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Improvements in the EU gas transmission network between 2009 and 2014

Grid developments and simulation assessment to test the increased ability to cope with gas crises

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Abstract

Improvement in the EU gas transmission network between 2009 and 2014

The report compares the European gas infrastructure between 2009 and 2014 to demonstrate how Reg. (EC) 994/2010 has promoted and reinforced security of gas supply. Infrastructure improvements and results of a country-based simulation model analysing a Ukrainian and a Russian shortage of gas are presented.

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EXECUTIVE SUMMARY

Policy context

On 28 May 2014 the European Commission adopted the "European Energy Security Strategy" (COM/2014/0330 final) providing a comprehensive proposal to strengthen the security of energy supply in Europe. In its plan for an "Energy Union" (COM/2015/080 final), launched early in 2015, the European Commission identifies as one of the five strategic dimensions "Energy security, solidarity and trust" and proposes – among other tools - the development of a clear common strategy for Liquefied Natural Gas (LNG) and natural gas storage within a fully developed European Energy Market.

In this context, Regulation (EU) 994/2010 and its on-going revision plays an overarching role in the security of gas supply and in strengthening regional cooperation in case of crisis.

This short report aims at providing a first assessment of the improvements put in place by Member States and Transmission System Operators in the area of infrastructure after the enactment of Regulation (EU) 994/2010. This is a robust and sound quantitative analysis of the changes in the European infrastructure between 2009 and 2014 which complements the Commission Staff Working Document "Report on the implementation of Regulation (EU) 994/2010 and its contribution to solidarity and preparedness for gas disruptions in the EU" (SWD(2014) 325 final).

The report outlines a description of the changes in the national infrastructure of Member States by focusing on LNG terminals, underground gas storage (UGS) facilities and cross-border interconnection points. A holistic assessment of the performance of the European transmission grid is carried out using the "Gas EMergency FLOW" simulator model (GEMFLOW) for different crisis scenarios.

Key conclusions

- The analysis shows how Regulation (EU) 994/2010 on security of supply and the third package of legislative proposals for electricity and gas markets have provided an effective legislative framework to increase the resilience of the EU gas grid to supply shocks.
- The EU gas infrastructure still needs some strategic investments to eliminate the isolation of some Member States and increase the interconnection level of others.

Main findings

- Relevant investments, pushed forwards by many TSOs and strategically supported by the European Commission with "Projects of Common Interest", have created the conditions to boost the technical capacities of the gas grid to transfer more easily natural gas among Member States.
- The number of LNG terminals has increased by four units since 2009 and the nominal annual aggregated send-out capacity increased by 41% from 134 to 189 Bcm per year.
- The number of UGS facilities and the working storage capacity have increased between 2009 and 2014 11% and 21% respectively, with a total of 143 sites and a capacity of 100 Bcm.
- Reverse flow has been substantially implemented within the EU as the number of interconnection points with this capability has increased from 24% in 2009 to 40% in 2014.

- Along with the implementation of physical bi-directional capacity among MS, the overall cross-border capacity of the EU high pressure grid (between MS and with neighbouring countries) has improved as a whole by 10,6% from 2.997,4 Mcm/d to 3.315,0 Mcm/d between 2009 and 2014.
- Some relevant bottlenecks still exist in the EU grid (e.g., the South-East corridor, interconnections between France and Spain or France and Germany and Belgium) and some member States are poorly or not connected to the main EU system (e.g., the Baltic Region and Finland, Croatia, Bulgaria and Greece).
- The improvements realised by 2014 have considerably increased the resilience of the European grid to react to supply shocks and, in particular, for those Member States which still suffer from a very low supply diversification. In general the simulated crisis scenarios between 2009 and 2014 show how volumes of unserved gas decrease and first day of crisis is postponed.

Related and future JRC work

The need of flexible and reliable tools to explore and assess the impact of further developments in the infrastructure and of future policies on security of supply in the field of natural gas has prompted the Institute of Energy and Transport of the Joint Research Centre to continue developing GEMFLOW and to complete the EUGas project (i.e., a full hydraulic model of the gas transport network of the European Union).

Quick guide

The report analyses the improvements in the EU natural gas transmission network since the major supply crisis of 2009. Overall the network has made strategic enhancements in underground storage capacity, LNG facilities and capability of moving gas among Member States through interconnection points. Supply shocks comparable to the 2009 crisis are evaluated using a simulation model. Results show how volumes of unserved gas decrease and the beginning of a national crisis is substantially delayed. Both come as positive outcomes of the network improvements. Regulation (EC) 994/2010 on security of supply has been one of the main drivers of the increased ability of Europe to cope with gas crisis.

1. INTRODUCTION

Regulation (EU) 994/2010 concerning measures to safeguard security of gas supply was enacted following the 2009 natural gas crisis, which showed important weaknesses of the European high pressure transmission system. It repealed Council Directive 2004/67/EC [1] on measures to safeguard security of natural gas supply by providing a consistent framework to carry out a full risk assessment of national grids, identifying tools and criteria to improve performance and resilience, and providing means to increase preparedness and skills to cope with crises. The lessons learnt from the implementation of Directive 2004/67/EC had shown that it was necessary to harmonize national measures in order to ensure that all Member States are prepared at least on a common minimum level. It was felt that, if all Member States were to comply with a set of minimum standards, this would enhance solidarity between them in case of crisis, since no one could be seen "to take a free ride" on the efforts made by others. At the same time, the legislator considered that excessive protection of own gas consumers in some Member States could leave consumers in other Member States more exposed and/or could disproportionally restrict trade.

During the 2009 gas supply crisis the necessary amounts of gas were available in the European Union (EU) internal market but it was physically impossible to ship them to the most affected Member States in Eastern Europe. Against this background, Regulation (EU) 994/2010 [2] aims to improve cross-border capacities by pursuing the development of new infrastructures, or upgrading the existing ones, which is essential in terms of security of supply. The two tools chosen are the Infrastructure Standard (the so-called N-1 rule) and the implementation of permanent bi-directional capacity (physical "reverse flows") in cross border points [3].

On 28 May 2014 the Commission adopted its European Energy Security Strategy providing a comprehensive plan to strengthen the security of energy supply in Europe [4]. A common European strategy, along with a common European Energy Market – as it has been reinforced by the enactment by the European Commission (EC) of the third package of legislative proposals for electricity and gas markets[1] - is more and more a fundamental need for the European Union in light of the role played by natural gas in the European energy mix, as the share of natural gas in the European final energy consumption is still slowly increasing, moving from 21,9% in 2009 to 22,9% in 2013[2]. In its plan for an “Energy Union” [5], launched early in 2015, the European Commission foresees – among others tools - the need of a clear common strategy for LNG and natural gas storage. This strategy looks at the long term role of LNG and gas storage in ensuring a secure, affordable and sustainable EU energy system and identifies what further action may be needed in those areas in the future.

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[1] The European Commission has adopted on 21 September 2009: Directive 2009/72/EC concerning common rules for the internal market in electricity and repealing Directive 2003/54/EC; Directive 2009/73/EC concerning common rules for the internal market in natural gas and repealing Directive 2003/55/EC; Regulation (EC) No 714/2009 on conditions for access to the network for cross-border exchanges in electricity and repealing Regulation (EC) No 1228/2003; Regulation (EC) No 715/2009 on conditions for access to the natural gas transmission networks and repealing Regulation (EC) No 1775/2005; Regulation (EC) No 713/2009 of the European Parliament and of the Council of 13 July 2009 establishing an Agency for the Cooperation of Energy Regulators.

[2] Data from calculation on EUROSTAT indicator “Final energy consumption by product” (ten00095).

Furthermore, to meet the ambitious targets of the 2020 Climate and Energy Package[3] [6] and live up to the objectives of the 2030 Framework for Climate and Energy Policies [7] (i.e., the European Council endorsed a binding EU target of at least 40% domestic reduction in greenhouse gas emissions by 2030 compared to 1990), greater investments in the energy infrastructure will be required in the near future in all the sectors that make up Europe's energy market. New investments in energy infrastructure across the Union are also instrumental in ensuring an integrated and efficient internal energy market and security of energy supply.

Since 2009 the effects of the energy policy of the European Commission have laid down the basis for a more mature energy market and a more flexible and secure natural gas market. But still Europe suffers of strong import dependence for natural gas, which is weakening its position at the international level. This is why more efforts should be made in the same directions of the achievements of the last five years. In particular with the new European Energy Security Strategy, the European Commission underlines again areas of further development and addresses the medium- and long-term security of supply challenges. The Commission proposes actions in several key areas:

- completing the internal energy market and building missing infrastructure links are essential to quickly respond to possible supply disruptions by directing energy flows across the EU as and where needed;
- diversifying supplier countries and routes, e.g. in the Caspian Basin region by further expanding the Southern Gas Corridor; by developing the Mediterranean Gas Hub and by increasing LNG supplies;
- strengthening emergency and solidarity mechanisms by reviewing the provisions and implementation of the Security of Gas Supply Regulation;
- improving the coordination of national energy policies and speaking with one voice in external energy policy.

With this short report we aim at providing a first analysis of the improvements put in place by Member States and Transmission System Operators after the enactment of Regulation (EU) 994/2010 and their effects. Firstly, we provide a description of the changes in the national infrastructure, and then we perform a comparison of the behaviour of the European transmission grid under two crisis scenarios for 2009 and 2014 by using the “Gas EMergency FLOW” [8, 9] simulator model (GEMFLOW).

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[3] The 2020 Climate and Energy Package sets three key objectives: (i) 20% reduction in EU greenhouse gas emissions from 1990 levels; (ii) raising the share of EU energy consumption produced from renewable resources to 20%; (iii) a 20% improvement in the EU's energy efficiency.

2. CHANGES IN THE EU GAS INFRASTRUCTURE BETWEEN 2009 AND 2014

Understanding and assessing how investments in infrastructure and the impact of new legislation – like Regulation (EU) 994/2010 – have improved the European natural gas high pressure network is a challenging research task. On one side we face the analysis of a complex dynamical system designed to transport and distribute natural gas in multiple countries. On the other, the "natural gas business" [10] has undergone relevant changes in a more general context of economic difficulties. We provide here some general remarks and in the following sections of this chapter we perform a comparison of the status of four strategic areas of the EU natural gas system (i.e., LNG facilities, UGS facilities, cross-border capacity and physical reverse flow) between 2009 and 2014 to start to shade light on this research topic.

We avoid presenting any result concerning how the liquidity of the natural gas market has changed and how the value chain has been transformed along with the general business model, though we recognize the relevance of such topics for a mature and well-shaped Energy Union. Our major focus is here on improvements of the physical infrastructure and its ability to better provide the commodity within Europe. For this, we prefer to move forward to a simple comparison of two key indicators of the structure of the high pressure grid of any Member State (MS) - like the total length of the grid and the total compressor power installed - to offer a more complete picture of the complex interaction and feedbacks among the components of the integrated European gas grid. The total length of the grid provides an idea of how investments were translated into a better connection from sources to customers to increase volumes, distribution and generally the resilience of the network. The total compressor power installed gives an indication of increased capacity and commitment in improving directional flows. The general overview given in Table 1 shows how, with some remarkable differences between MS, the EU high pressure grid has grown to better address issues related to increased interconnectivity (within and between MS) and volumes (i.e., higher total installed compressor power). The role of some MS (like Germany and the Netherlands) as pivotal elements in the grid (along with the role of users of the commodity) is marked by the changes in the two indicators. Other MS (in particular from Eastern Europe) show less relevant improvements generally linked to a minor role as key players (e.g., the Baltic Region and the Southern-East corridor).

