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All quiet on the eastern front? Disruption scenarios of Russian natural gas supply to Europe

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HIGHLIGHTS

- We analyze disruption scenarios of Russian natural gas exports to Europe.
- Most EU countries are only weakly affected by a complete Russian supply disruption.
- We find that Eastern Europe is vulnerable to Russian supply disruptions.
- We identify infrastructure bottlenecks in the European natural gas network.
- We find that the large EU LNG import capacity is not sufficiently connected.

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ABSTRACT

The 2014 Russian–Ukrainian crisis reignited European concerns about natural gas supply security recalling the experiences of 2006 and 2009. However, the European supply situation, regulation and infrastructure have changed, with better diversified import sources, EU member states being better connected and a common regulation on the security of supply has been introduced. Nevertheless, European dependency on natural gas remained high. This paper investigates different Russian natural gas export disruptions scenarios and analyses short- and long-term reactions in Europe. We use the Global Gas Model (GGM), a large-scale mixed complementarity representation of the natural gas sector with a high level of technical granularity with respect to storage and transportation infrastructure. While we find that most of the EU member states are not severely affected by Russian disruptions, some East European countries are very vulnerable. Prioritizing the removal of infrastructure bottlenecks is critical for securing a sufficient natural gas supply to all EU member states.

1. Introduction

The 2014 tensions between the Russian Federation and Ukraine reignited European concerns about the security of its natural gas supply. Civil war in Ukraine and the sanction policies of the West and Russia have led to fears that Russian natural gas supplies will be interrupted not just to Ukraine but also the EU. At first glance, the dispute over natural gas prices and potential interruptions to supply was comparable to 2006 and 2009, although the situation is more severe with an actual looming war between Russia and Ukraine. However, since 2009 both the global and the European natural gas sectors have significantly changed

- Since the inauguration of the Nord Stream pipeline in late 2011, Russian exports of natural gas via the Ukraine have diminished from 65% of total Russian natural gas exports to Europe in 2010 to about 50% in 2013 (IEA, 2014a). The direct link to a West European importer has stopped the long-term reduction trend of the Russian share in total EU natural gas imports: Russia's share in the natural gas imports of the EU28 was above 50% in 2001 and fell to 37% in 2012, before increasing to 44% in 2013 (IEA, 2013b, 2014b).
- EU security-of-supply regulation 994/2010 (EU, 2010) was introduced in order to harmonize national emergency plans. Many EU interconnectors have been expanded in the aftermath and now allow for reverse flows (cf., ENTSO-G, 2010, 2014).
- The import capacity of Liquefied Natural Gas (LNG) in the EU has been expanded by 16% between 2009 and 2013; an increase to more than 185 bcm of physical import potential (cf. GIIGNL, 2010, 2014). EU LNG imports can potentially be increased since utilization rates are low; only averaging about 25% in 2013 (IEA, 2014b).
- In 2013, natural gas consumption in the EU was 6% lower than

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in 2009 (IEA, 2013a, 2014b). This is due to the economic crisis and low CO_2 prices which favor the use of coal in power generation. The mild 2013/14 winter left storage facilities filled above-average in the spring 2014.

- In the world markets, US natural gas imports were lower in 2013 than in 2009 by more than 50%, since US production increased by almost 20% due to a boom in the extraction of shale gas (EIA, 2014b). In particular, US LNG imports are much lower than previously expected and current projections suggest that the USA will become a net exporter of natural gas as of 2020 (EIA, 2014a; Richter, 2015).
- Japan, on the other hand, attracts more LNG imports to compensate for the (at least temporary) phase-out of nuclear power following the Fukushima Daiichi nuclear accident (cf. Hayashi and Hughes, 2013). Compared to the ten year linear trend prior to 2010, Japanese LNG imports (IEA, 2013b, 2014b) were about 15–20 bcm higher in 2013. Moreover, total LNG imports to Asia have increased by 50% between 2009 and 2014 (IEA, 2013b, 2014b).

Behrens and Wieczorkiewicz (2014) see the EU as better prepared for any disruption of Russian supply and highlight the dependence of Russia on the EU as its main customer. Although the Asian market is an attractive alternative for Russia, with good prospects (Paltsev, 2014), in the short-run actual trade flows are limited due to a lack of production and transportation infrastructure in East Russia. LNG export capacities and pipeline infrastructure toward Asian consumption regions have yet to be constructed on a large scale.

Despite the progress in the EU, the disruption of Russian natural gas exports to Europe may nevertheless have severe consequences, particularly for several East European countries. Consequently, the aim of this paper is an impact assessment with a focus on short- and long-term adjustment possibilities. We investigate the European natural gas market position, alternative natural gas suppliers, and the expansion of existing infrastructure in order to ensure the secure supply of natural gas. Complementary to Hecking et al. (2014) and EC (2014), we can highlight global trade flows of natural gas and infrastructure expansions that would attenuate the impact of Russian natural gas disruptions.

For this purpose, we use the Global Gas Model (GGM; Egging, 2013; Holz et al. 2013), a partial equilibrium model of the natural gas sector with a pronounced focus on natural gas trade and infrastructure. Notably, the current EU natural gas infrastructure is taken into account with its connection to external suppliers as well as the transportation network within the EU. Cross-border pipelines and global infrastructure to trade LNG are included in the model. We account for recent infrastructure developments, in particular reverse flows to Ukraine, that took place in response to the current Russia-Ukraine crisis. Hence, our results differ from earlier modeling exercises with less interconnection of Ukraine (e.g. Richter and Holz, 2014).

We compare three Russian natural gas supply disruption scenarios to a Base Case projection: two short-term disruption scenarios affecting, respectively, the Ukrainian supply and transit, and all Russian export pipelines to Europe, as well as one long lasting disruption of Russian natural gas supply to the European customers. Although unlikely, these scenarios serve to identify bottlenecks within the European natural gas infrastructure and highlight possibilities and necessary expansions in order to diversify the European natural gas supply.

The role of Russian natural gas supplies to Europe and in particular the importance of the individual transit routes has been discussed since the 1990s when Russia started to diversify from its traditional export route via Ukraine by constructing the so-called Yamal-Europe pipeline via Belarus (Fig. 1). Hirschhausen et al.

