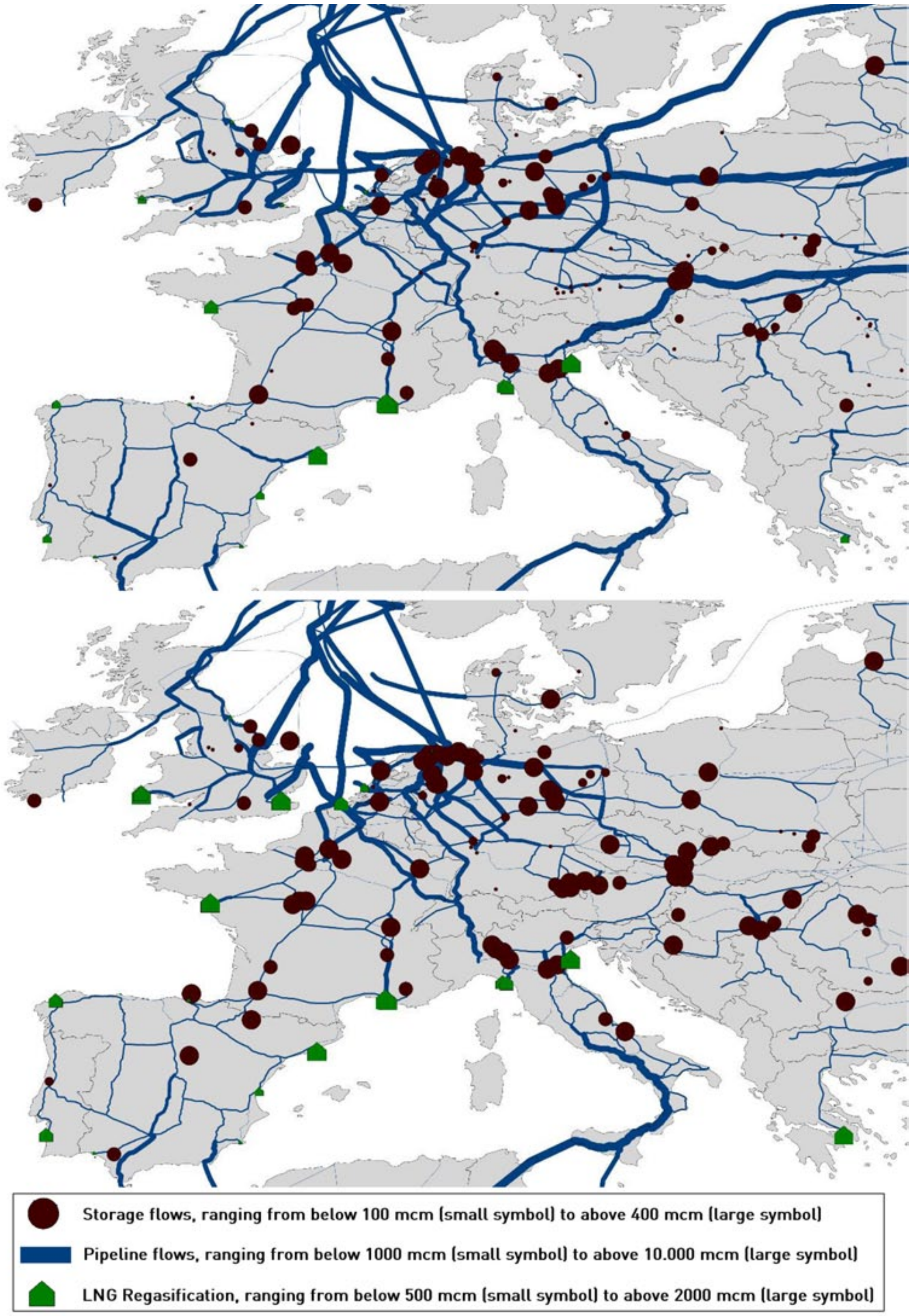

Fig. 1 European gas infrastructure utilization, November 2014–April 2015. (*Top*: no embargo; *Bottom*: 6-month embargo)

pean gas infrastructure compensates for missing gas imports from Russia: an intense utilization of storages, a shifting of pipeline flows and increased LNG imports. Nonetheless, supply shortfalls occur during a 6-month embargo.