Additionally, we have avoided assessing the effects of the application of the Regulation (EC) No. 715/2009 [11]. In order to enhance market transparency, under the coordination of the European Network of Transmission System Operators for Gas (ENTSOG), the transmission network operators have facilitated access to information provided to network users and market participants through the implementation of a common standardized format for publication of the required data in compliance with Chapter 1 of Annex 1 of the Reg. (EC) 715/2009. TSOs have to publish information regarding the services they offer and the relevant conditions applied, together with the technical, tariff and operational information necessary for network users to gain effective network access. ENTSOG has supported the efforts of EU TSOs by creating an *ad hoc* web-based platform for transparency[4] and data dissemination. But still TSOs have to overcome a fear in providing a complete and rich collection of information to the public, since the requirements of Reg. (EC) 715/2009 were formally met by only 86% as it has been underlined by a recent report on the topic by the Agency for the Cooperation of Energy Regulators (ACER) [12]. Some major areas of improvement for ACER still are: providing information "near real-time" of actual physical flows; providing historical information on capacities, nominations, interruptions, physical flows; providing measured values of the gross calorific value or Wobble index. It is our opinion that even the description of the network, though formally met by almost all TSOs, shows a high

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[4] Available at https://transparency.entsog.eu/

heterogeneity in the level of detail, which hampers the understanding of any change in the grid.

Annex 1 provides an overview for all Member States of the type of information available through the transparency platform developed by TSOs.

Table 1. Total length of high pressure transmission and transit systems and total power of compressor stations by Member States in 2010 and 2014 [13, 14, 15, 16, 17].

	Total length (km)			**Total installed power in Compressor Stations (MW)**		
	2010	*2014*	*% ’14 –‘10*	*2010*	*2014*	*% ’14 –‘10*
Austria	1600*	1600		551	621	13%
Belgium	3900	4100	5%	116	116*	
Bulgaria	2645	2645		263	263	
Croatia	2085	2662	28%	-	-	
Czech Republic	3643	3813	5%	297	297	
Denmark	800	953	19%	-	18,3	+
Estonia	877	885	1%	-	-	
Finland	1186	1314	11%	63	64	2%
France	36617	37156	2%	643	636	-1%
Germany[5]	31515	38125	21%	1679	2542	51%
Greece	1218	1291	6%	-	13	+
Hungary	5564	5784	4%	188	233	24%
Ireland[6]	2004	2055	3%	94	94	
Italy	33584	34415	3%	857	867	1%
Latvia	1281	1240	-3%	-	-	
Lithuania	1865	2007	8%	42	42	
Luxemburg	410,7	412,7	1%	-	-	
Poland[7]	9777	10077	3%	150	156	4%
Portugal	1299	1374	6%	-	-	
Romania	13110	13138	0,2%	30	32	7%
Slovakia	2270	2367	4%	700*	700	
Slovenia	1018	1094	8%	16	16	
Spain	9984	10512	5%	413	525,9	27%
Sweden	620	620		-	-	
the Netherlands	11650	15500	33%	734	808	10%
United Kingdom	7880	7891	0,1%	1611	1611*	

* The value has been assumed equal to the other reference year for lack of publicly available information.

- No compressor station exists.

+ New compressor station after 2009.

(Source: JRC analysis on Southern Corridor GRIP 2014-2023, Central Eastern Europe GRIP 2014-2023, Baltic Energy Market Interconnection Plan GRIP 2014-2023, ENTSOG TYDP 2011-2012, ENTSOG TYNDP 2015 and from data provided on their home pages by the TSOs REN, Enagás, GRTgaz TIGF, Energinet.DK, Swedegas, Gasum, National Grid, Gaslink, Gaz-System, Gasunie Transport Services B.V.)

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[5] It is important to note that the value for Germany in 2010 is partial as not all German TSOs were collaborating in providing data for the “Country profile” of the TYNDP 2011-2020.

[6] Only onshore pipelines are considered as provided by the “Gaslink Performance Report” for 2010 and 2013.

[7] Figures are excluding the data concerning the transit line from Belarus to Germany with a total of 684 km of length and five compressor stations with a total installed power of 400 MW.

2.1 LNG FACILITIES

The European LNG market has been characterized by a substantial reduction since 2011 (Figure 1) due to a combination of factors like a general decrease in demand linked to weather conditions, the economic crisis, competition with other markets (mainly the far East markets), cheaper prices for natural gas from pipelines (with Russian origin in the first place), and competition with other fuels in the power generation sector. Demand in Europe fell to 34,3 Bcm of LNG in 2014 [18], accounting for a 8,5% reduction compared to 2013. This is the third year of a decline in LNG demand and the overall demand is 43,3% lower than in 2009.

This current market contraction is not reflected in the strategic role of LNG in the EU policy. The recent adoption of the "European Energy Security Strategy" [4] pointed to a strong dependence of the EU on a single external supplier (i.e., Russia) and identified LNG as a relevant tool for diversification. Along with this argument LNG has been identified as one of the most efficient answers to short-term crises or shocks, together with the use of UGS [19].

The evolution of the LNG sector in the EU is summarized in Table 1 for all that concerns the main features of the facilities operating in Europe. The number of regasification plants has increased by four units, from 17 in 2009 to 21 in 2014, after the coming into operation of two Floating Storage and Regasification Units (FSRU; one in Italy and one in Lithuania) and two on-shore plants (one in the Netherlands and one in France) (Figure 2). The nominal annual aggregated send-out capacity increased by 41% from 134 to 189 Bcm per year, as a combination of the new facilities and the upgrading of existing facilities (e.g., the United Kingdom showed an increase of 64,5%, Figure 2 and Table 1). The maximum daily aggregated send-out capacity has further increased from 483,5 to 616,5 Mcm per day, so providing an extra 27,5% capacity over five years (Figure 2).

Spain and the United Kingdom play a major role in the EU as LNG hubs, both in terms of infrastructure and in terms of imports (29,6% and 30,9% respectively of the total import in Europe in 2014). But the capacity of transfer natural gas from those hubs to the rest of Europe is constrained by multiple factors as, for instance, a cheaper price of pipelines imports from Eastern Europe and a peripheral position respect Central-Eastern European Member States.

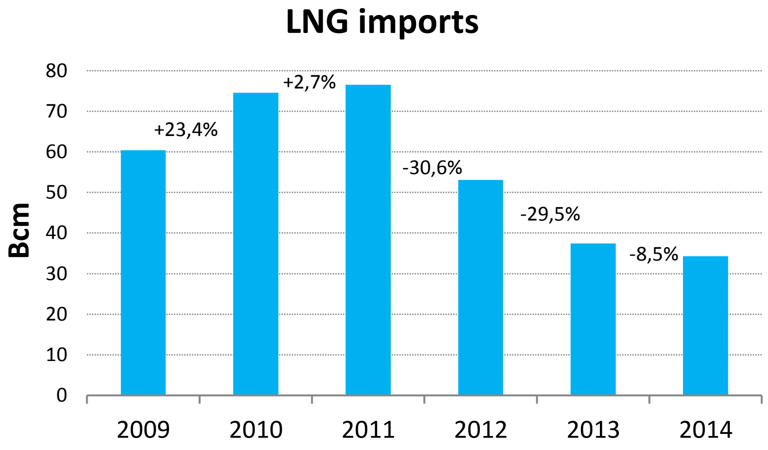
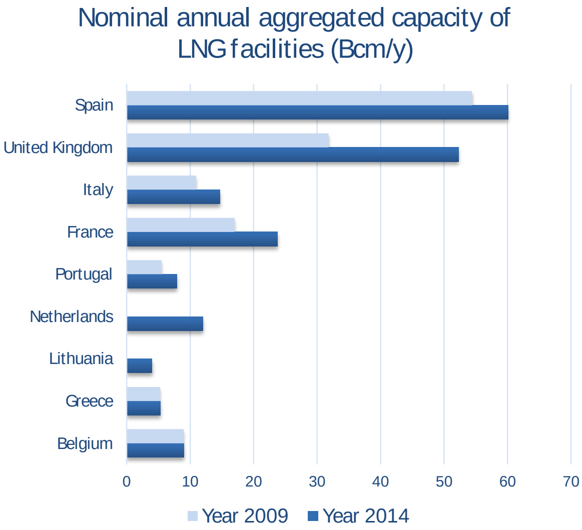


Figure 1. Evolution of LNG imports – net of re-exports - in EU from 2009 to 2014 in billion cubic meters of liquefied natural gas in gaseous form (Source: GIILNG [18]).

Table 2. Total number of LNG facilities, nominal annual aggregated capacity and maximum daily aggregated send-out capacity by Member State in EU in 2009 and 2014 (Source: [20, 21]).

	Number of facilities		**Nominal annual aggregated capacity (Bcm/y)**				**Maximum daily aggregated send-out capacity (Mcm/d)**			
	2009	*2014*	*2009*	*2014*	*Change 2014-2009*	*Percent change 2014-2009*	*2009*	*2014*	*Change 2014-2009*	*Percent change 2014-2009*
Belgium	1	1	9	9			40,8	40,8		
Greece	1	1	5,3	5,3			17,6	17,6		
Lithuania	-	1	-	4	4	+	-	11	11	+
Netherlands	-	1	-	12	12	+	-	39,6	39,6	+
Portugal	1	1	5,5	7,9	2,4	43,6	21,6	32,4	10,8	50
France	2	3	17	23,8	6,8	40	66	93,8	27,8	42,1
Italy	2	3	11	14,7	3,7	34,7	36,9	50,9	14	37,9
United Kingdom	4	4	31,8	52,3	20,5	64,5	141,8	165,6	23,8	16,8
Spain	6	6	54,4	60,1	5,7	10,5	158,7	164,7	6	3,8
Total EU	17	21	134,0	189,1	55,1	41,1	483,4	616,4	133	27,5

- No LNG terminal exists.
+ New LNG terminal after 2009.



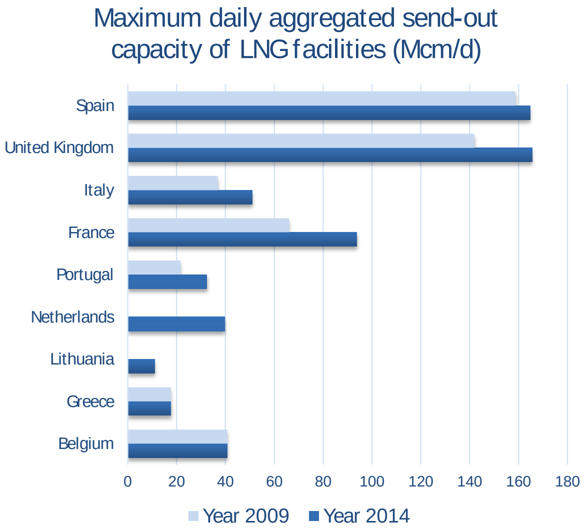


Figure 2. Total number of LNG facilities (A), nominal annual aggregated capacity (B) and maximum daily aggregated send-out capacity (C) by Member State in EU in 2009 and 2014 (Source: [20, 21]).

2.2 UNDERGROUND STORAGE

Underground gas storage facilities (UGS), together with increased scope for reverse flows, can play a key role as a tool to balance the supply-demand situation in the event of supply disruption in the EU [4]. An UGS can act as a buffer in case of a disruption of gas deliveries, but the volume availability of natural gas depends on storage level inventories and the withdrawal rate with which gas can be delivered to the consumers. According to GSE there were 143 UGS facilities in the European Union in 2014, with an increase of 11% since 2009, comprising a combined capacity of 100 Bcm (an increase of 21% since 2009) (Table 3). Though the majority of the facilities and the greatest share of working gas are in Central-Western Europe (i.e., Germany, Italy and France, Figure 3.A and Figure 3.B), the ratio gas consumption/storage capacity is similarly spread across the EU with some exceptions such as Austria and Latvia, whose storage capacity exceeds consumption.

Since 2006 the general improvements in storage have been driven by the need to address the decrease of European production, to cope with an increasing consumption (whose trend has changed after 2008), to provide flexibility to the market, as well as the opportunity to take advantage of price volatility of the newly liberalised markets. Furthermore, some difficulties of accessing existing storage, booked through long term contracts, may have also played a role [22]. But it appears that the role of measures aimed at strengthening security of supply (e.g., storage obligations) has been marginal.