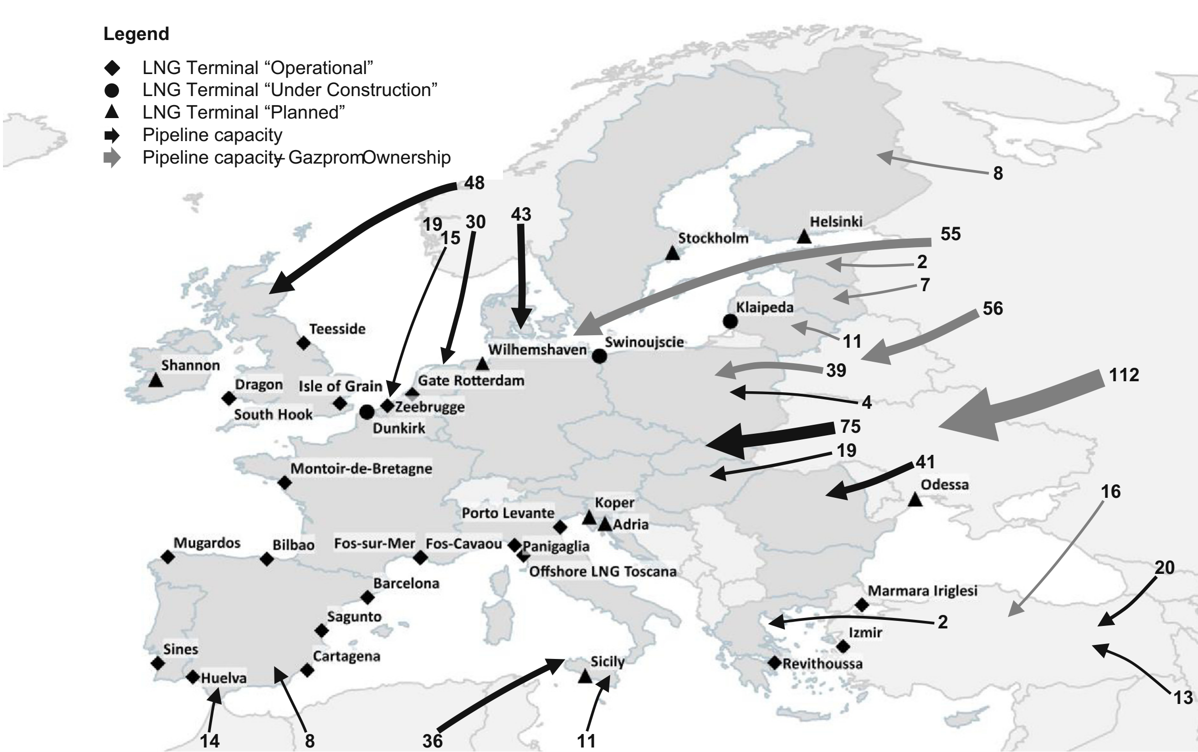

Fig. 1. European LNG and pipeline import infrastructure from external suppliers in 2014.
Note: Relative arrow sizes correspond to current capacities; figures represent current capacities in bcm/a. Source: Own illustration based on GGM database including information from GIIGNL (2014), ENTSO-G (2013a, 2014) and various sources. The blank map (shape file) is available from Eurostat: http://epp.eurostat.ec.europa.eu/portal/page/portal/gisco_Geographical_information_maps/geodata/reference.

(2005), for example, show that Yamal-Europe helped Russia to enforce cooperative behavior by the transit country Ukraine. Similarly, Hubert and Ikonnikova (2011) discuss the bargaining threat of the direct pipeline link between Russia and Germany (Nord Stream) on both Ukraine and Belarus as transit countries. However, the construction of the Nord Stream pipeline indicates that Russia did not perceive the threat to divert its exports as credible enough to discipline Ukraine and Belarus.

In addition, several numerical models of European and global natural gas markets can be found in the recent literature. Depending on the model setup, they may yield quite different results of disruption scenarios. In particular, one has to distinguish optimization models with a cost-minimization focus from equilibrium models with market power considerations by strategic players. While the former can hardly represent real-world trade flows with their diverse suppliers, the latter yield higher price levels than actually observed.

Lochner (2011) and Lochner and Dieckhöner (2012) use the optimization model TIGER to investigate the impact of Russian or North African supply disruptions, respectively. Lochner (2011) emphasizes the role of reverse flows and storage during a short-term disruption of Russian supplies to Eastern Europe. Lochner and Dieckhöner (2012) show that Italian consumers can to a large extent divert to additional LNG imports if North African supplies are interrupted. Hartley et al. (2009) also find that there is enough alternative supply to replace Russian exports using the Rice World Gas Trade Model, even in a short-term disruption scenario of a few months. They show that the subsequent replacement of Russian supplies by alternative sources, both from within and outside the EU, lasts more than a decade after a disruption.

Using an equilibrium model, Holz (2007) argues that the diversification of European supplies has led to situation in which Russia's exertion of market power actually reduces the Russian profits compared to competitive market behavior. In a similar non-cooperative game setup, Chyong et al. (2014) investigate the market power potential of the transit country Ukraine. They show that only if Ukraine effectively exerts market power, Russia has an incentive to develop an alternative export route to Southeast Europe, namely the South Stream pipeline.

Using the European Gas Model, which is also an equilibrium model, Egging et al. (2008) analyze a disruption of the Ukrainian transit and calculate European natural gas price increases by almost 20% on average and that Hungary is the country most affected. Huppmann et al. (2011) present a more comprehensive long-term disruption scenario of Russian supplies with the World Gas Model. They obtain a 40% price increase in Europe in 2015, in line with a reduction of consumption by more than 10%. In the long run, in a rather unconstrained model run, Russian supplies would be replaced by considerable LNG imports to Europe which require significant LNG import capacity investments. Russia would be hard hit in this scenario with 40% less profits than in the Base Case due to the smaller sales volumes.

Compared to this earlier literature, we use an updated and more refined data set with a particular focus on European infrastructure. Similar to Egging et al. (2008), our results show that a disruption of Russian natural gas exports to and transit through Ukraine severely affects some East European countries, in addition to Ukraine itself. On average, however, the EU is affected with only slightly higher prices. A complete disruption, as in Huppmann et al. (2011), would affect all EU countries with an average price increase of more than 20% in the first year of the shock with large regional deviations across European countries: East European countries are affected far more severely. The change of the import structure is dominated by a stronger reliance on LNG imports. Results indicate that the EU LNG import capacity is insufficiently connected to large parts of the European market.

In case of a long lasting interruption of Russian supply, more investments in the transportation infrastructure are necessary than in the Base Case to diversify the EU imports and balance the internal market. These include the connection of the Iberian Peninsula and Italy to Central Europe to distribute the large import potentials of both regions from North Africa and the global LNG market. Pipeline expansions to reach the Baltics from Poland are advisable, as well as investments in the pipeline network in the Southern Corridor to bring natural gas from the Caspian region and the Middle East via Turkey to those countries that are most affected of a Russian supply disruption.

The remainder of this paper is organized as follows. Section 2 provides a description of the GGM and presents the underlying data set with a specific focus on the European natural gas import infrastructure. In Section 3 we discuss our model results. Section 4 concludes and highlights policy implications of our analysis.

2. Methods

We make use of GGM to numerically simulate future patterns of natural gas production, consumption and trade, as well as to analyze scenarios around supply disruptions of Russian natural gas to Europe.

2.1. Model and data description

GGM is a partial equilibrium model of the global natural gas sector; it is based on a stylized representation of market entities along the entire natural gas value chain, i.e. producers, traders, transmission and storage system operators (TSO and SSO). These agents are characterized by profit maximizing behavior under operational and technical constraints, such as transportation and storage capacity restrictions. Final natural gas consumption across the sectors of industry, power sector, residential and commercial is represented by an aggregated inverse demand function for each consumption node.[1]

The model features seasonality in form of a high and low demand season, as well as market power of selected traders. Investments in infrastructure can be decided endogenously: Investment costs are weighted by the TSO, or the SSO, against the future stream of revenues from pipeline transit fees or and storage rents, respectively. Players are assumed to behave rationally under full information and perfect foresight; the results are thus to be interpreted as long-term cost-efficient equilibria in the presence of market power. We abstract from institutional frictions, such as long-term contracts or oil-price linking. Consequently, simulated trade flows may differ from actually observed exports and imports.[2]

The GGM is set up as mixed complementarity problem (MCP; cf. Facchinei and Pang, 2003), numerically applied and solved using the PATH solver (Ferris and Munson, 2000) with the software GAMS. Equilibria are calculated in five years steps starting in 2010 and reported until 2040; the model horizon is extended by two periods in order to give incentives for investments in the last periods.

The GGM data set includes 79 countries represented by 99 geographical nodes (see the Appendix for a complete list of countries), being close to global coverage with 98% of natural gas consumption in the year 2010 represented.[3] Each node is characterized by current

[1] The inverse demand function,, or the willingness-to-pay function, shows for each quantity which price the consumers in a certain market are willing to pay and usually is a downward-sloping curve.

[2] A more thorough model description including the mathematical formulation can be found in Egging (2013). See Holz et al. (2013) and Holz et al. (2015) for model applications.

[3] The GGM database includes 26 EU member states across 24 geographical nodes

and projected reference consumption and production levels (see the next section for a description of the Base Case), reference prices, production capacities and costs, as well as capacities of the transmission and storage system.

For each consumption node and model period, we construct a specific inverse demand curve using reference consumption levels and prices as well as demand sector shares and sector specific elasticities; we assume an elasticity of −0.4 for the industrial sector, −0.75 for the power sector and −0.25 for residential and commercial demand. A country with a high share of natural gas usage in power generation is consequently represented by a more price elastic demand function than a country where natural gas is predominantly consumed in the residential and commercial sector. The price responsiveness of suppliers in turn is determined endogenously and depends on production and transportation costs and capacities as well as on the potential to exert market power.

The model data originate from various and generally publicly available sources. For instance, cross-border capacities of pipelines toward and within Europe are provided by ENTSO-G (2013a, 2014),[4] information for worldwide LNG infrastructure is given by GIIGNL (2011–2014) and storage capacities by GIE (2011–2014). Furthermore, we make use of IEA and EIA publications, data from national statistics offices, and company reports.