5.2 Which Countries Would Suffer from Supply Shortfalls?

In the case of a **3-month disruption**, gas supply in all central and western European countries would be secured by intensi-

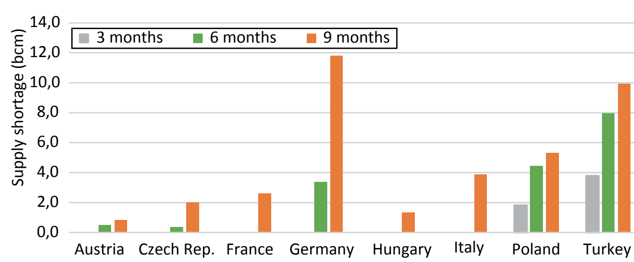

Fig. 2 Supply shortfalls in selected European countries for different embargo lengths (bcm)

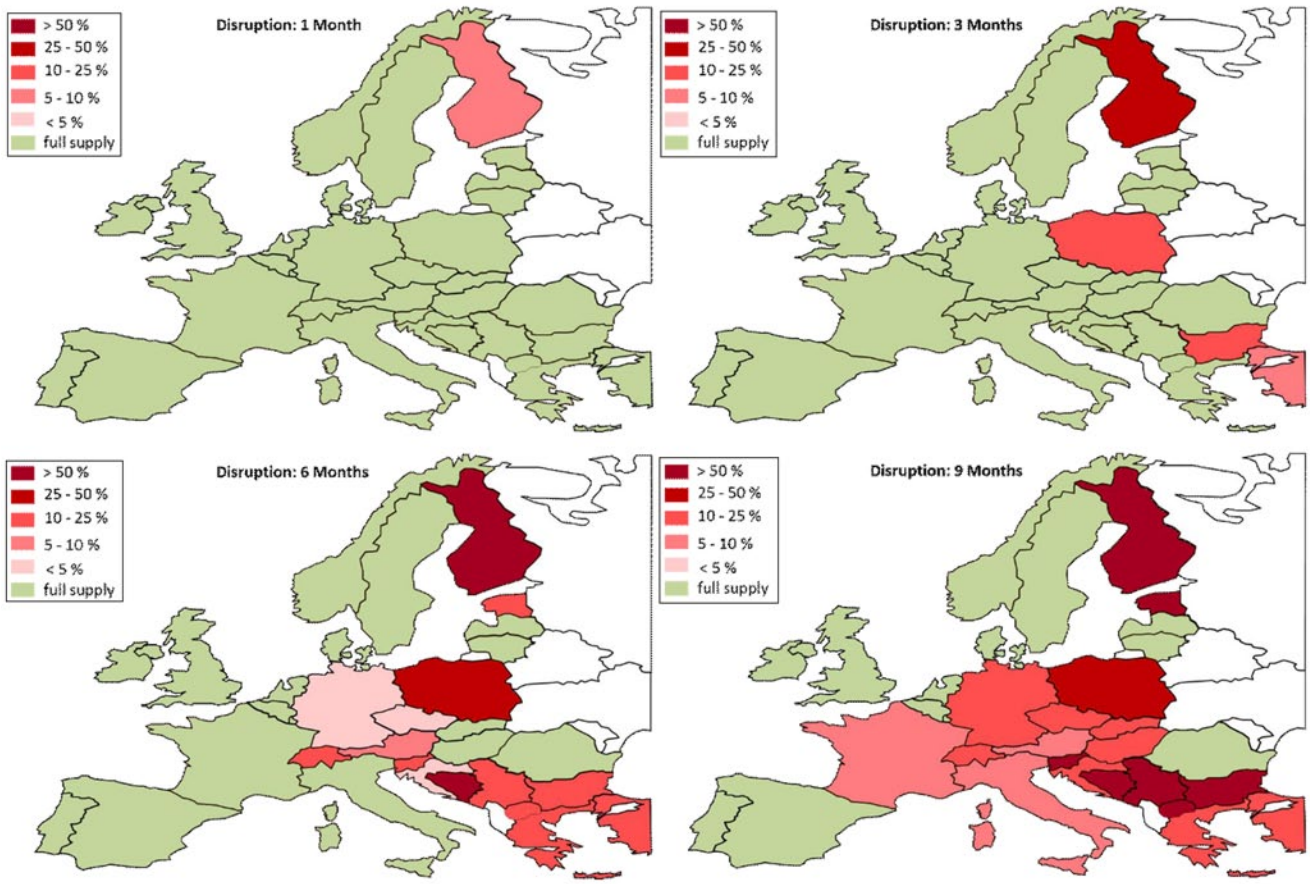

Fig. 3 Supply shortfalls in European countries relative to their annual demand

fied LNG imports and storage utilization. However, supply shortfalls would already occur in certain countries such as Bulgaria (0.5 bcm), Finland (1.1 bcm), Poland[2] (1.8 bcm) and Turkey (3.8 bcm) as illustrated in Fig. 2 and 3. Finland has no storage and no other gas supply options except for Russia. Poland and Turkey depend heavily on Russian gas as well.

A **6-month disruption** would incur supply shortfalls in large parts of Eastern Europe, but also in Germany (3.4 bcm). Italy and France, although being major importers of Russian gas, could secure gas supplies due to their high degree of supply-side diversification. Both countries benefit from their long-term contracts with Norway and the Netherlands, from LNG imports and extensive storage withdrawal. Italy additionally benefits from pipeline deliveries from Algeria and Libya. In total, 21 bcm of European gas demand could not be served during the disruption.

A **9-month disruption** would have severe effects on the gas supply of many European countries.[3] Despite their high degree of supply diversification, shortfalls would occur in both Italy (3.9 bcm) and France (2.6 bcm). In total, the supply shortfall in Europe would amount to 46 bcm. The four largest importers of Russian gas, i.e., Germany (11.8 bcm), Turkey (9.9 bcm), Poland (5.3 bcm) and Italy make up the majority of overall supply shortfalls. Even if storages only had to be refilled to 50 % (implying a high risk of supply shortages in the subsequent winter of 2015/16), overall shortages would amount to 26 bcm in Europe and 6 bcm in Germany.

The Western European countries in which gas supply would be secure even during a **9-month disruption** would include large gas producing countries such as Norway, the Netherlands and the UK. Additionally, Belgium (well integrated with the Netherlands plus LNG imports), Ireland (well integrated with the UK) and Portugal and Spain (both countries mainly rely on Algerian gas exports and LNG) could secure gas supplies during a 9-month disruption.

[2] The Polish LNG terminal of Świnoujście is not included in this analysis since the earliest launch is expected not before 2015.

[3] In the extreme scenario of a 9-month disruption, we even assume a lower storage refilling to only 70 %.