By comparing 2009 and 2014, the EU shows a marked increase in withdrawal capacity (23,5% up to 2.030,2 Mcm/d and an additional 117,6 Mcm/d proposed with new projects) and total injection capacity (33,3% up to 1.122,3 Mcm/d and an additional 41,8 Mcm/d proposed with new projects), with approximately three quarters of the facilities providing access through a negotiated regime (Table 3). Withdrawal capacity is unevenly distributed among MS, with the Netherlands, Italy and Latvia showing the higher average levels (Figure 3.C).

However, the business model for filling gas storages is not necessarily setting incentives to store gas to prevent crisis situations. Gas storages are being filled on the basis of price spreads between summer and winter time, and the recent inventory dynamics show a certain level of variability (Figure 4). Analysis of such spreads, based on historic events, does not help predicting unexpected events [22]. Moreover the price spread between winter time and summer time has been decreasing over the last years. In general the value of storage has been undermined by the decreasing spreads and volatility, due to a combination of factors such as excess of supply in Europe and competition with other sources of flexibility (i.e., new interconnectors or improvements in capacity for existing interconnectors, and short-term contracts or spot LNG gas) and increasing storage-to-storage competition.

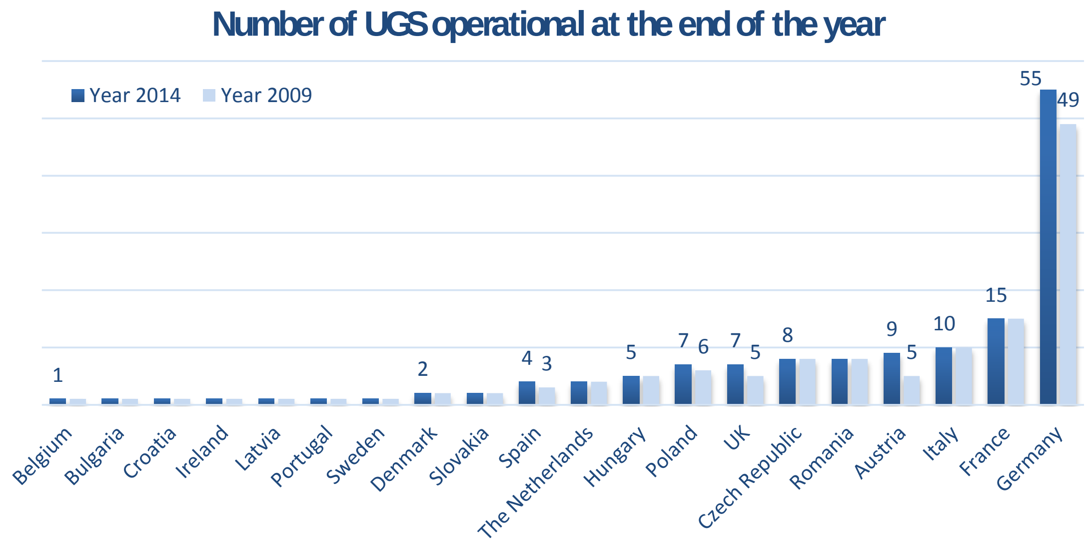
In addition the recent communication on the preparedness for a possible disruption of supplies from the East during the fall and winter of 2014/2015 (COM(2014) 654 final) [19] has showed that the way MS address the use of storages may hide important risks for the security of supply in the medium term. If countries rely on a short term increase in withdrawal rates (unless measures are taken subsequently to avoid emptying storages too rapidly), they may face the repercussions later in case a disruption or problems endure, including that withdrawal rates at low storage levels decrease substantially.

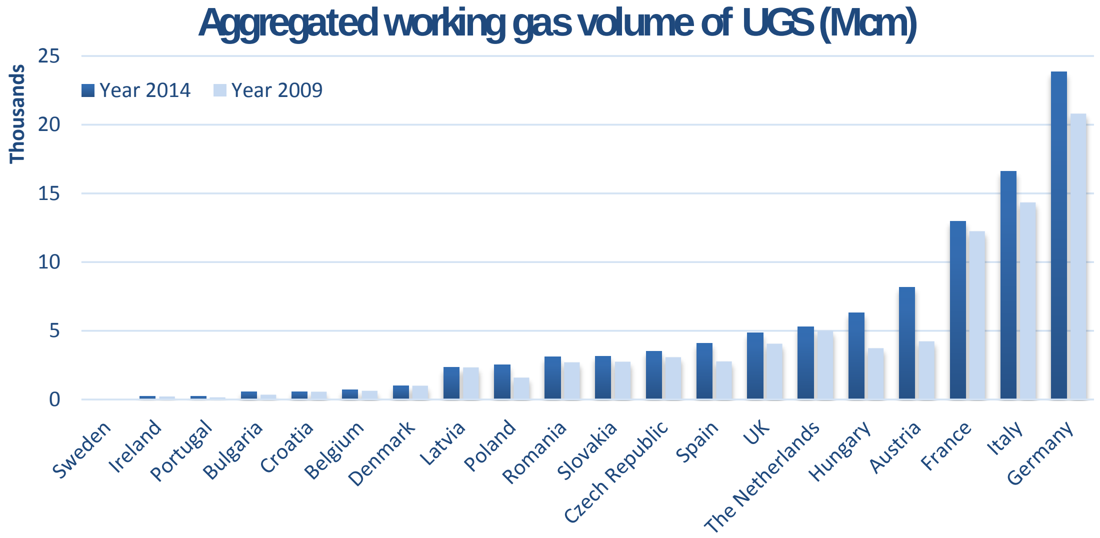
Table 3. Number of UGS facilities in EU classified by type, aggregated working volume, total withdrawal capacity, total injection capacity (plus extension of operational facilities) and access regime for 2009 (upper table) and 2014 (lower table) [23, 24, 25, 26].

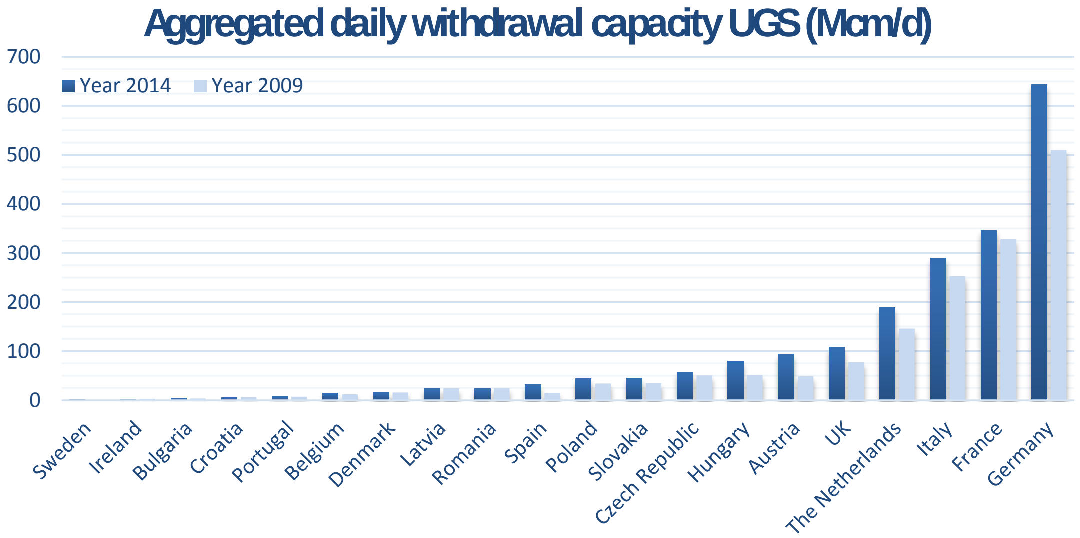
	Number of facilities					**Working Gas (Mcm)**		**Withdrawal Capacity (Mcm/d)**		**Injection Capacity (Mcm/d)**		**Access regime**	
YEAR: 2009	Total	By type:											
		Depleted Field	Acquifer	Salt Cavity	Other	operating	extension	operating	extension	operating	extension	regulated	negotiated
Austria	5	5				4230	1200	48,88		40,48			5
Belgium	1		1			625	75	12,00	3	6,00	1,8	1	
Bulgaria	1	1				350		3,30		3,00		1	
Croatia	1	1				553		5,76		3,84		1	
Czech Republic	8	6	1	1		3077		50,70		36,25			6
Denmark	2		1	1		1001		15,70		6,50			2
France	15		12	3		12255	1250	328,50		150,00			15
Germany	49	14	10	24	1	20804	3227	509,86		236,63			49
Hungary	5	5				3720	600	51,00	6,8	25,87	4	5	
Ireland	1	1				218		2,50		1,70			
Italy	10	10				14335	2002	253,00		132,70		10	
Latvia	1		1			2320		24,00		16,80			
Poland	6		5	1		1575	950	33,80		18,69			
Portugal	1			1		150	30	7,00	7	2,50	2,5		
Romania	8	8				2694	750	25,07		31,07		8	
Slovakia	2	2				2750		34,35		28,85			2
Spain	3	3				2775	846	14,80	11,6	9,60	7,9	3	
Sweden	1				1	10		0,60		0,49			
The Netherland	4	3			1	5000		146,00		39,60			2
UK	5	3		2		4051	30	77,62	0	51,52	0	1	1
EU	129	62	31	33	3	82.493,0	10.960,0	1.644,4	28,4	842,1	16,2	30	82

	Number of facilities					**Working Gas (Mcm)**		**Withdrawal Capacity (Mcm/d)**		**Injection Capacity (Mcm/d)**		**Access regime**	
YEAR: 2014	Total	By type:											
		Depleted Field	Acquifer	Salt Cavity	Other	operating	extension	operating	extension	operating	extension	regulated	negotiated
Austria	9	9				8166		94,38		76,06			9
Belgium	1		1			700		15,00		7,80		1	
Bulgaria	1	1				550		4,20		3,50		1	
Croatia	1	1				553		5,76	6,72	3,84		1	
Czech Republic	8	6	1		1	3497		57,40		40,50			8
Denmark	2		1	1		998		16,20		8,40			2
France	15	1	11	3		12965	160	347,00	10	160,90	4		15
Germany	55	11	10	33	1	23852	2902	643,24		350,94			54
Hungary	5	5				6330		80,10		46,45		5	
Ireland	1	1				230		2,60		1,70			
Italy	10	10				16615		290,50		136,30		10	
Latvia	1		1			2320	500	24,00	5	16,80	5	1	
Poland	7	5		2		2524	775,91	43,45	20,91	25,52	4,84	7	
Portugal	1			1		239	56	7,14	0	2,02	0	1	
Romania	8	8				3100	650	24,27	36	30,27	6	8	
Slovakia	2	2				3135		45,11		38,77			2
Spain	4	3	1			4103	1300	31,50	25	22,70	8	4	
Sweden	1				1	9		0,96		0,36			
The Netherland	4	3		1		5300		189,20		66,00			1
UK	7	3		3	1	4842	432	108,23	14	83,50	14		3
EU	143	69	26	44	4	100.027,6	6.775,9	2.030,2	117,6	1.122,3	41,8	39	94