Short-term production capacities are determined by the reference production levels, scaled up by assuming country-specific slack capacities, which vary between 2% and 15% across producers and periods. The larger the slack, the more flexibly a producer can increase its production (at rising costs) in response to an exogenous shock. For instance, slack production capacities in Norway and the Netherlands are assumed to be about 15% each in the model period 2015.

Capacities of pipelines, LNG and storage facilities are determined by exogenous initial capacities (i.e. infrastructure that is operational or currently under construction), and by potential endogenous expansions after 2015. Expansions in later model periods are solely determined by endogenous decisions; in 2010 no endogenous investments (that would be effective in 2015) are allowed.

Compared to Richter and Holz (2014) we use updated transport infrastructure data for 2015. Some projects have been delayed compared to earlier anticipations and will not yet be available in 2015, for example South Stream (originally scheduled for end of 2014) and a major pipeline from Russia to the Chinese demand centers on the Eastern coast (originally scheduled before 2015).

All current European and global pipeline, storage and LNG capacities are included in the data set (e.g. from ENTSO-G, 2014; GIE, 2014 and GIIGNL, 2014). Fig. 1 shows the European infrastructure to import natural gas from external suppliers, both through LNG terminals and pipelines. Pipeline capacities are depicted in Fig. 1, while Table 1 provides information on capacities of operating LNG regasification terminals in the EU in 2010 and 2013, as well as the exogenous 2015 additions for the GGM simulation runs. We take into account new LNG regasification capacity in Lithuania and Poland (3 bcm and 5 bcm, respectively) in 2015; terminals planned or under construction in France (13 bcm), Croatia (5.5 bcm), Finland (4 bcm) and Ireland (3.5 bcm) are available only as of the model period 2020.

(*footnote continued*)
(Lithuania, Latvia and Estonia are aggregated in the region "BALT"). The EU member states not included are Luxembourg and Malta.

[4] Note that entry/exit capacities given by ENTSO-G are not necessarily equal to physical restrictions but rather represent "capacity simulations performed by the respective TSOs" (ENTSO-G, 2013b, p. 29). Due to lack of an alternative comprehensive data set, we implement the ENTSO-G data as initial capacities.

Table 1
LNG regasification capacity in the EU in 2010 and 2013, as well as exogenous additions for 2015 in GGM, in bcm.
Source: GIIGNL 2011, 2012 and 2013 and project homepages.

Country	Terminal	2010	2013	2015 GGM additions
Belgium	Zeebrugge LNG Fluxys LNG	9.0	9.0	
France	Fos Tonkin and Fos Cavaou Elengy	8.3	8.3	
France	Fos-sur-Mer	5.5	5.5	
France	Montoir de Bretagne Elengy	10.0	10.0	
Greece	Revithousa	5.0	5.0	
Italy	Panigaglia	3.3	3.3	
Italy	Rovigo (Atlantic) Cavarzere Porto Levante	8.0	8.0	
Italy	Offshore Livorno	–	4.1	
Lithuania	Klaipeda Floating Terminal	–	–	3.0
Netherlands	GATE Rotterdam	–	12.0	
Poland	Swinoujscie	–	–	5.0
Portugal	Sines REN Atlantico	5.2	7.6	
Spain	Barcelona Enagas	17.1	17.1	
Spain	Bilbao BBG	7.0	7.0	
Spain	Cartagena	11.8	11.8	
Spain	Huelva	11.8	11.8	
Spain	Mugardos Reganosa FERROL	3.6	3.6	
Spain	Sagunto Saggas	8.8	8.8	
Spain	Gijon (El Musel); mothballed (7.5 bcm)	–	–	
UK	Dragon	6.0	7.6	
UK	Isle of Grain	19.5	20.5	
UK	South Hook	21.0	21.2	
UK	Teesside Dockside	4.6	4.2	
EU	**Total regasification capacity**	**165.5**	**186.4**	**194.4**

2.2. Scenario definitions

We set up the GGM *Base Case* in line with projections of the *New Policies Scenario* (NPS) of the *World Energy Outlook* 2013 (IEA, 2013c), on which we base the reference production and consumption values. The NPS is a moderate climate policy scenario. It assumes the implementation of current policies leading for instance to a reduction of CO_2 emissions between 1990 and 2035 of almost 40% for the EU, while global CO_2 emissions further increase to 20% above the 2011 level.[5] Relative production and consumption levels across EU member states are given by EC (2013). The shares of each EU country from EC (2013) are applied to the total EU forecast by IEA (2013c) to ensure consistency in the worldwide context.

Three disruption scenarios of Russian supply to Europe are constructed that deviate from this *Base Case*; two short-term disruptions of Gazprom majority-owned infrastructure and one long lasting. In the first two disruption scenarios only the model period 2015 is shocked, i.e. affected by exogenous assumptions.

- In the first scenario, "*Ukraine Disruption*", it is assumed that all pipeline connections to Ukraine, which serve to deliver Russian natural gas, are interrupted in 2015. Hence, no exports of Russian natural gas to Ukraine and no transit via Ukraine can take place.
- In the second scenario, "*Gazprom*", the total infrastructure which is majority-owned by OAO Gazprom or by any of its subsidiaries is interrupted in 2015. Belarus is assumed to be continuously supplied but does not serve as transit country during the shock. Hence, all Russian exports to Europe are cut

[5] See Holz et al. (2015) for an analysis of the role of natural gas under ambitious global climate policies.

off. Additionally, storage facilities in several European countries are affected. It is assumed that the merger with Wingas AG is successfully completed until 2015, which gives Gazprom the ownership of the largest European storage facility in Rehden, Germany, and of the Haidach storage in Austria.

- In the third scenario, "*Long Disruption*", we assume that Russian natural gas supply to Europe is interrupted from 2015 until the end of the model horizon 2040. As in the Gazprom scenario, all Gazprom majority-owned infrastructures are shut down. We allow for unrestricted pipeline capacity expansions by all other players as of 2015 in response to the lasting disruption. Hence, this scenario indicates the most important infrastructure projects in case of a lasting Russian supply disruption.

See Table 2 for detailed scenario descriptions, while Table 3 shows the capacity differences of all affected pipelines across scenarios. In order to avoid any inconsistencies, in all disruption scenarios all the decision variables in the first model period 2010 are fixed at *Base Case* levels. Hence, any disruption in or as of 2015 are not anticipated by any model agent; infrastructure capacities and trade patterns in 2010 are the same across scenarios.

3. Results and discussion

3.1. Base case projections until 2040: the setting

The GGM *Base Case* is characterized by an increasing world production and consumption of natural gas over time (+65% between 2010 and 2040). Notably, the Asia-Pacific region (see the Appendix for country assignments to the regions) plays a dominant role by strongly increasing consumption and import levels of natural gas, jointly occurring with rising production.

Table 3
Selected pipeline (gross) capacities at the time of disruption in 2015, in bcm/a.

From	To	*Base Case*	*UKR Disruption*	*Gazprom*
Russia	Finland	8.36	8.36	0
Russia	Germany	57.17	57.17	0
Russia	Turkey	16.49	16.49	0
Russia	Ukraine	114.29	0	0
Belarus	Baltics	10.69	10.69	0
Belarus	Poland	39.92	39.92	0
Belarus	Ukraine	25.25	0	0
Germany	Czech Republic	44.50	44.50	13.32

Note: Assumptions for the Long Disruption *scenario are similar to those in* Gazprom *but lasting until the end of the model horizon.*

By contrast, the EU's import needs increase in line with its declining domestic production, which reduces by about 60% between 2010 and 2040; the import dependency increases to about 85% of total consumption until 2040. While total imports increase over time, the share of Russian supply to the EU market decreases (see Fig. 2). *Base Case* model results thus hint at a long-term diversification of European supplies with a higher reliance on natural gas from Africa, the Caspian region and LNG exporting countries in the next decades.

In 2015—the model period which is subject to Russian disruptions in the following scenarios—global production and consumption levels are 10% higher than in 2010; EU natural gas consumption is lower by 8%, EU production substantially lower by 20% relative to 2010.

3.2. Two short-term disruption scenarios

We next analyze and discuss the results of both short-term scenarios relative to the *Base Case* setting. All results shown in this

Table 2
Scenario descriptions of GGM simulation runs.