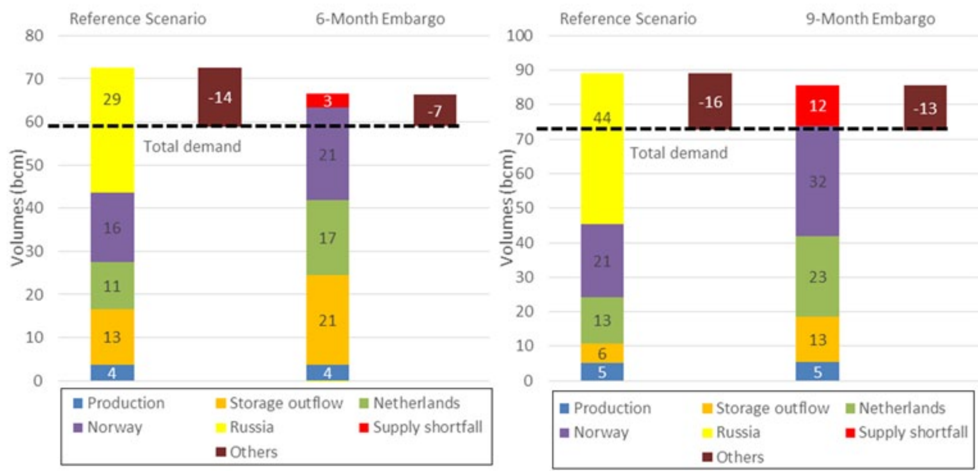

Fig. 4 German gas balance no embargo, a 6-month embargo and a 9-month embargo

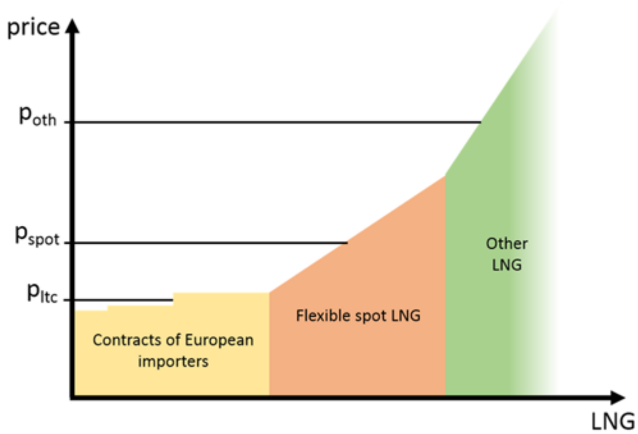

Fig. 5 Stylized overview of European LNG import sources

Table 1 Additional LNG supplies and supply shortfalls (bcm)

	3-month embargo		6-month embargo			9-month embargo	
(bcm)	25	45	25	45	65	45	65
Germany	1,6	0,0	8,8	3,4	0,0	18,4	8,3
Rest of Europe	10,9	7,1	44,9	17,3	15,4	41,8	31,6

Table 2 Refilling level of European storages and supply shortfalls (bcm)

	6-month embargo			9-month embargo	
(%)	70	85	100	50	70
Germany	0,0	3,4	6,7	5,5	11,8
Rest of Europe	13,7	17,3	28,6	20,6	45,5

5.3 How would Germany be Affected by a Russian Embargo?

Figure 4[4] illustrates the gas balance for Germany for the reference case and a 6-month embargo for the time period between November and May. Missing Russian gas (including some transit gas for, e.g., France or the Czech Republic) is compensated by higher flows from the Netherlands (including LNG from Rotterdam) and Norway. Additionally, gas storage plays a major role in securing supply. Nonetheless, over 3 bcm of demand cannot be satisfied during a 6-month embargo. We see similar effects for a 9-month embargo.

However, the ability of storages to secure supply decreases the longer the embargo takes. In a 3-month and a 6-month embargo, storages are very powerful to provide additional gas supply, in particular due to the unusually high fill level of almost 100 % that can be expected in the fall of 2014. If we assume that storages are refilled at November 1st 2015 by 85 % (hence, even slightly lower than the usual fill level), 15 % of the storage volumes or ca. 3 bcm can be interpreted as gas reserve provided by storages. In a 9-month disruption storages are less powerful to compensate the embargo. Even if the end-level in November 2015 is assumed to be only at 70 % of the storage capacity (thus providing a gas reserve of 6 bcm), the storages cannot be emptied to the full extent because otherwise they could not be refilled sufficiently.

5.4 Could LNG Fully Compensate a Russian Embargo and How much LNG Would be Needed?

The amount of LNG that European importers could additionally purchase on the global market is crucial for compensating a Russian gas embargo and avoiding supply shortfalls. Most of the global LNG is sold on the basis of short- and long-term contracts. The contracts are highly confidential, and therefore it is very speculative to determine the exact amount of LNG available to Europe. Figure 5 illustrates the opportunities that European importers have to source LNG.

[4] Transits through Germany comprise, e.g., gas flows from Russia to Czech Republic via the OPAL pipeline.