Source: JRC analysis on GSE maps for 2009 and 2014, and from LBEG 2010, 2013

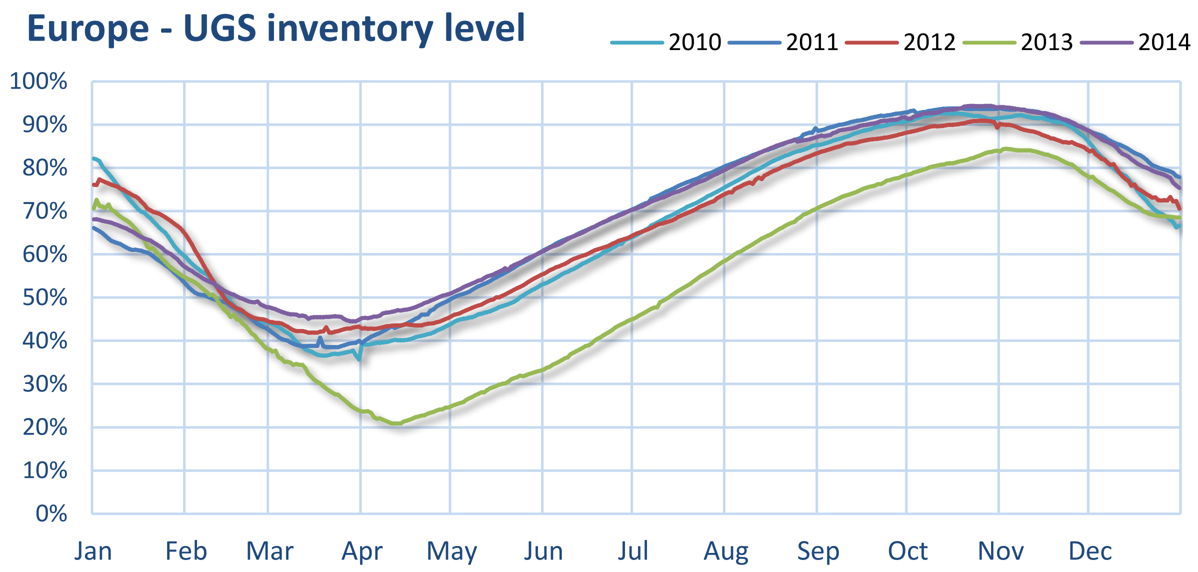






Source: JRC analysis on GSE maps for 2009 and 2014, and from LBEG 2010, 2013

Figure 3. Total number of UGS (A), aggregated working volume (B) and average aggregated daily withdrawal capacity (C) per country in EU in 2009 and 2014.



Source: JRC analysis on GSE data

Figure 4. Inventory level in percentage of the total working volume in the UGS in Europe from 2010 to 2014.

2.3 CROSS-BORDER CAPACITY AND PHYSICAL REVERSE FLOW

Among different tools foreseen by Regulation (EU) 994/2010 [2] to increase and strengthen the level of EU security of supply, the use of physical bi-directional gas flow[8] (or reverse flow) has a special role. TSOs were obliged by the Regulation to enable permanent physical bi-directional capacity on all relevant cross border points by 3 December 2013[9] and Competent Authorities are obliged to regularly check the need for reverse flows when they update their risk assessments and plans.

In general the benefits of implementing reverse flow at a particular cross-border interconnection can be summarized in:

- reverse flow can be an efficient and cost effective way of increasing entry capacity[10];
- it is a way to have access to new gas sources of supply;
- it helps the shippers to rapidly and massively reroute gas deliveries within the internal market;
- it provides a tool to change the direction of traditionally one-way transport routes in case that one of the Union's major supplies becomes unavailable.

Reverse flow has been substantially implemented within the EU as the number of interconnection points increased from 24% in 2009 to 40% in 2014 (Table 4). Because of this natural gas can flow via almost every second interconnection point between Member States in both directions. Furthermore the geographical location of the new bi-directional interconnections provides an increased flexibility of moving natural gas among MS and directions like North-South (with Denmark-Germany, Austria-Italy, Greece-Bulgaria and Romania-Hungary) or East-West (with Germany-Poland, France-Spain, Austria-Slovakia) (Figure 5). All these improvements can certainly be regarded as an important success, though some strategic elements (like the cross-border interconnection of Obergailbach and Waidhaus, or the BBL pipeline) are still far from implementing bi-directional physical flows.

As it has been clearly explained in the working document SWD(2014) 325 final [3]: "*The majority of this development has come from commercial projects incentivized by the market demand. Nevertheless, Regulation 994/2010 has been instrumental in putting in place or speeding up physical reverse flows on some interconnections where voluntary market developments did not bring about the necessary results on time although reverse flows are crucial for security of supply reasons, such as on the Yamal pipeline between Poland and Germany, on the interconnection between Romania and Hungary and*

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[8] Physical reverse flow stands for the technical and commercial possibility that natural gas is transported in both directions across a certain interconnection point (up to the available technical capacity), independently from the quantity of gas coming from the prevailing forward direction.

[9] But the Competent Authorities may grant an exemption in case that the bi-directional capacity would not significantly enhance the security of supply of any Member State or region, or if the investment costs would significantly outweigh the prospective benefits for security of supply.

[10] Implementing physical reverse flow is in general a cheap option. When a system has been designed to propel gas in one direction, making it bidirectional is a matter of upgrading the originally deployed compressor stations to propel gas also in the opposite direction. This is achieved by deploying the right pipelines and valves to allow suctioning gas from the pipelines that normally downstream and pushing the gas to the pipelines that are normally upstream. In general there is no need of deploying new compressor stations or other expensive facilities; nevertheless, gas quality and odorization may be an issue at some cross-border points that may make more expensive the achievement of bi-directional physical flow.

between Greece and Bulgaria. At the same time, the Regulation did not bring about changes in other, major interconnection points such as at Obergailbach (France-Germany), Waidhaus (Czech Republic-Germany) or on the BBL pipeline (Netherlands-UK)."

The majority of interconnection points remaining unidirectional since 2009 (Figure 5) is due to an "exemption" granted by the Competent Authorities[11]. Exemptions were granted for different reasons like:

- the interconnection links a MS at the end of the supply route ("cul-de-sac") with no possibility of having gas (e.g. through UGS) that could be shipped in the reverse direction, or the connection is directly linked with a distribution network or a production field;
- different odorization practices on both sides of the border technically prevent the reverse flow;
- it is unnecessary to make investments for ensuring reverse flows of L-gas into areas where L-gas may be supplied by blending H-gas.

Along with the implementation of physical bi-directional capacity among MS, the overall capacity of the EU high pressure grid has improved as a whole of 4,1% since 2009 (Table 5). Along with some new interconnections and associated capacity (like Romania-Hungary, Hungary-Croatia), some MS have increased their capacity of moving gas substantially like Germany, Austria and Belgium (Figure 6). In the Netherlands, relevant improvements in the high pressure grid did not turn out in an increase of firm capacity – mainly with Germany – possibly for the downward general trend in gas consumption in the period 2010-2014 (a drop in total inland sales of 26% and of 12% respectively for the Netherlands and Germany [27, 28]).

Capacity at international cross-border interconnections with non-EU countries shows a remarkable increase like with Norway (25% since 2009), with Northern Africa (32% mainly due to Almeria), and from Russia directly through Nord Stream or indirectly through Belarus (i.e., the Jamal pipeline) and Ukraine (17,5 % since 2009) (Table 5). Furthermore during 2014 reverse flow to Ukraine has been strengthen from Poland, Slovakia and Hungary with an overall capacity of 22,9 Mcm/d. Still, the diversification of supply sources to EU is not enough to provide safer conditions to its high dependency from a small number of producing countries.

The improvements in interconnections, facilities (i.e., LNG and underground gas storages) and reverse flow capacity are reflected for many Member States in a general increase of the infrastructure standard (cfr. Art. 6 and Annex I of Reg. (EC) 994/2010) between 2012 and 2014[12] (Figure 7). The infrastructure, calculated using the N – 1 formula, describes the ability of the technical capacity of the gas infrastructure to satisfy total gas demand in the calculated area in the event of disruption of the single largest gas infrastructure during a day of exceptionally high gas demand occurring with a statistical probability of once in 20 years. Figure 7 shows that the number of MS not satisfying the standard (i.e., N – 1 equal or greater than 100%) has decreased and the figures have increased on average 19 percentage points. In many cases this is primarily linked to the changes in the gas system and reinforced by a reduction of the demand in peak conditions.

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[11] See Art. 7 "Procedure for enabling bi-directional capacity or seeking exemption" of Reg. (EC) 994/2010.

[12] Since Reg. (EC) 994/2010 entered in force, the Risk Assessment, the Preventive Action Plan and the Emergency Plan have been revised one time after their submission by 2012. The only exception is Croatia, which joined the European Union in 2013.

Table 4. Number of unidirectional and bi-directional cross-border interconnection points in the EU in 2009 and 2014 [29, 30].

	In EU*		With EU**	
	2009	2014	2009	2014
Number of bi-directional interconnection points	12	21	1	3
Number of unidirectional interconnection points	37	32	24	27
Total number of cross-border interconnection points	49	53	25	30

* The analysis does not take into account low-pressure pipelines which cross the border to serve local demand and which are not part of the high-pressure transmission network and any cross-border interconnection with non EU Member States, with the exception of Switzerland. Source: JRC analysis on GIE and ENTSOG maps.

** The analysis considers all pipelines cross-border points among an EU Member State and other neighbouring Countries (excluding Switzerland). The interconnection between the Republic of Serbia and Bosnia and Herzegovina (i.e., Zvornik) is not considered.

Source: JRC analysis on GIE and ENTSOG maps.

Table 5. Capacity in million cubic meters per day (Mcm/d) at the interconnection points within Europe and among Europe and Norway, Northern Africa, Russia, Belarus and Ukraine, and other Countries (i.e., FYROM, Serbia, Bosnia Herzegovina and Turkey).

	2009	*2014*	*% 09 – 14*
Aggregated capacity at cross-border points within the EU*	1804,6	1879,4	4,1
Aggregated capacity at cross-border points with Norway	335,0	418,8	25,0
Aggregated capacity at cross-border points with Northern Africa	144,7	191,0	32,0
Aggregated capacity at cross-border points with Russia, Belarus, Ukraine	650,6	764,2	17,5
Aggregated capacity at cross-border points with other Countries**	62,5	61,7	-1,3
Overall Total	2.997,4	3.315,0	10,6

* And Switzerland.

** Republic of Serbia, Former Yugoslav Republic of Macedonia, Turkey. To make comparable this table to the cross-border points of Figure 5, the capacity for Zvornik (Republic of Serbia and Bosnia and Herzegovina) should be considered for 2009 with a capacity of 1,9 NMcm/d, and for 2014 of 1,6 NMcm/d.

Values were derived using the provided gross calorific value or, if missing, a reference value of 11,18.

Source: JRC analysis on GIE and ENTSOG maps.