Scenario name	Description	Specific assumption
Base	*Base Case:* Projections of future natural gas production, consumption and trade based on the *New Policies Scenario* of the IEA (2012)	
Ukraine disruption	*Disruption of supply to and transit via Ukraine:* Interruption of Russian pipeline connection to Ukraine (neither direct pipeline connection from Russia nor indirect connection via Belarus included) in 2015	• Zero capacity on pipeline RUS-UKR • Zero capacity on pipeline BLR-UKR
Gazprom	*Disruption of Gazprom infrastructure to Europe (incl. Turkey):* Reduction of total cross-country pipeline and storage capacity in 2015 that is currently majority-owned by Gazprom (incl. subsidiaries). Belarus is not affected, i.e. the pipeline from Russia and the Belarussian storage capacity has full capacity. However, the transit via Belarus is disrupted. Affected pipelines: • Nord Stream • Brotherhood • Yamal Europe • Blue Stream • South Stream • OPAL	• Zero capacity on pipeline RUS-DEU • Zero capacity on pipeline RUS-FIN • Zero capacity on pipeline RUS-BALT • Zero capacity on pipeline RUS-BGR • Zero capacity on pipeline RUS-TUR • Zero capacity on pipeline RUS-UKR • Zero capacity on pipeline BLR-UKR • Zero capacity on pipeline BLR-POL • Zero capacity on pipeline BLR-BALT • Reduced capacity on pipeline DEU-CZE by 70%
	Affected storage facilities • Rehden in Germany • Haidach in Austria • Incukalns in Latvia • Banatski Dvor in Serbia	• Reduced storage capacity in DEU by 20% • Reduced storage capacity in AUT by 35% • Reduced storage capacity in BALT by 100% • Reduced storage capacity in SRB by 100%
Long disruption	*Long-lasting Disruption of Gazprom infrastructure in Europe* Continuous disruption of Russian natural gas supply to all EU member states and other European countries (Ukraine, Serbia, Switzerland and Turkey). All Gazprom majority-owned infrastructures are not used after 2010. This lasting supply disruption can be anticipated and responded to by investments in the pipeline network from 2015 onwards (being operational as of 2020).	• Same as in Gazprom but for all model periods after 2010 • Anticipation and unlimited investment as of 2015

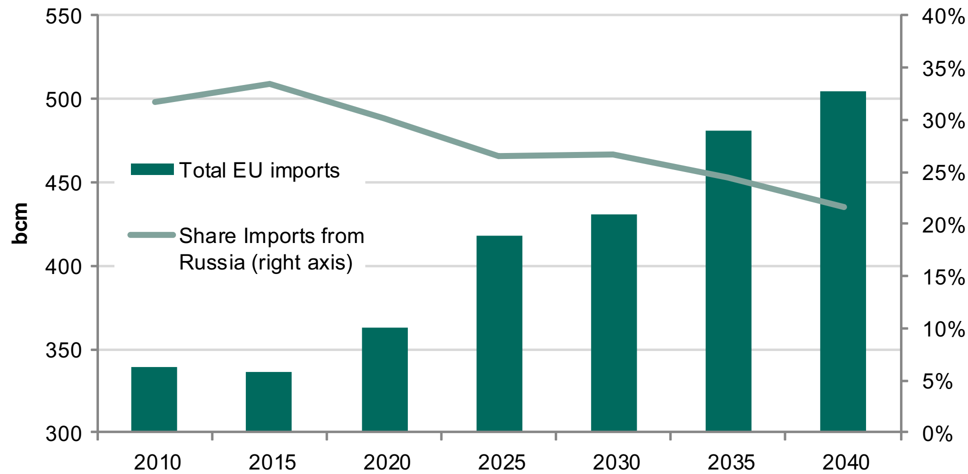

Fig. 2. Total EU natural gas imports (left axis) and Russian share (right axis) in the *Base Case*, in bcm and percentages.

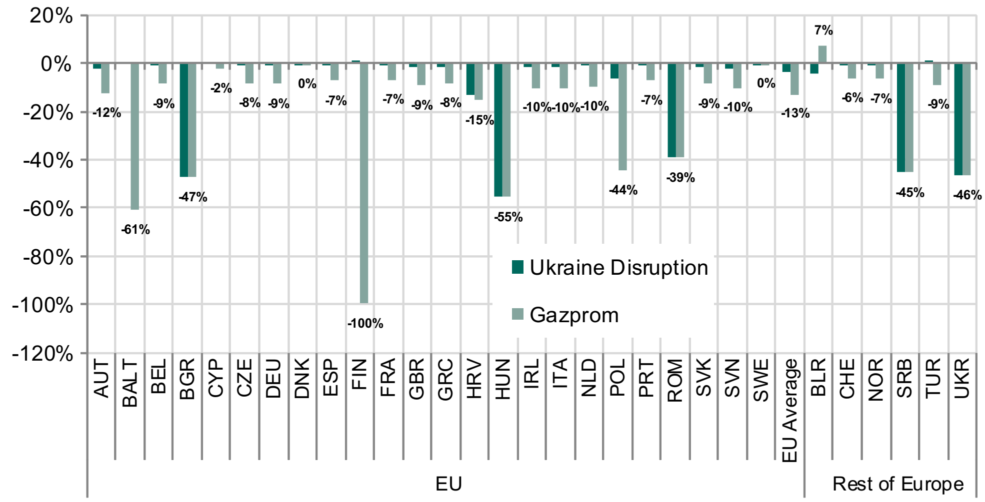

Fig. 3. Changes of consumption levels relative to the Base Case in 2015, in percentages. *Note: Values for the Gazprom scenario are provided next to the respective bars.*

section refer to 2015, the year of the hypothetical disruption. Of particular interest are changes in consumption levels and associated prices, as well as adjustments of the EU's import structure. We focus on the role of LNG, highlight infrastructure bottlenecks and analyze the Russian position as well as global adjustments in production.

3.2.1. Reduced consumption and shift in European supply structure

By construction, in the *Ukraine Disruption* scenario Ukraine is substantially affected. Its natural gas consumption is reduced to almost 50% in 2015 relative to the *Base Case*, supplied via reverse flows from Poland and Slovakia as well as by its marginally increasing domestic production.

On the other hand the EU is on average only slightly affected with small reductions of consumption levels (by 4%, or 20 bcm relative to the *Base Case*), although the deviation across countries is large (see Fig. 3). In particular, in Bulgaria, Hungary and Romania consumption is reduced substantially by more than 35%, but also in Croatia and Poland the Ukrainian transit disruption can be felt (−13% of natural gas consumption and −6%, respectively).

The *Gazprom* scenario is characterized by similar effects on Ukraine but a stronger impact on the EU member states. At the aggregate level, EU consumption in 2015 is reduced by 13%, or 65 bcm. Notably, Finland, East European countries and the Baltics are affected the most, but also consumption in major Central European countries decreases, like in Germany by 8% or 7 bcm.

A reduction in consumption levels can be the result both of physical limitations of the available infrastructure and of economic considerations, i.e. the relation between the willingness-to-pay and the price for natural gas. Note that for each country and model period, an equilibrium price-quantity pair along the constructed demand curve is reached. Accordingly, natural gas prices are changed relative to the *Base Case* (see Figs. 4 and 5).

Similar to consumption levels, prices in *Ukraine Disruption* are significantly higher only in Ukraine, Hungary, Serbia, Romania and Bulgaria relative to the *Base Case*, while in *Gazprom* almost every EU country is affected by price increases of more than 10%; by 23% on consumption-weighted average. For the Baltic countries the price increase is particularly pronounced in the high demand season due to the complete interruption of storage facilities.