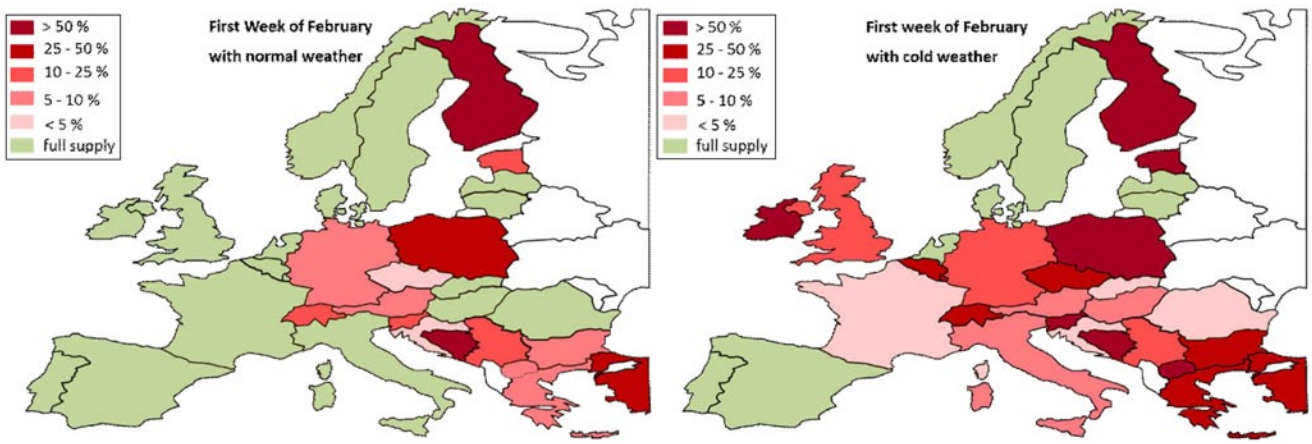

Fig. 6 Supply shortfalls during an embargo of 6 months with an average cold week (*left*) and with a cold spell week (*right*)

First, there are contracts by European importers that are currently not being used to full extent. Importers could purchase LNG for the contract price, e.g. based on oil-indexation. Second, fully flexible spot market LNG is available, most of which is currently bought by Asian importers. In order to purchase that kind of LNG, European importers had to compete with high Asian LNG spot prices. Third, European importers could bid so high prices such that importers, e.g., from Asia have an incentive that part of their contracted volumes are rerouted to Europe. Clearly, this supply source is kind of speculative and would be very costly, since LNG is usually also scarce in Asia.

As Table 1 shows, an additional 25 bcm of LNG per year would be insufficient to avoid supply shortages during a 3-month scenario. An additional 45 bcm of LNG per year would reduce supply shortages substantially and would stabilize gas supply in most European countries.

In a 6-month scenario, 65 bcm of additional LNG per year could help to avoid supply shortages in many European countries. For example, Germany, although not home to a LNG terminal, benefits from higher LNG imports thanks to large pipeline connections to the nearby LNG terminals in Belgium and the Netherlands.

In a 9-month scenario, even an additional 65 bcm of LNG would be insufficient to avoid supply shortages in many European countries, including Germany (8 bcm) and Italy (3.6 bcm).

5.5 What is the Role of Storages During an Embargo?

European gas storage volume amounts to 100 bcm, which is roughly 20 % of total demand. The primary usage of gas storage is to balance higher winter gas demand. During a crisis, storage could additionally work as a gas reserve: Storage was almost entirely filled by the end of August 2014. If storage is set to be refilled to 85 % before the winter of 2015/16, storage is capable of providing a gas reserve of 15 bcm during the embargo. If storage is expected to be refilled to 70 % before the next winter, storage is capable of providing a gas reserve of 30 bcm during a crisis. However, it is very speculative to determine the future storage level. Nonetheless, it is a crucial question when it comes to security of gas supply during a Russian gas embargo.