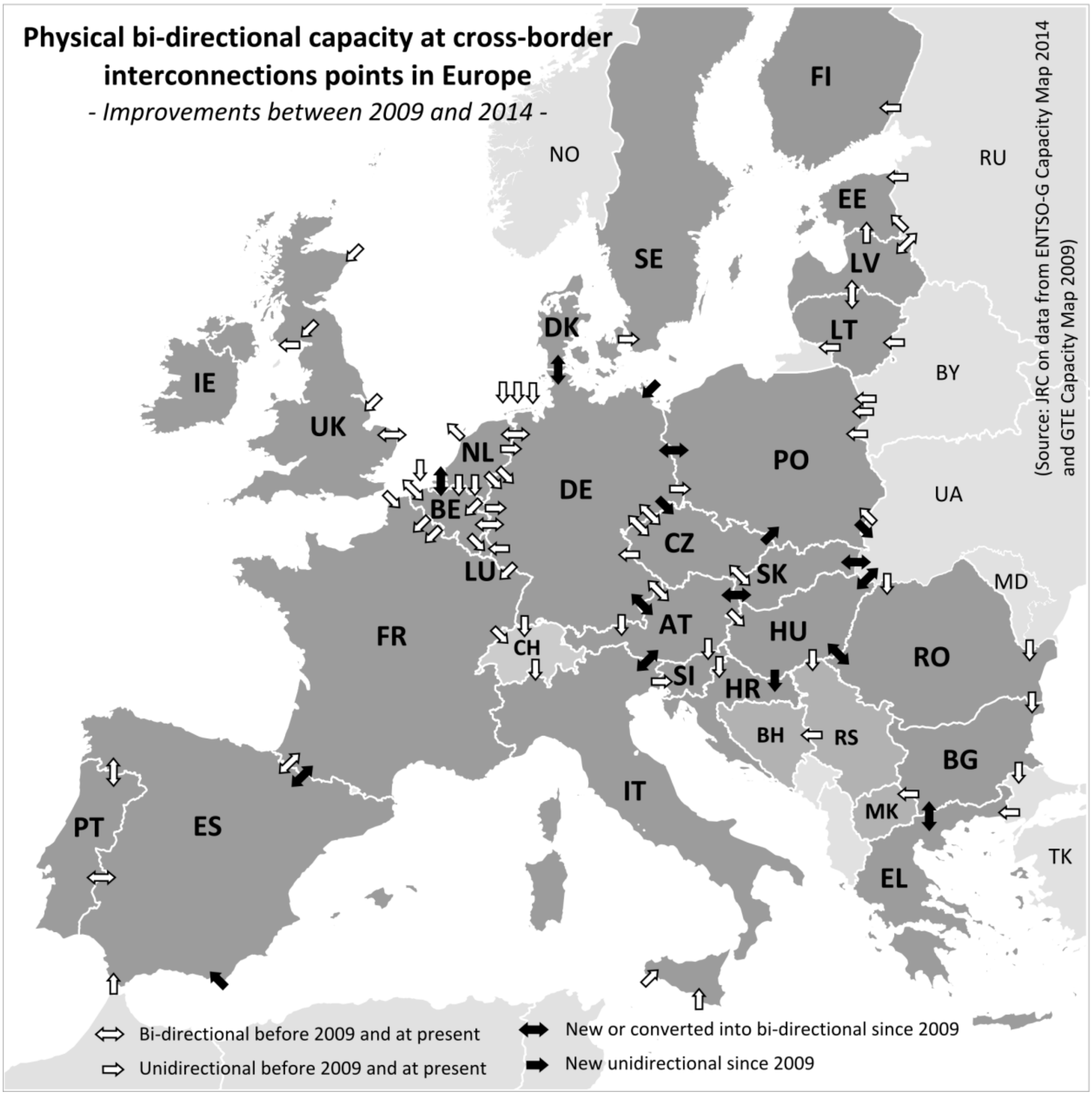
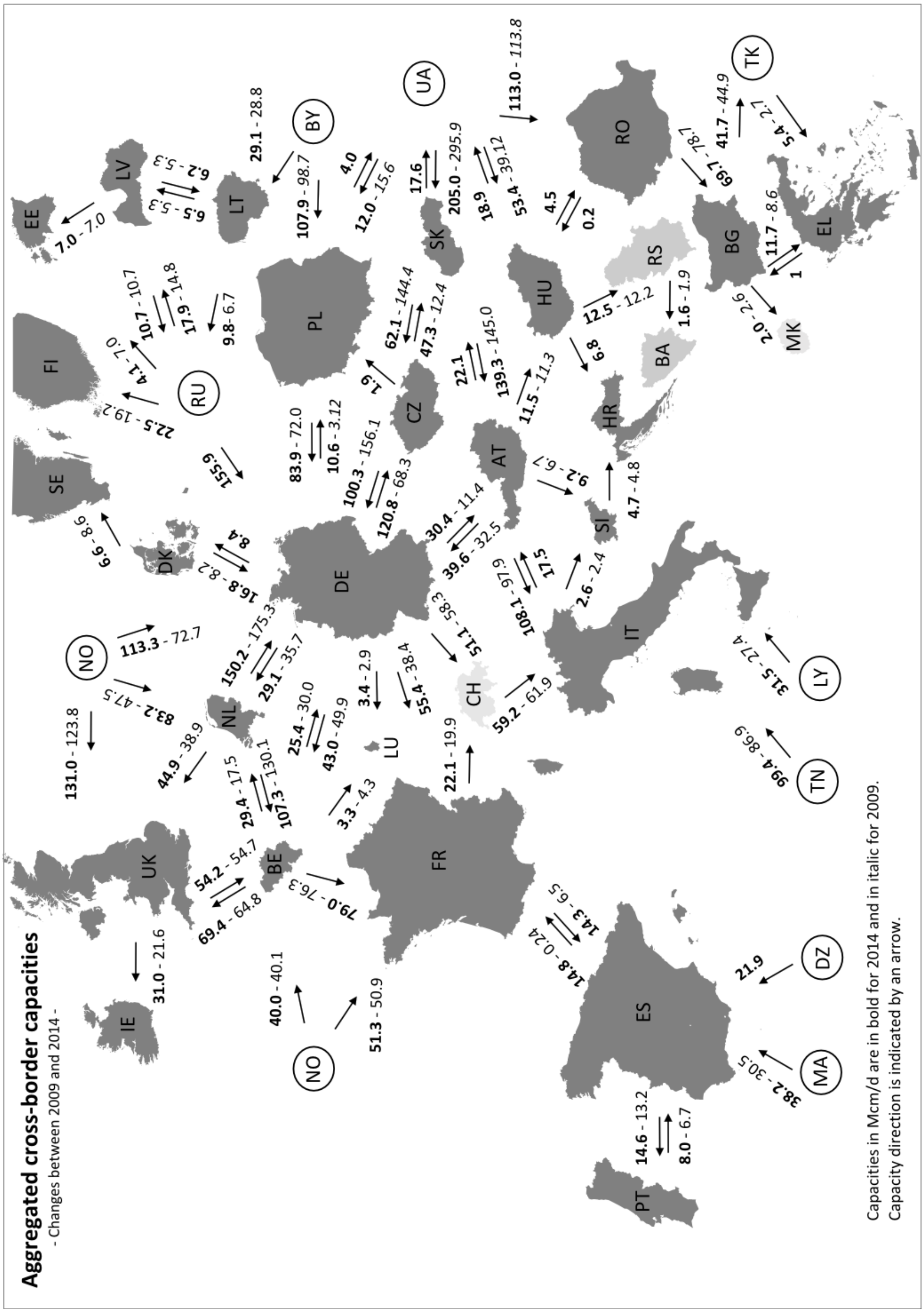
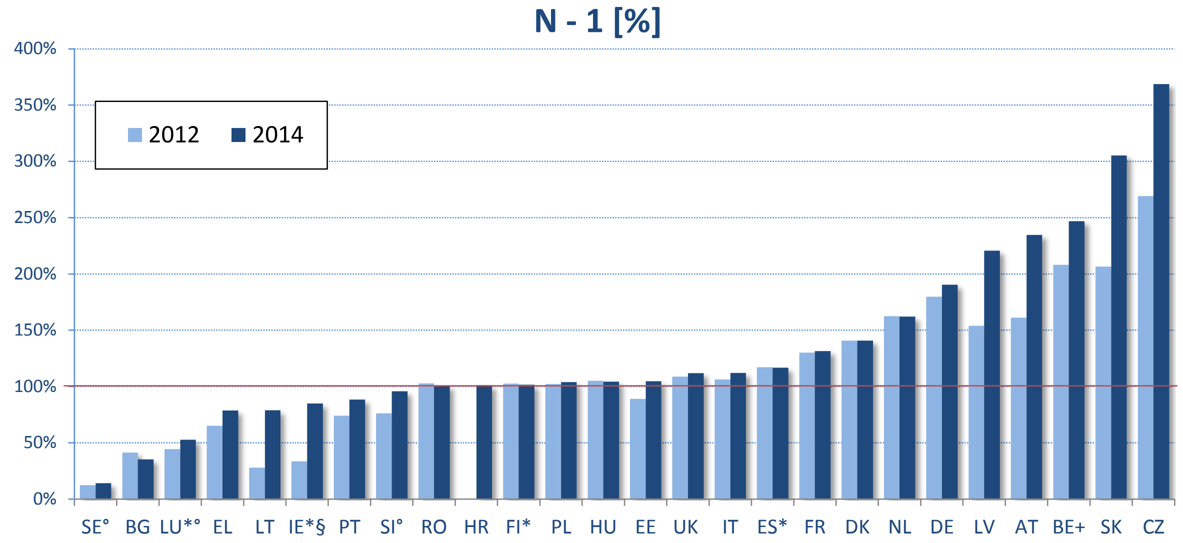


Figure 5. Map that indicates the physical bi-directional capacity (i.e., reverse flow) at cross-border interconnection points in the EU and Switzerland for 2009 and 2014, pointing to locations where improvements in the physical bi-directional have taken place [29, 30].



Source: JRC on data from ENTSOG Capacity Map 2014, GTE Capacity Map 2009

Figure 6. Comparison of the aggregated cross-border capacities among EU Member States and neighbouring Countries for 2009 and 2014 [29, 30]. See Annex 2 for details on data processing.



* The Member State applies demand-side measures (Annex I, Reg. (EC) 994/2010).

° MS exempted. + The value is for the H-gas network. § The standard is satisfied at the regional level with UK.

N.B.: Croatia joined the European Union in 2013. Ireland fulfils the requirement at the regional level with UK. Greece should be able to reach a Deff of 4.1 mcm/d in order to fulfil the requirement.

Figure 7. Comparison of the infrastructure standard (i.e., N-1 formula) between 2012 and 2014 for EU Member States.

3. GEMFLOW. A MASS BALANCE BASED MODEL OF THE EUROPEAN GAS SYSTEM

Within the legal framework provided by the Regulation (EU) 994/2010 and the Directive 2008/114/EC, simulation tools have been developed by the JRC to model the National Natural Gas Transmission System (NNGTS) of the EU Member States. The "Gas Emergency FLOW" model (GEMFLOW) is one of the technical tools created to deeply investigate emergency cases and supply crises [8, 9]. GEMFLOW is a model coupling a Monte-Carlo approach and a set of rules created to describe the behaviour of a NNGTS at the country level. The model has been built using the language of technical computing MatLab™ from MathWorks™.

GEMFLOW is a mass balance network model in which 30 countries are defined as European countries (26 EU MS which are gas consumers plus Switzerland, Bosnia-Herzegovina, Serbia and the Former Yugoslav Republic of Macedonia). Nine other countries are described as gas suppliers to Europe (Algeria, Belarus, Libya, Morocco, Norway, Russia, Tunisia, Turkey and Ukraine), although some of them are just transit countries. Each country is defined as a node and it is connected to a neighbouring country through a single virtual pipeline that sums up the capacity of all the real pipelines that connect the two countries. The capacity of the virtual pipeline establishes the upper limit of gas that can be transported between them. Each country is defined by 4 flow variables: domestic production (PROD), storage withdrawal flow (STO), regasification flow (LNG) and domestic consumption (CONS). The gas flow imported (IMP) and exported (EXP) is the result of the aggregation of all the gas flowing in and out of the country via pipeline.

GEMFLOW aims at reaching the balance in the 30 European countries at any moment. A country i is balanced when the following equation is fulfilled:

$$\mathrm{PROD}_i + \mathrm{STO}_i + \mathrm{LNG}_i - \mathrm{CONS}_i + \mathrm{IMP}_i - \mathrm{EXP}_i = 0 \qquad \text{(Eq. 1)}$$

If the result of the equation is lower than zero, the country will be unbalanced and therefore it will be unable of satisfying the demand. The countries with a balance lower than zero are *in-need* countries. The countries which have a balance higher than zero are *gas provider* countries and will send their spare gas to *in-need* countries.

The model can simulate gas disruptions by decreasing the values of production, storage, regasification flow or the gas imported from one or several countries. GEMFLOW can also simulate the effect of an incremented gas demand by increasing the value of gas consumption in one or more countries. The length of the scenario simulated is a variable to be decided by the user. Scenarios with duration between 1 day and 6 months (180 days) can be simulated. However, it must be born in mind that the initial value of the variable CONS (consumption) defined in eq. 1 is not changed during the simulation. It means that if a 30 day scenario is simulated, it is assumed that the consumption of a country remains constant during the whole period and it is set to its average daily consumption during that period.