The shortfall of Russian supply in 2015, affecting some countries (*Ukraine Disruption*) or almost all European countries (*Gazprom*), is compensated to some extent by an increase in production as well as by imports from other producing regions. Fig. 6 shows that the impact is most visible in a pronounced change in the EU import structure with a significant increase in the share of LNG imports. EU

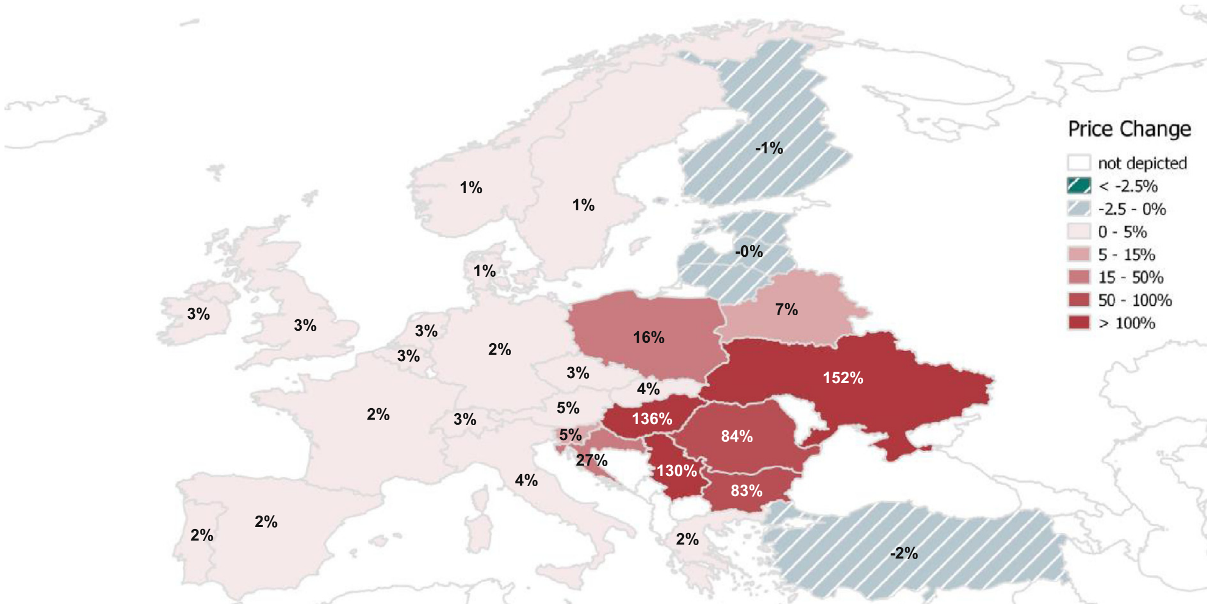

Fig. 4. *Ukrainian Disruption* price changes in 2015 relative to the *Base Case*, in percentages.

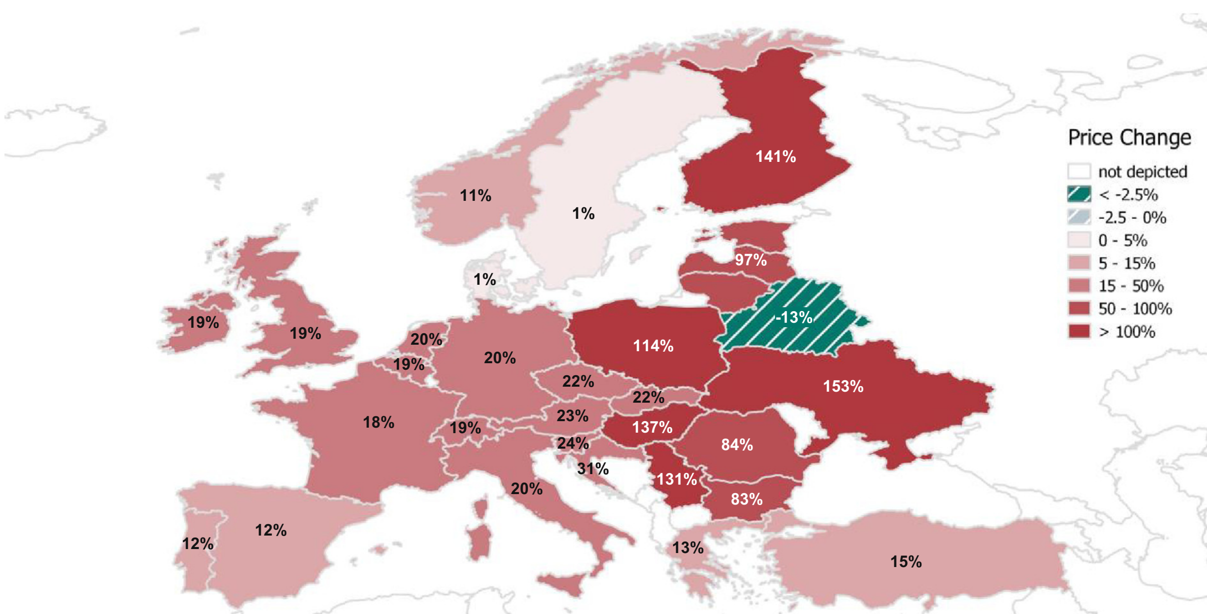

Fig. 5. *Gazprom scenario* price changes in 2015 relative to the *Base Case*, in percentages.

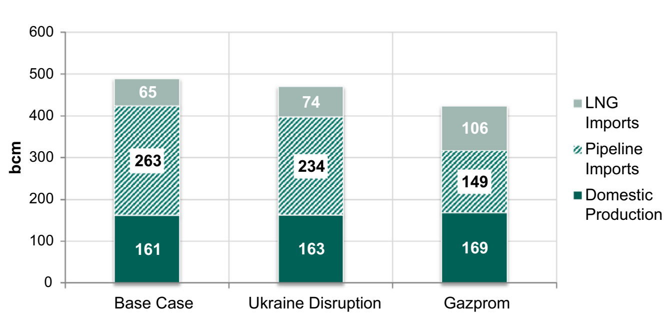

Fig. 6. EU supply structure in 2015 across scenarios, in bcm.

LNG imports are 41bcm or almost 65% higher in *Gazprom* than in the *Base Case*, while total pipeline imports drop significantly, despite small increases from Norway and North Africa.

In the *Gazprom* scenario, the shortfall of 113 bcm (5 bcm) imports from Russia (the Caspian region)[6] relative to the *Base Case* is countervailed by the increase of about 8 bcm in domestic production (almost entirely in the Netherlands) and by 45 bcm of imports from other suppliers. The remaining 65 bcm reflect the reduction in EU consumption. As can be seen in Fig. 7, natural gas is imported to a larger extent from Africa (+26 bcm), the Middle East (+10 bcm), and South America (+7 bcm). Despite these alternative supply opportunities, total imports fall by almost 25% to about 260 bcm.

3.2.2. Focus on European LNG imports

The most important source in balancing short-term Russian trade interruptions are LNG imports. In the *Gazprom* scenario the

[6] Note that exports from the Caspian region toward Europe currently need to transit Russia and, hence, are also affected by our scenario assumptions.

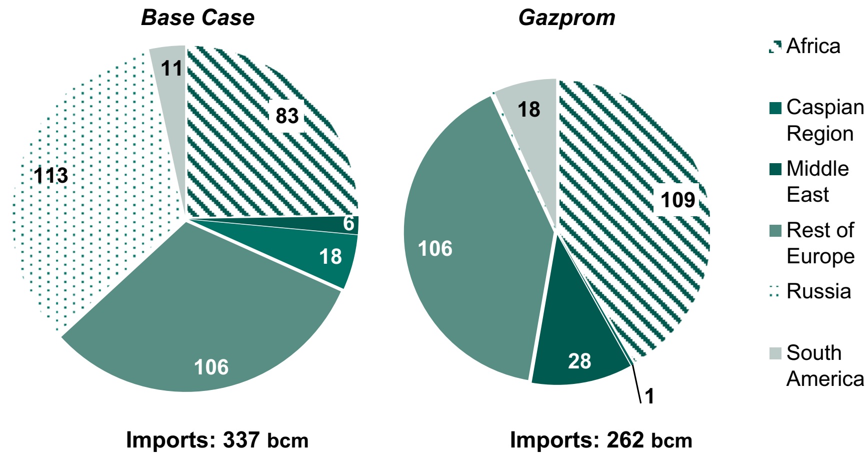

Fig. 7. EU import structure by supplier in 2015 in the *Base Case* and in *Gazprom*, in bcm.