As Table 2 shows, refilling the storages to only 70 % would secure gas supply in almost every European country given a 6-month disruption. Exceptions are, e.g., Turkey or Poland, where limited pipeline infrastructure leads to supply shortfalls. In a 9-month scenario, even a 50 %-storage refilling could not prevent supply shortfalls in most European countries, Germany included.

Furthermore, the use of storages as a gas reserve is not a sustainable strategy: The more that storages are used during winter of 2014/15, the more vulnerable the gas market is during the winter of 2015/16, e.g. against further gas crises or an extremely cold winter.

5.6 What Would be the Effects of a Cold Spell During the Embargo?

So far, this analysis has focused on an average temperature level with average cold winter days and average warm summer days. However, the supply situation in many European countries could be more critical, during a disruption, if a one-week cold spell would occur. In this case, gas demand would increase significantly due to increased space heating and gas-fired power plants providing peak-load power. To simulate security of gas supply under such conditions, we model one week of extreme cold in the beginning of February 2015.[5] We further assume a 6-month disruption of Russian gas flows starting on November 1st, 2014.

[5] The respective peak demand week in February 2015 is derived from the 14-days average scenario by the Ten-Year Network Development Plan 2013–22 (ENTSO-G 2013). We even underestimate the severe-

Figure 6 shows that supply shortfalls would occur in almost the entirety of Europe. In many countries such as Italy, France and Belgium, gas supply would be secure under average conditions (left chart). However, in a peak-demand situation (right chart), i.e., a situation in which pipelines and storage infrastructure have to be utilized at even higher rates, missing Russian volumes cannot be compensated for in these countries.

Secured gas supply is much more difficult to achieve for a variety of reasons:

- Daily storage withdrawal capacity is limited.
- In February, storages are already on low levels (in particular during an embargo), and the lower pressure further decreases storage withdrawal potentials.
- Storage withdrawal can be limited by the capacity of the pipeline, which connects the storage to the grid.
- LNG imports to Europe will already be on very high levels because of the crisis.
- Increasing LNG imports even further will provide no immediate help, since ships have to be rerouted.
- Production flexibility will already be at the limit because of the crisis and cannot provide any extra gas during a cold spell.

5.7 How much Revenue Would Russian Gas Exporter Gazprom Lose in an Embargo?

A potential embargo of Russian gas flows would not only have severe effects on European gas supply, but also on the revenue of Russian gas exporter Gazprom. In 2013, Russia exported more than 160 bcm to the countries that would be affected by an embargo in this analysis (BP 2014). At contract prices between 240 and 320 EUR/kcm (Izvestia 2014) depending on the country the total sales volume of Russian gas sold to Europe amounted to roughly 45 to 48 billion EUR in 2013. Accounting for slightly higher winter exports of natural gas, monthly revenue can be estimated to equal 4 to 4.5 billion EUR for each month of an embargo. The total revenue of Gazprom, which holds the Russian export monopoly for pipeline gas, was estimated at 122 billion EUR in 2013[6] (OIES 2014). Thus, each month of gas embargo would decrease Gazprom's annual revenue by roughly 3.5 percentage points. We estimate that, accounting for transit and transport costs, this is equivalent to a cash contribution of gas sales of about 2.5 billion EUR per month which compares to the annual 2013 EBITDA of Gazprom of about 47 billion EUR (Gazprom 2014).

6 Conclusion and Outlook

A Russian gas export embargo during the winter of 2014/15 lasting for more than 6 month would cause supply shortfalls in many European countries, in particular, in Central and Eastern Europe, including Germany.

Since most of the European gas production runs at almost full capacity, three factors are crucial in securing gas supply in Europe: the availability of LNG imports and gas storages as well as no other shocks (such as a cold spell) occurring during the embargo.

Most crucial is the amount of LNG imports that European importers are able to purchase and that European gas consumers are willing to pay. Because of well-established interconnections between different countries (in particular in Northwestern Europe), additional LNG does not only help the LNG importing countries: Even though there is no LNG terminal in Germany, the availability of LNG is crucial for German gas supply. Because of the sound pipeline connections to Belgium and the Netherlands, Germany would benefit from LNG imports from these two countries. However, the LNG would only be available at prices well above today's standards.