In order to obtain a balanced Europe, a strategy of three steps happening each day of the simulation has been designed in GEMFLOW (see Figure 8). The GEMFLOW strategy implements a Monte-Carlo approach for carrying out simulations. A Monte-Carlo simulation is a statistical technique to explore the behaviour and sensitivity of a complex system by manipulating parameters within defined statistical constraints. The core idea is to simulate a system, built up on a specific set of rules, by repeated random sampling of parameters from reference probability distributions to produce multiple possible outcomes, and record the outputs. The analysis of the statistical properties of the distribution of the outputs provides insights in the unknown probabilistic entity. Based on such an approach, GEMFLOW does not look for the "optimal" strategy through the minimization of some indicators but allows the system to evolve freely following the model rules and producing a number of possible strategies to face the crisis. In this way (taking account of nearly all possible system operator decisions) it is possible to have a probabilistic picture of the resilience (stability) of the system.

At the beginning of an analysis the user must specify the length of the simulation (i.e., the number of iterations to be completed by GEMFLOW) and the length of the scenario. A scenario of 30 days with 100 simulations means that a scenario is assessed for 30 days and the assessment will be repeated 100 times. The solution obtained at the end of the simulation will show the probability of failure of each country and the average amount of unserved gas per country – considering all iterations – during the period of the study.

GEMFLOW is built upon three steps. The first step is the "self-centred" step. When GEMFLOW finds an unbalanced country, named country i, it will try in the first place to use the domestic resources of the country in trouble to reach the balance. Thus, GEMFLOW will increase the production flow (until the maximum defined value). If this is not enough, it will increase the regasification flow and if it is still insufficient, it will change the storage withdrawal flow. The storage flow will be changed randomly from zero to the maximum withdrawal capacity.

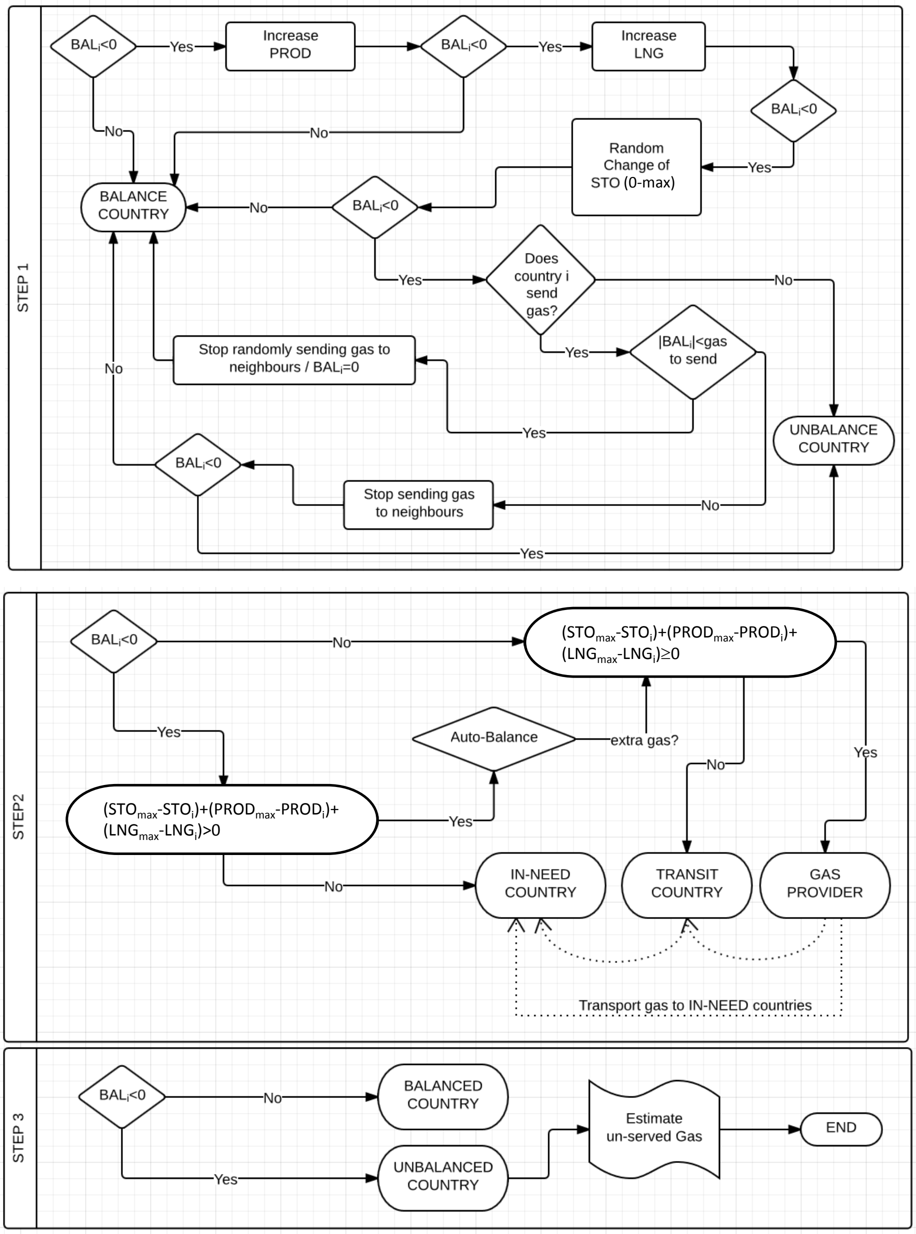
If the country i is still unbalanced after the use of the internal resources, the exports of gas to neighbouring countries will be analysed. It may occur that country i sends to one or more neighbouring countries a big enough amount of gas as to satisfy its own balance. If this is the case, at this point of the simulation, the country i will stop sending gas to the neighbours in order to reach its own equilibrium. In case there are several gas neighbours to be shortened, the order and amount of gas curtailment will be chosen randomly by GEMFLOW. If the country i sends gas to one or more neighbours but the amount of gas exported is not enough to reach its own balance, anyway the country i will stop sending gas to the neighbours to decrease its own unbalanced situation.

At the end of step 1 there will be a number of unbalanced countries that managed to reach equilibrium after the measures taken during the step. But there will be other countries that they may have started from a balanced position and that became unbalanced after the curtailment of gas from the side of an unbalanced country.

The second step is called the "solidarity" step. In this step GEMFLOW tries to reach the balance of all countries by means of sharing the spare gas of a *provider* country with the *in-need* neighbouring countries. The countries that are balanced at the beginning of the step are classified in terms of spare gas availability. Those countries balanced and with spare capacity - either to produce gas, to increase the withdrawal of stored gas or with additional regasification capacity - are classified as *gas providers*. Those countries balanced but with non-availability of spare gas are classified as *gas transit countries*. This means that, although they are no donors of gas, they can serve as a bridge between the *gas provider countries* and the *in-need countries*. On the other hand there are countries that start step 2 as unbalanced countries. It is possible that those countries have spare capacity in storage, production or regasification facilities due to the fact that the change in storage withdrawal in step 1 is done randomly or due to the curtailment of gas from a neighbouring country at the end of step 1. If the spare capacity of an unbalanced country is more than enough to balance itself, the extra gas will put the country in the position of becoming a gas provider. Once the countries are classified into gas providers or gas receivers the algorithm starts sending the gas from one to another provided that there is capacity available in the interconnection between countries. The algorithm of distribution of gas between neighbouring countries operates in a random manner. In this way there is not a determined strategy to prioritize one country over another. The higher the number of simulations introduced in GEMFLOW is, the bigger the spectrum of solutions obtained.

Step 3 of GEMFLOW is the "counting" step. In this final step the countries are classified into balanced and unbalanced countries. The deficit of gas for the unbalanced countries is recorded and the volume of gas remaining in the storage facilities is updated accordingly.

When the three steps are completed, one day of the simulation has occurred. The second day of the simulation will start at step 1 with the updated values of each of the parameters.

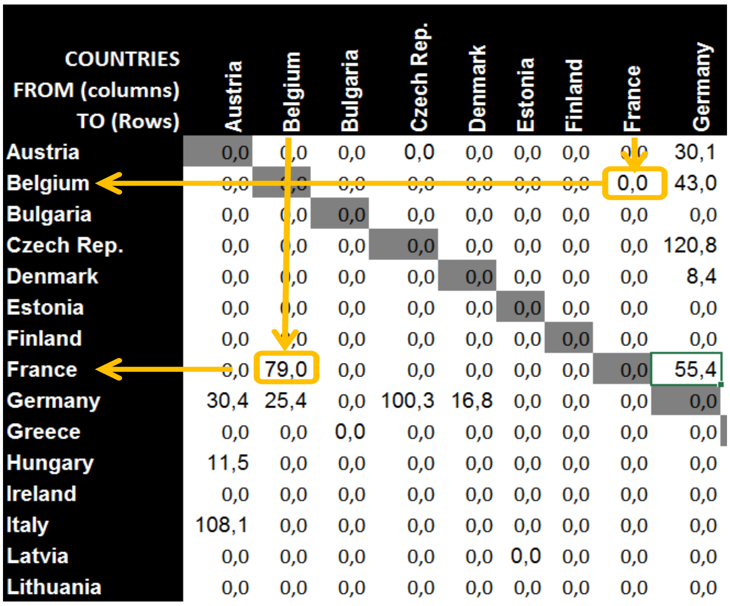


BAL_i is the calculated balance of country i in a certain time step. PROD indicates production. STO indicates the storage withdrawal capacity. LNG indicates the flow from the LNG facilities.

Figure 8. Flow diagram of GEMFLOW model.

3.1 INPUT DATA REQUIRED IN GEMFLOW

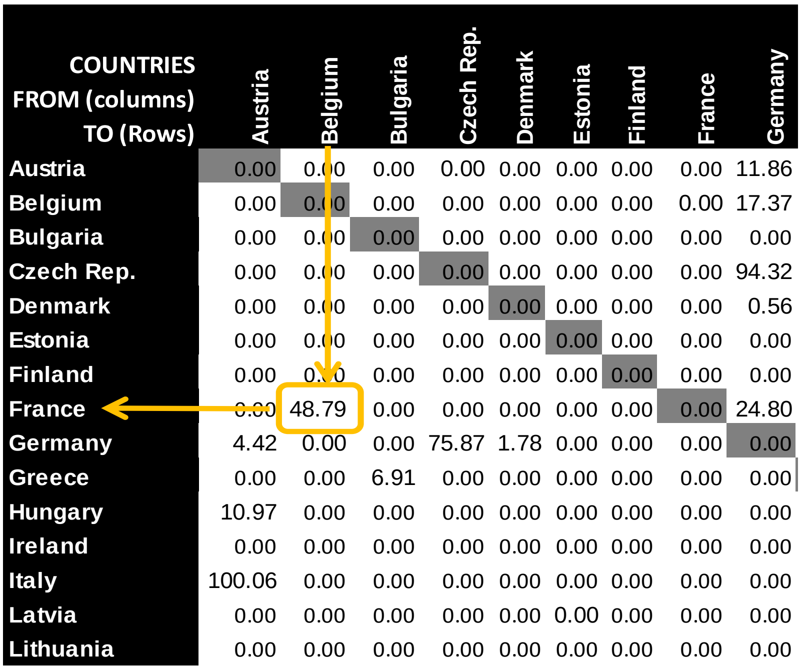
GEMFLOW requires three different sets of input data to define the starting scenario from which all simulations are carried out. All data are organized in spreadsheets to be easily managed and updated. The first spreadsheet file is named the capacity matrix. It is a matrix that indicates the aggregated technical capacity between two countries. The exporting countries are in columns and the importing countries are in rows. Figure 9 shows part of the capacity matrix used as input file in GEMFLOW. It can be seen, for example, that the technical capacity from Belgium (2nd column) to France (8th row) is 79 Mcm/d. Between Belgium and France there are three interconnections and the aggregated maximum capacity for the three of them is 79 Mcm/d. On the contrary, the capacity from France (8th column) to Belgium (2nd row) is zero. This means that there is no reverse capacity in any of the three interconnections. The value of the capacity establishes the upper limit of gas that can be transferred from one country to another.