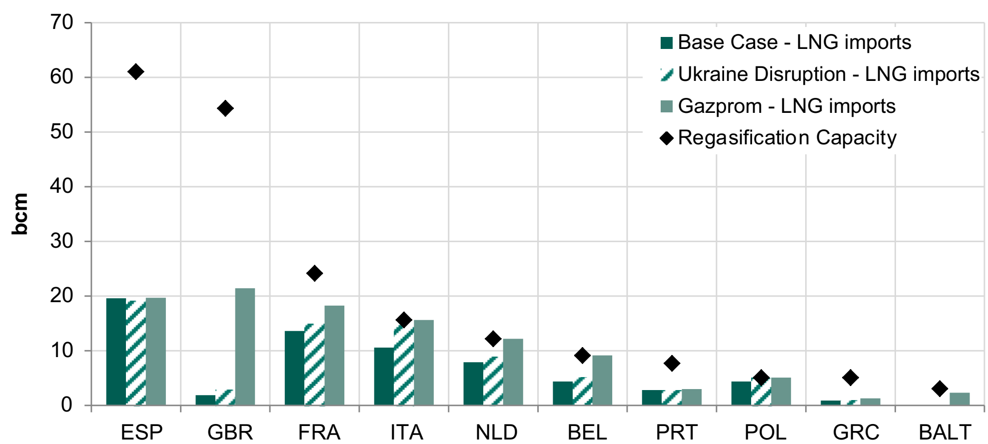

Fig. 8. EU LNG imports by destination country in 2015, and available regasification capacity, in bcm.

increase of LNG imports to the EU is mainly supplied by Qatar, African countries like Nigeria, Algeria and Egypt, and by Trinidad and Tobago. Fig. 8 depicts EU LNG imports by destination country and contrasts them with LNG regasification capacity in place. The largest additional LNG imports in the *Gazprom* scenario relative to the *Base Case* can be observed in the UK, increasing by almost 20 bcm.

While regasification terminals in Italy, the Netherlands, Belgium and Poland are completely utilized in the *Gazprom* scenario, we show in Fig. 7 that utilization rates of regasification capacity in some EU countries is low in the two disruption scenarios. For instance, the utilization rate of Spanish terminals only reaches 32% in the *Gazprom* scenario. On average, the utilization rate in the EU is low with about 55% (33% in the *Base Case*), despite the need for import alternatives in the EU.

In particular, cross-border pipeline capacity restrictions prevent LNG imports from being efficiently used across Europe: For instance, the transit of Spanish LNG imports to Central Europe is restricted by the limited pipeline capacity from Spain to France. This pipeline has an annual capacity of only about 5 bcm, which is completely utilized in the *Gazprom* scenario and cannot be expanded in the short run. This has also been noted by the European Council which concluded in March 2014 that “interconnections should also include the Iberian peninsula.”[7] Similar to the bottleneck between Spain and France, an efficient transportation of French LNG imports across the EU is prevented by a lack of pipeline capacity toward Germany and Italy.[8] Hence, the large installed EU regasification capacity of about 195 bcm in the model period 2015 cannot be completely used to balance import needs in all member states.

It should be noted that EU countries compete with other world regions for limited international LNG supply. This can best be seen in the ratio of the current worldwide annual LNG regasification capacity of around 975 bcm to the global LNG liquefaction capacity of only 365 bcm in 2013 (cf. GIIGNL, 2014). Asian import countries are and will remain the main competitors with the EU for international LNG supply. In contrast to previous expectations, current projections suggest that the USA will become a net exporter of LNG in 2016 (cf. EIA (2014a)).

In the *Gazprom* scenario one can observe an increase in global LNG supply by 5% and a pronounced shift of LNG trade flows from Asia toward the EU. These reduced LNG flows toward Asian consumers (−33 bcm) can only be partly backed by an increase in Asian pipeline imports from the Caspian region (+4 bcm relative to the *Base Case*) due to lacking pipelines.

3.2.3. *Changes in the Russian supply of natural gas*

In both short-term disruption scenarios, the pattern for Russia is that exports are lower than in the *Base Case* (by 20% in *Ukraine*

[7] Cf. European Council 20/21 March 2014 Conclusions, p. 10: http://www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/ec/141749.pdf, accessed on May 22, 2014.

[8] Italy in turn is poorly connected to central Europe and cannot serve as transit country for African pipeline gas.

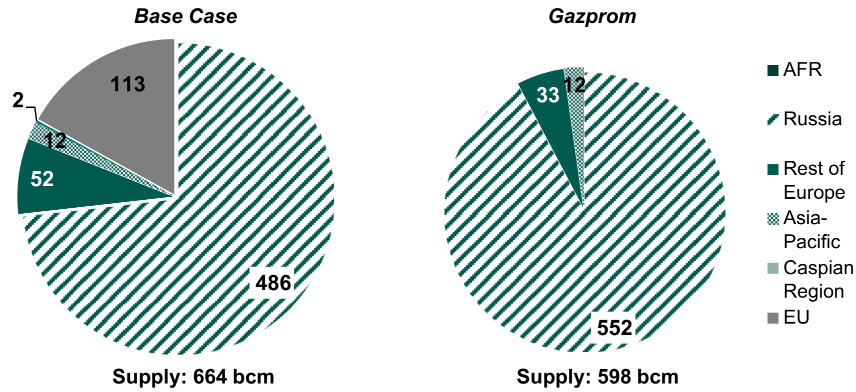

Fig. 9. Consumption of Russian natural gas by region in 2015 in the *Base Case* and in *Gazprom*, in bcm.

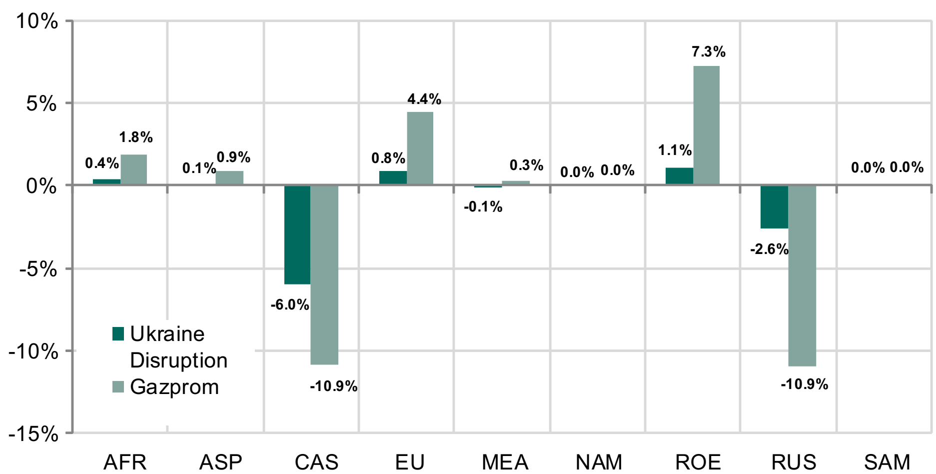

Fig. 10. Changes in regional production levels in 2015 relative to the *Base Case*, in bcm.

Disruption, and 73% in *Gazprom*), domestic consumption increases but to a small extent (by 4% and 14%, respectively), such that overall production is reduced (by 3% and 11%, respectively). Hence, Russia loses market shares in the global production of natural gas.

This is explained by the limited export possibilities of Russia given the available capacities in 2015. The (East) Russian LNG export terminal in Sakhalin is already completely utilized in the *Base Case*, and an increase of LNG exports is thus no alternative to the shortfall of exports toward Europe; Russian pipeline exports toward Asia, on the other hand, are not yet possible due to a lack of pipeline infrastructure.

Hence, one can observe a shift of Russian natural gas toward domestic consumption as illustrated in Fig. 9 due to the lack of export alternatives. This, of course, results in a substantial reduction of revenue, both for Gazprom and for Russia (in form of profit, mineral extraction and export tax income).

A similar pattern arises for the Caspian region, which is limited to its export possibilities toward Europe via the Russian transit in the short-term. Production is lower in the disruption scenarios in 2015 relative to the *Base Case*, while domestic consumption increases. All other world regions are also affected: global production patterns show a significant increase relative to the *Base Case* in Africa, the EU and Rest of Europe partly balancing the reduced production in Russia and the Caspian region (see Fig. 10). In some regions, exports are further increased at the expense of domestic consumption (e.g. in Africa, where consumption is reduced by 8% in the *Gazprom* scenario).