With each additional month of an embargo, gas supply would become more critical since the potential of storages to offset gas volumes from Russia decreases. A 9-month disruption would cause a supply shortfall of more than 45 bcm in Europe. Germany, Italy, Turkey and Poland, being the four largest importers of Russian gas, would be most severely affected by supply shortfalls in that case.

However, a Russian gas embargo would not only have negative effects for Europe but also for Russia: Each month of an embargo would reduce revenues of Russian gas export monopolist Gazprom by roughly 4 to 4.5 billion EUR, or ca. 3.5 percentage points of its annual revenue.

Mid- to long term, the mutual dependency may be reduced. On the one hand, the European vulnerability to a Russian embargo may be mitigated by capturing a larger share of global LNG trade, currently sold via long-term contracts to other parts of the world. On the other hand, Russia's cooperation with China may offer alternative marketing opportunities for Russian gas, which may or may not be of comparable profitability for Gazprom.

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ness of a cold spell since the model can anticipate the extreme demand. In reality, market participants would not know the demand and would e. g. use storages less appropriately in this event.

[6] OIES (2014) cites an estimation of 162 billion USD derived by Sberbank.

Table 3 Assumptions of European gas demand in the cold and warm weather cases (bcm)

	Reference	Cold winter	Warm winter
Austria	8,5	9,0	8,1
Germany	89,0	94,9	84,6
France	47,3	50,3	44,2
United Kingdom	80,0	85,0	76,2
Poland	16,7	17,8	15,9
Italy	69,8	73,7	66,8
Turkey	45,7	48,3	43,5
Total Europe	528,7	559,4	502,0

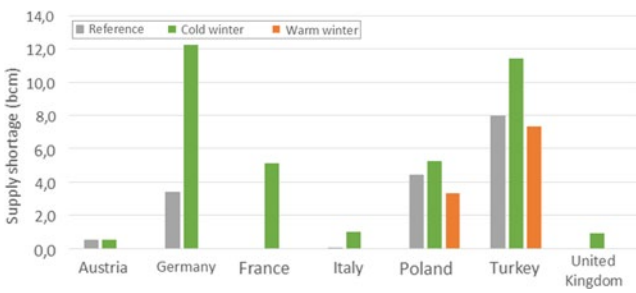

Fig. 7 Supply shortfalls during a 6-month embargo assuming a cold and a warm winter (bcm)

7 Annex: Robustness Check

Gas demand obviously is a crucial parameter for the severeness of a Russian gas embargo. Therefore, we include calculations assuming a rather warm and a rather cold winter (lasting from October till the end of March) during a 6-month embargo. In case of the warm year, the heating gas demand is reduced by 10 %, whereas heating gas demand is increased by 10 % in the cold year case. The gas demand for power generation (including "combined heat and power") is increased or reduced by 5 % in case of a very cold or very warm winter. The assumed demand values can be found in Table 3.

Figure 7 shows the simulation results for selected countries for a gas embargo lasting for six months. As expected, in the cold winter case, the overall supply shortage in Europe is above (48 bcm) that of the reference case (21 bcm) whereas in the warm winter case the opposite is true (14 bcm).

Assuming a 6-month embargo of Russian gas during a cold winter, supply shortages will occur, e.g. in France and Italy. Both countries were not affected by shortages in the reference case. In the case of Germany or France, the shortages increase more than the respective gas demand does when assuming a cold winter. One explanation for that finding is that gas demand is also assumed to be higher in other countries; gas supply, such as the import of LNG, is however limited, in particular on a daily basis. The higher the European winter gas demand is, the more stressed becomes the system.

In a 6-month embargo of Russian gas, a rather mild winter would relax the supply situation in many countries such as Germany. Poland and Turkey however would suffer from supply shortfalls even during a mild winter. Although warmer temperatures may reduce gas demand in those countries, alternative supplies will nonetheless miss such that supply shortages cannot be avoided.

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