COUNTRIES FROM (columns) TO (Rows)	Austria	Belgium	Bulgaria	Czech Rep.	Denmark	Estonia	Finland	France	Germany
Austria	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	30,1
Belgium	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	43,0
Bulgaria	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Czech Rep.	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	120,8
Denmark	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	8,4
Estonia	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Finland	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
France	0,0	79,0	0,0	0,0	0,0	0,0	0,0	0,0	55,4
Germany	30,4	25,4	0,0	100,3	16,8	0,0	0,0	0,0	0,0
Greece	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Hungary	11,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Ireland	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Italy	108,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Latvia	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Lithuania	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Figure 9. Part of the capacity matrix which reflects the aggregated technical capacity between countries; from countries in the columns to countries in the rows (units: Mcm/d).

The second spreadsheet file required by GEMFLOW is named the flow matrix. This matrix has the same structure as the capacity matrix but in this case the values in the intersection between columns and rows indicate the aggregated flow between countries for the particular scenario that the user wants to study. Figure 10 for example shows that the gas flow from Belgium to France for that specific scenario is 48,79 Mcm/d. The flow exchanged between countries cannot be higher than the maximum capacity between countries indicated in the capacity matrix.



COUNTRIES FROM (columns) TO (Rows)	Austria	Belgium	Bulgaria	Czech Rep.	Denmark	Estonia	Finland	France	Germany
Austria	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.86
Belgium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	17.37
Bulgaria	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Czech Rep.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	94.32
Denmark	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.56
Estonia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Finland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
France	0.00	48.79	0.00	0.00	0.00	0.00	0.00	0.00	24.80
Germany	4.42	0.00	0.00	75.87	1.78	0.00	0.00	0.00	0.00
Greece	0.00	0.00	6.91	0.00	0.00	0.00	0.00	0.00	0.00
Hungary	10.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ireland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Italy	100.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Latvia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lithuania	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 10. Part of the flow matrix which reflects the flow exchanged between countries in a particular time frame (units: Mcm/d).

The last spreadsheet file required by GEMFLOW indicates the gas features of each country for the specific time frame of the simulation. Table 6 shows part of an example of a spreadsheet file with the values of average daily consumption (CONS), minimum daily consumption (Min. CONS), average daily national production (PROD), maximum daily production (Max. PROD), average daily regasification flow (LNG), maximum daily regasification capacity (Max. LNG), average daily storage withdrawal (STO), maximum daily storage withdrawal capacity (Max. STO), average volume of gas in the storage (STO Inventory), maximum capacity volume of gas in the storage (STO Max. Inventory) per each country. Annex 2 provides the data used for determining the features for each country for the year 2009 and 2014 with reference period January.

Table 6. An example of the structure and data types used to build the country features table.

COUNTRY	CONS	Min. CONS	PROD	Max. PROD	LNG	Max. LNG	STO	Max. STO	STO Inventory	STO Max. Inventory
Austria	38,18	38,18	3,06	5,10	0,00	0,00	18,14	94,38	4400,50	8166,00
Belgium	72,93	72,93	0,00	0,00	3,39	40,80	2,27	15,00	471,13	700,00
Bulgaria	11,60	11,60	0,72	1,03	0,00	0,00	3,12	4,20	357,19	550,00

Units: Mcm/d; units of STO Inventory and STO Max. Inventory: Mcm

The capacity matrix establishes the limits for the import and export flows and therefore it is a fixed matrix with determined values for the reference year of the simulation. However the flow matrix and the gas features table can be changed to simulate a crisis or a disruption. For instance, the impact of decreasing gas production in Europe can be simulated by decreasing the value of maximum daily production (Max. PROD) of Figure 9 in all countries. Another example of a simulation is to decrease the gas flow coming from a gas supplier to Europe. In order to simulate this, the gas flows of the column of a European gas supplier (for example Norway or Russia) in the flow matrix of Figure 8 should be decreased or set to zero.

Table 7 provides the relevant official data source used for populating the input to GEMFLOW. The cross-border capacity matrix has been calculated by using data provided by ENTSOG and GIE (for 2009). The flow matrix has been computed as average daily flow from the monthly data of IEA for January 2014 and 2009. The country feature data set is built using figures (see Annex 3):

- from GIE-GLE, GIE-GSE (i.e., Table 2 and Table 3) for the infrastructure maximum flows and capacities;
- from AGSI+ and ALSI for the inventory level and average send-out of January 2014 (using the first half of the month), while for 2009 data from a report to the Gas Coordination Group were used to have an estimate;
- domestic production has been estimated as the average from the monthly production of January and as the maximum daily production by considering the average over the last three years for each reference year (e.g., for 2014 data were pulled by 2014, 2013 and 2012);
- consumption levels for 2014 and for 2009 were estimated from IEA monthly total consumption figures by dividing for the number of days in January. For the MS most affected during the gas crisis of 2009, consumption was estimated by considering an average between December 2008 and February 2009.

Table 7. Data sources used to build the input data sets for the comparison of the behaviour of the European high pressure natural gas grid for the year 2009 and 2014.

Input for GEMFLOW	**Data Source**	**Web page**
Country feature:		
UGS	Gas Infrastructure Europe (GIE) – AGSI+ Aggregated Gas Storage Inventory	transparency.gie.eu
	GIE-GSE Storage MAP 2014, 2009	
LNG	Gas Infrastructure Europe (GIE) – ALSI Aggregated LNG Storage Inventory	lngdataplatform.gie.eu
	GIE-GLE LNG MAP 2014, 2009	
Consumption and Production	IEA data for .OECD countries	www.iea.org/statistics/relatedsurveys/monthlygasdatasurvey www.jodidata.org/gas/database/data-downloads.aspx epp.eurostat.ec.europa.eu
	JodiGas for non OECD countries and EUROSTAT data ()	National web-pages
	National statistics for Republic of Serbia, Bosnia and Herzegovina and FYROM	
Cross-border capacities	ENTSOG Transparency Platform and ENTSOG map for capacity at cross-border interconnection points (for year 2009)	www.gas-roads.eu
Cross-border flows	*IEA – Gas Trade Flow in Europe*: Monthly aggregated values of flows among European countries	www.iea.org/gtf/index.asp

3.2 PERFORMANCE OF THE EUROPEAN GRID DURING SIMULATED CRISIS

A simulation approach has been used to carry out a first assessment of the behaviour of the high pressure European natural gas grid and the effects of the changes in the infrastructure between 2009 and 2014. The main objective is to explore the gas network resilience under non market conditions (i.e., due to a geopolitical crisis, a commercial dispute between different parties or a disruption of a main import route to Europe).

The use of GEMFLOW allows to assess in statistical terms the likelihood and extent of unserved gas to customers in a country as a result of different possible allocation strategies and import-export options. This provides a better way of evaluating changes in the infrastructure (i) by considering the entire system, (ii) by explicitly using interactions among the system's components (i.e., LNG, UGS, production, import and export) and (iii) by addressing the geographical nature of the problem (i.e., peculiarities of interconnections between neighbouring countries, partial / total isolation of some EU regions and characteristics of the different national transmission systems). The improvements of gas infrastructures, the adoption of bi-directional capacity together with the decrease of gas consumption in Europe might indicate beforehand that Europe is better equipped to tackle a major gas crisis in 2014 than in 2009. However, in order to establish a fair playfield for the simulations carried out, some assumptions have been adopted.

The total EU gas consumption in 2014 decreased 6% respect to 2009. However the decrease in gas demand has not been continuous since 2009. In 2010 the gas consumption increased (8 % respect to 2009, [31, 32]) and represents the highest European gas demand in history. Therefore in all scenarios, both 2009 and 2014, the values of gas consumption corresponding to 2010 are used. In this manner, the impact of new infrastructure is really assessed and the seasonal changes of gas consumption are ignored.

The monthly volume of gas in storages is another seasonal factor that varies along the months and may change among the years. For this reason, for all cases studied in this paper the volume of storages has been set at 70% of the maximum working capacity. It means that when the crisis starts the volume in all the EU storage facilities is set to 70% of the maximum inventory capacity. The regasification capacity has been treated in the same manner. LNG terminals have a maximum send-out capacity that it is somehow related to the size and stock level of the LNG tank. Maintaining a certain stock level in the LNG tank depends in turn on the frequency that ships are received. The regasification terminals are designed to maintain the maximum send-out for at least one day without restrictions however the crises in this study have 30 or 90 days duration. Bearing in mind the possible limits of a LNG terminal to operate at its maximum send-out capacity during long periods of times, the maximum regasification capacity has been set at a rate of 70% of its real maximum in all scenarios simulated both in 2009 and 2014.

Based on the above assumption two scenarios are studied with GEMFLOW model, corresponding to the cut of supply from one of the most important natural gas providers to Europe, which is Russia[13]. In the first scenario a disruption of the flows in transit through Ukraine is considered. In the second scenario all flows of natural gas originated in Russia are cut (i.e., natural gas in transit through Ukraine, through Belarus and by the Nord Stream pipeline to Germany). The length of the disruption is set to 30 and to 90 days for both scenarios, with the 30 days scenario starting in January. A total number of 300 simulations per scenario are carried out in GEMFLOW.

In order to evaluate the impact of a gas disruption at country level three variables are considered: the percentage of failure, the first day of failure and the average percentage

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[13] Russia covered approximately 39% of EU gas imports by volume in 2013 [19].

of unserved gas. The percentage of failure represents the number of simulations out of the total in which a country is not able to satisfy its demand for the entire simulation period. Since the scenarios simulated represent crisis of long duration (30 and 90 days) and random strategies are applied in each run, it might happen that a country only experiences lack of gas at the end of the period when a specific strategy is applied. The variable named first day of failure indicates the average first day in which a country experiences lack of gas. This value is obtained by averaging the first day of failure obtained only in the runs where a country fails. Therefore, the runs in which the country does not experience lack of gas (failure day null) are not taken into account in the average. The variable named average percentage of unserved gas computes the amount of unserved gas in a country out of the total gas demanded during the 30 or 90-day duration of the crisis simulated. In this case the average is computed over all simulations performed, not only on those where there is some non-null unserved gas.

The results obtained for the Ukrainian scenario, i.e. disruption from Russian gas only through Ukraine, are reported in Table 8 and Table 9 for a crisis of 30 and 90 days duration respectively. The results obtained for the Russian scenario, i.e. total gas disruption from Russia, of 30 and 90 days are shown in Table 10 and Table 11 respectively.

The percentage of failure and the average percentage of unserved gas are both key variables that provide insights in the ability of a country to survive a gas disruption. There are countries that have a high probability of failure however the amount of unserved gas is insignificant. The impact of a gas disruption is higher when both variables, probability of failure and percentage of unserved gas, are high. Figure 11 and Figure 12 show the percentage of unserved gas for the Ukrainian and Russian scenario of 30 and 90 days in a geographical way. Values below the threshold of 2,5% are not displayed as they are deemed to be not significant.

The comparison of the results obtained for the simulated crises reveals an increase in the resilience of the gas system to cope with gas disruptions. In general, 2014 scenarios show a lesser impact in terms of unserved gas than 2009 scenarios. In addition, 30-day duration scenarios have a lower impact than 90-day cases.

Although in general terms most of the countries improve their capacity to tackle these gas disruptions, the effect of gas shortages is still severe for some Member States dependent mainly on a single supply source or only a national cross-border entry. This is the case of Bulgaria, Former Yugoslav Republic of Macedonia and Finland. It is observed that the changes in the South-Eastern corridor (i.e., Romania – Bulgaria – Greece) along with the new improvements in Hungary have provided better options for the region to cope with a relevant shortage of supply both from Ukraine and total disruption from Russia. The increased storage capacity in Poland and Germany, the increment of LNG send-out capacity in France and the Netherlands, and the new bi-directional cross-border points in many MS are important upgrades to moderate the impact of the Russian crisis in 2014 scenarios. This is evident for the 30-day scenario and also for the 90-day case.