3.3. *Long-term disruption scenario*

In case of a long lasting disruption of Russian natural gas exports, adjustments can be made through infrastructure expansions. Both intensified connections to external suppliers and expansions of the intra-European pipeline network serve to attenuate the disruption of Russian natural gas supply.

3.3.1. *Impact of a long-term disruption*

Fig. 11 shows aggregate consumption levels of the EU, as well as consumption-weighted prices for the *Base Case* and *Long Disruption*. The divergence between both cases is particularly pronounced in the initial period of the external shock: as in the *Gazprom* scenario, consumption in 2015 is lower by 13%, while the consumption-weighted average price is more than 23% higher than in the *Base Case*. These differences diminish already in 2020 to 5% lower consumption levels at 11% higher prices on average. Over time, both the consumption and price paths tend to converge to a gap of, respectively, 3% and 7% between the two scenarios. This highlights the potential of mid- to long-term adjustment possibilities that exist, but only at higher costs.

In the *Long Disruption* scenario one can observe an increased balancing within the EU over time, such that only the Baltics remain considerably affected after 2020: Despite adjustment possibilities of the infrastructure, here natural gas consumption is lower at significantly higher prices (by more than 30% higher after 2020) than in the *Base Case*.

As in the short-term disruption scenarios, LNG imports are most important in compensating the drop out of Russian supply.

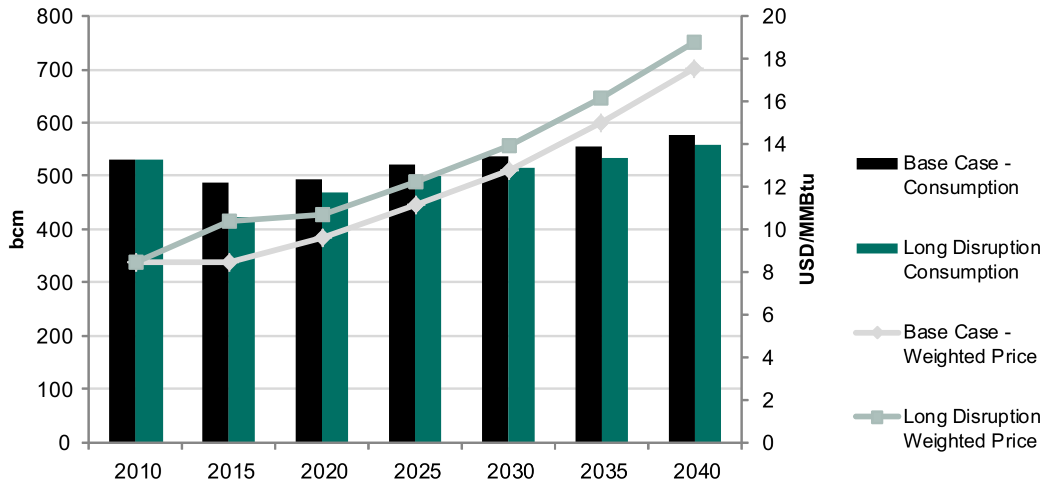

Fig. 11. EU natural gas consumption (left axis) and consumption-weighted prices (right axis) in the *Base Case* and in *Long Disruption*, in bcm and USD/MMBtu.

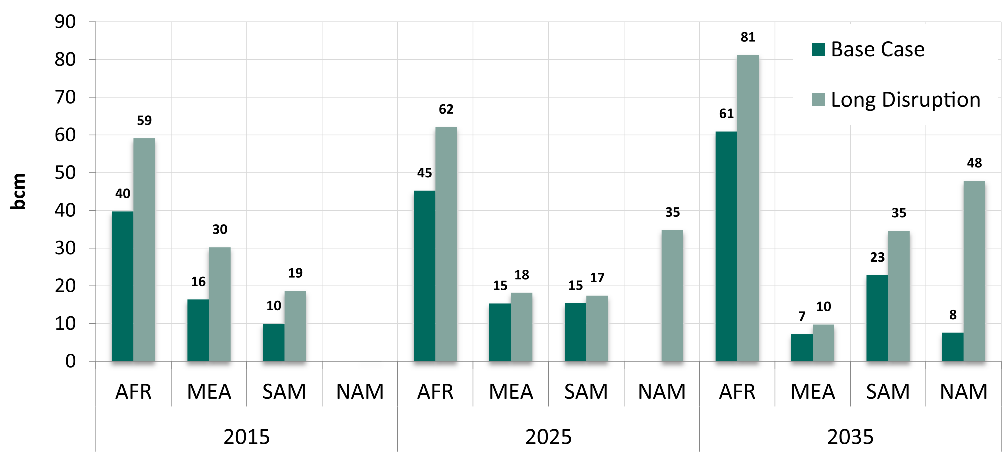

Fig. 12. EU LNG imports by origin in the *Base Case* and in *Long Disruption*, in bcm.

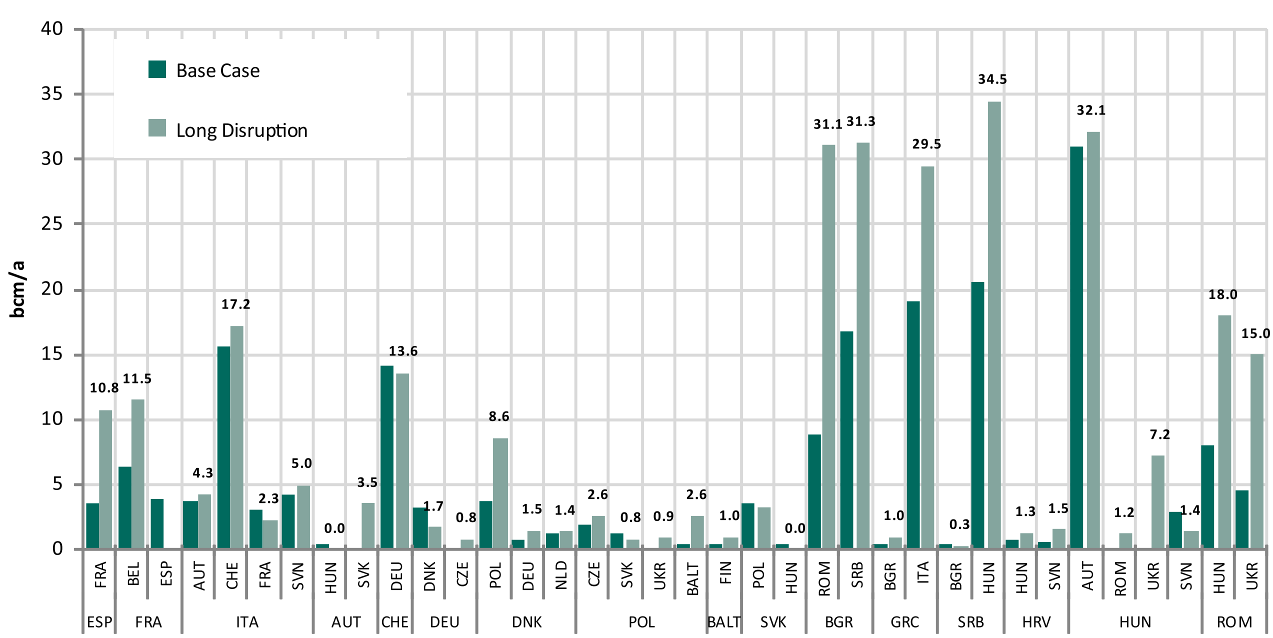

Fig. 13. Cumulative intra-European pipeline expansions between 2015 and 2040, in bcm.
Note: The lower part of the horizontal axis is the pipeline's origin.

While they account for about a quarter of total imports throughout in the *Base Case*, LNG imports eventually reach 40% in *Long Disruption*. Central and Eastern European countries become significant importers of LNG with newly developed import capacity like Germany, Finland and Poland.

LNG originates from Africa, the Middle East, South America and notably, in periods after 2025, the USA (see Fig. 12). While in the *Base Case* total US LNG exports are small, they reach the EIA (2014a) projections of 100 bcm in the *Long Disruption* scenario. On the other hand, LNG exports from the Middle East to Europe decline over time due to a shift in export orientation toward Asia and an increasing reliance on pipeline exports via Turkey to Europe.

Total imports to the EU (LNG plus pipeline imports) are dominated by African suppliers. Exports from the Middle East serve to replace Russian supply in South East Europe, namely Turkey, Bulgaria, Romania and Ukraine, while the Caspian region suppliers are more focused on Asian consumers; mainly because the transit route via the Ukraine is blocked.

3.3.2. *Infrastructure expansions*

In order to connect the Middle East and reconnect the Caspian region to Europe, substantial pipeline expansions in the Southern Corridor are needed in case of a long lasting disruption of Russian supply. Here, expansions in 2015 are significantly higher than in the *Base Case*. In the *Long Disruption* scenario the pipeline routes from the Middle East and the Caspian region to Europe via Turkey (together expanded by almost 75 bcm compared to less than 20 bcm in the Base Case) dominate all other expansions from external suppliers like North African countries or Norway. From Turkey, serving as hub, the connection to Bulgaria is expanded to a greater extent (43 bcm) than that to Greece (11 bcm). Moreover, additional LNG regasification capacities are built and used in Northern Central and East Europe, such as in Germany, Finland, or Poland.

In addition, the intra-European pipeline network is expanded and allows for an efficient balancing of natural gas supplies within a better integrated European market. This is illustrated in Fig. 13 by cumulative expansions through 2040 in the *Long Disruption* scenario and the *Base Case*. Four principal geographical regions can be distinguished.

First, the connection of Western Europe LNG import capacity from Spain to France and further to Central Europe is expanded. This bottleneck, as discussed above, warrants the recovery of the necessary investment costs. Second, the Italian import potential is connected to the North to a larger extent. LNG imports, pipeline imports from North Africa as well as from the Caspian Region and the Middle East through the Trans-Adriatic Pipeline (TAP) via Greece all transit via Italy. Third, the energy island formed by the Baltics is better connected to Poland. After this expansion, the region can be supplied by Norway, the Netherlands and other suppliers outside Europe if transport costs are recovered.

Fourth, South East Europe sees investments in both reverse flows and in import capacity from the Middle East and the Caspian region. Here, investments are substantially larger in *Long Disruption* than in the *Base Case*. The import pipeline in the Southern Corridor would be similar to the earlier Nabucco project that was abandoned in 2013 due to a lack of contracted supplies as well as competition from the South Stream pipeline from Russia. In the absence of Russian supplies, the Southern Corridor connection from Bulgaria to Serbia and Romania and further to Hungary and Ukraine is expanded to transport natural gas to those countries that are most affected from a Russian supply disruption. Hungary plays an important role both for the pipeline routes from North to South and vice versa.

4. Conclusions and policy implications

With the 2014 Russian–Ukrainian crisis, European concerns over the possibility of natural gas supply disruptions reignited, as experienced in 2006 and 2009. Despite being better prepared to Russian export disruptions—due to more diversified imports, better connections within Europe and a common EU regulation on the security of supply—several East European countries are highly dependent on Russian natural gas.

We use a model-based approach to analyze the consequences of supply disruptions of Russian natural gas on the European market. Short-term disruptions of Russian exports to Europe without anticipation severely affect several countries in East Europe due to insufficient physical capacities that limit supplies from other exporting regions. The complete drop out of Russian supply is compensated by an increase in domestic production, imports of LNG and pipeline gas from other regions, and by a reduction of natural gas consumption. Only East European countries are restricted physically, while on average the EU member states experience a price increase of about 23% in the first year of the disruption.

We find a vital role of LNG imports in replacing Russian pipeline gas, although a large part of the European LNG import capacity is not well connected to a broader market. Despite strong price increases and lower natural gas supplies in the Baltics, Finland and other East European countries, aggregate EU regasification capacity is only partially used.

A long lasting or early anticipated disruption of Russian supply can be mitigated by targeted pipeline expansions. We identify several geographical corridors where pipeline expansions help to ensure the secure supply of natural gas in case of a cut of Russian supplies: first, the Iberian peninsula and Italy must be connected to the rest of Europe in order to open up their large import

Table 4
Countries included in GGM and assignment to model regions.

European Union (EU)		**North America (NAM)**		**Asia-Pacific (ASP)**	
AUT	Austria	CAN	Canada	AUS	Australia
BALT	Baltics	MEX	Mexico	BGD	Bangladesh
BEL	Belgium	USA	USA	BRN	Brunei Darussalam
BGR	Bulgaria			CHN	China
HRV	Croatia	**South America (SAM)**		IND	India
CYP	Cyprus	ARG	Argentina	IDN	Indonesia
CZE	Czech Republic	BOL	Bolivia	JPN	Japan
DNK	Denmark	BRA	Brazil	KOR	Korea
FIN	Finland	CHL	Chile	MYS	Malaysia
FRA	France	COL	Colombia	MMR	Myanmar
GER	Germany	PER	Peru	PAK	Pakistan
GRC	Greece	TTO	Trinidad and Tobago	PNG	Papua New Guinea
HUN	Hungary	VEN	Venezuela	SGP	Singapore
IRE	Ireland			TWN	Taiwan
ITA	Italy	**Africa (AFR)**		THA	Thailand
NLD	Netherlands	ALG	Algeria	VNM	Vietnam
POL	Poland	ANG	Angola		
PRT	Portugal	EGY	Egypt	**Middle East (MEA)**	
ROM	Romania	EQN	Equatorial Guinea	IRN	Iran
SVK	Slovak Republic	LYB	Libya	IRQ	Iraq
ESP	Spain	MOZ	Mozambique	KUW	Kuwait
SVN	Slovenia	NGA	Nigeria	OMN	Oman
SWE	Sweden	ZAF	South Africa	QAT	Qatar
UK	United Kingdom	TUN	Tunisia	SAU	Saudi Arabia
				UAE	United Arab Emirates
Rest of Europe (ROE)		**Caspian Region (CAS)**		YEM	Yemen
BLR	Belarus	AZE	Azerbaijan		
NOR	Norway	KAZ	Kazakhstan		
SRB	Serbia	TKM	Turkmenistan		
CHE	Switzerland	UZB	Uzbekistan		
TUR	Turkey				
UKR	Ukraine	**RUS**	**Russia**		

Table 5
Long-term supply to the EU in the *Base Case* and the *Long Disruption* scenario, in bcm.

Region of origin	Base Case	Long Disruption	Base Case	Long Disruption	Base Case	Long Disruption	Base Case	Long Disruption
	2015		**2020**		**2030**		**2040**	
AFR	83	109	99	132	141	175	167	199
ASP	0	0	0	0	0	0	0	0
CAS	6	1	18	19	31	33	49	40
MEA	18	28	19	40	21	45	26	52
NAM	0	10	0	29	10	62	36	74
ROE	106	106	108	110	103	103	95	91
SAM	11	18	13	17	19	30	18	27
EU	161	168	134	132	114	108	90	81
RUS	114	0	109	0	117	0	114	0

potential from diverse suppliers of LNG and pipeline gas from North Africa to the rest of Europe. Second, the Baltics and Finland must be connected to the rest of Europe, in particular Poland. Similarly, reverse flow capacities must be expanded to supply the most affected East European countries in case of a disruption. And finally, the Southern Corridor would allow for imports from the Caspian region and the Middle East.

The European Union has set a framework designed to accelerate infrastructure expansion between member states (EU, 2010, 2013), but its implementation is lagging in some member states, in particular (but not exclusively) across Eastern Europe. However, while there has been some progress since the earlier crises in 2006 and 2009 in implementing reverse flows – as mandated by EU (2010) – several cross-border connections are not yet equipped with such facilities, e.g. between Bulgaria and Greece or Poland and the Czech Republic. EU Regulation 347 (EU, 2013) was enacted to better structure the process of cross-border investments which are challenging by their multi-player and international nature. This regulation needs to quickly prove its effectiveness in order to achieve the infrastructure expansions in the three intra-EU corridors that we identify. For the fourth corridor of natural gas imports from the Caspian region and the Middle East, the EU must integrate this energy dimension more explicitly in its neighborhood policy.

The reduction of natural gas consumption is, of course, partly compensated by the use of other energy carriers. This change in the energy mix should be in accordance with climate mitigation targets and not involve the more carbon-intensive fossil fuels coal and oil. Rather, the increased deployment of renewable energies and the intensified improvement of energy efficiency represent the sustainable complement to secure natural gas supplies.

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Appendix

See Tables 4 and 5.

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