It can be noted that in the 30-day and 90-day Russian gas disruptions the average unserved amount of gas is slightly higher in 2014 for some countries, such as Italy, Estonia or Sweden. This is related to the change in the firm capacity at interconnection points declared in 2014 [30] (see also Figure 6) and the new bi-directional capacity implemented between MS. The solidarity approach established by the model in order to distribute the spare gas of a country is influenced by the change in the interconnection capacities and therefore the sharing out of the spare gas experienced different strategies than in 2009. This effect can be appreciated, for example, in Italy in the Russian crisis of 90 days where the average percentage of unserved gas increases from 14.3% in 2009 to 16.7% in 2014 but nevertheless, countries highly interconnected to Italy, such as Slovenia or Austria, decrease the unserved gas. Another similar example can be seen in Sweden. Swedish unserved gas increases in 2014 since Denmark shares – in the simulations - spare gas primarily with Germany thanks to a higher interconnection capacity among both countries.

In general terms, when analysing the effect of a major gas disruption at European level, it can be seen that in the case of the Ukrainian crisis the average unserved gas observed for the scenario of 30 days duration is 1,2% in 2009 and 0,5% in 2014. The average unserved gas observed for the scenario of 30 days duration is 5,7% in 2009 and a reduction to 2,0% in 2014. The 30-day Russian crisis leads to an average 3,6% of unserved gas in 2009 and 2,2% in 2014. The same event happening during 90 days yields to a 9,9% and 6,6% average unserved gas in 2009 and 2014 respectively.

Overall it can be stated that the incorporation of new infrastructure to the European gas grid, including the availability of reverse flow, has provided more flexibility to better support shortages of supply from Eastern Europe pipeline routes.

Table 8. Percentage of failure, average first day of failure and average percentage of unserved gas obtained per country when simulating 30 days of gas disruption from Ukraine in 2009 and 2014.

UKRAINIAN CRISIS
Duration of the crisis: 30 days.
Number of Monte Carlo simulations: 300

COUNTRIES	2009 Percentage of Failure (%)	2009 First Day of Failure	2009 Average Unserved Gas (%)	2014 Percentage of Failure (%)	2014 First Day of Failure	2014 Average Unserved Gas (%)
Austria	0		0	0		0
Belgium	0		0	0		0
Bulgaria	100	1	81,3	100	1	71,6
Czech Republic	0		0	0		0
Denmark	0		0	0		0
Estonia	0		0	0		0
Finland	0		0	0		0
France	0		0	0		0
Germany	0		0	0		0
Greece	100	1	13,0	100	1	6,3
Hungary	100	1	6,5	0		0
Ireland	0		0	0		0
Italy	0		0	8	29	<0,1
Latvia	0		0	0		0
Lithuania	0		0	0		0
Luxemburg	0		0	0		0
Netherlands	0		0	0		0
Poland	0		0	0		0
Portugal	0		0	0		0
Romania	0		0	0		0
Slovakia	0		0	0		0
Slovenia	100	3	10,2	44	16	0,5
Spain	0		0	0		0
Sweden	0		0	93	8	2,4
Switzerland	0		0	0		0
United Kingdom	0		0	0		0
Bosnia	100	1	100	73	13	3,1
Serbia	100	1	92,3	21	28	0,1
Croatia	0		0	0		0
Former Yugoslav Republic of Macedonia	100	1	100	100	1	100

TABLE 9. Percentage of failure, average first day of failure and average percentage of unserved gas obtained per country when simulating 90 days of gas disruption from Ukraine in 2009 and 2014.

UKRAINIAN CRISIS
Duration of the crisis: 90 days.
Number of Monte Carlo simulations: 300

	2009			2014		
COUNTRIES	Percentage of Failure (%)	First Day of Failure	Average Unserved Gas (%)	Percentage of Failure (%)	First Day of Failure	Average Unserved Gas (%)
Austria	100	70	3,4	0		0
Belgium	0		0	0		0
Bulgaria	100	1	82,9	100	1	73,0
Czech Republic	100	69	17,5	3	87	0
Denmark	0		0	0		0
Estonia	0		0	100	79	1,1
Finland	0		0	0		0
France	100	68	8,1	4	85	<0,1
Germany	100	70	3,3	0		0
Greece	100	1	8,6	100	1	1,5
Hungary	100	28	14,2	93	77	0,3
Ireland	0		0	0		0
Italy	100	66	13,4	100	61	9,2
Latvia	0		0	0		0
Lithuania	0		0	100	79	0,3
Luxemburg	100	69	6,0	44	86	0,3
Netherlands	0		0	0		0
Poland	0		0	0		0
Portugal	0		0	0		0
Romania	100	73	0,3	100	67	0,2
Slovakia	100	69	10,0	30	87	0,2
Slovenia	100	3	35,1	100	55	9,5
Spain	0		0	0		0
Sweden	0		0	99	43	1,4
Switzerland	100	70	23,6	1	83	<0,1
United Kingdom	0		0	0		0
Bosnia	100	1	100	100	54	22,9
Serbia	100	1	75,0	100	59	7,3
Croatia	0		0	0		0
Former Yugoslav Republic of Macedonia	100	1	100	100	1	100

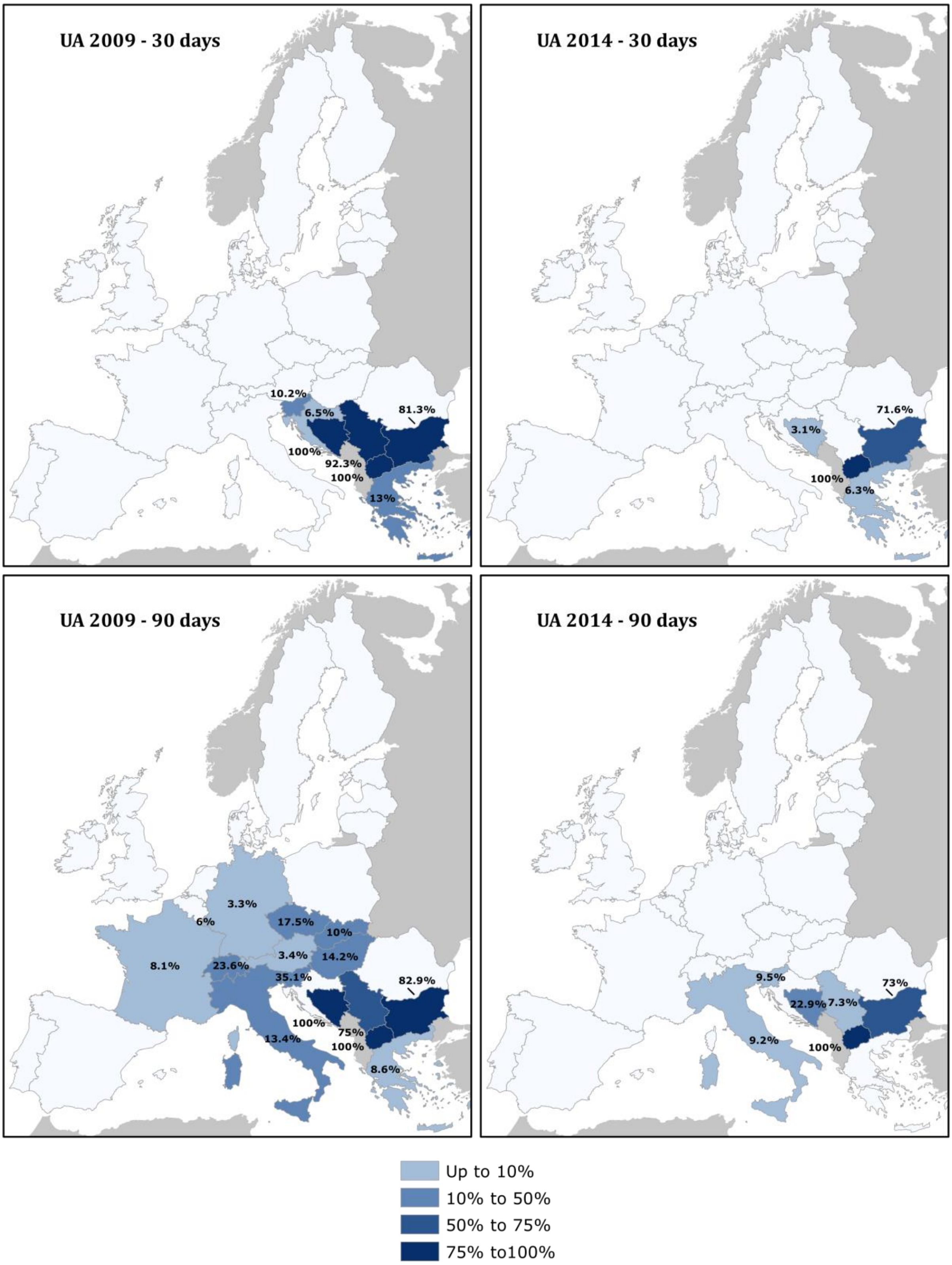

Figure 11. Comparison of the average percentage of unserved gas for the two scenarios of 30 (top) and 90 (bottom) days crisis for a disruption through Ukraine between 2009 (left) and 2014 (right).

Table 10. Percentage of failure, average first day of failure and average percentage of unserved gas obtained per country when simulating 30 days of gas disruption from Russia in 2009 and 2014

RUSSIAN CRISIS
Duration of the crisis: 30 days.
Number of Monte Carlo simulations: 300

COUNTRIES	2009			2014		
	Percentage of Failure (%)	First Day of Failure	Average Unserved Gas (%)	Percentage of Failure (%)	First Day of Failure	Average Unserved Gas (%)
Austria	0		0	0		0
Belgium	0		0	0		0
Bulgaria	100	1	81,3	100	1	71,6
Czech Rep.	0		0	0		0
Denmark	0		0	0		0
Estonia	100	2	9,1	100	2	21,7
Finland	100	1	100	100	1	100
France	0		0	0		0
Germany	0		0	0		0
Greece	100	1	13,0	100	1	6,3
Hungary	100	1	6,2	0		0
Ireland	0		0	0		0
Italy	4	1	<0,1	8	29	0
Latvia	0		0	0		0
Lithuania	100	1	66,1	100	1	63,1
Luxemburg	0		0	0		0
Netherlands	0		0	0		0
Poland	100	1	36,9	100	1	13,0
Portugal	0		0	0		0
Romania	0		0	0		0
Slovakia	0		0	0		0
Slovenia	100	2	11,3	64	14	0,8
Spain	0		0	0		0
Sweden	0		0	100	7	3,1
Switzerland	0		0	0		0
United Kingdom	0		0	0		0
Bosnia	100	1	100	90	11	5,4
Serbia	100	1	92,3	35	28	0,1
Croatia	0		0	0		0
Former Yugoslav Republic of Macedonia	100	1	100	100	1	100

Table 11. Percentage of failure, average first day of failure and average percentage of unserved gas obtained per country when simulating 90 days of gas disruption from Russia in 2009 and 2014

RUSSIAN CRISIS
Duration of the crisis: 90 days.
Number of Monte Carlo simulations: 300

COUNTRIES	2009			2014		
	Percentage of Failure (%)	First Day of Failure	Average Unserved Gas (%)	Percentage of Failure (%)	First Day of Failure	Average Unserved Gas (%)
Austria	100	64	3,9	0		0
Belgium	0		0	0		0
Bulgaria	100	1	82,9	100	1	73,0
Czech Rep.	100	64	21,4	100	68	18,3
Denmark	0		0	0		0
Estonia	100	2	30,9	100	2	37,8
Finland	100	1	100	100	1	100
France	100	66	9,3	100	74	3,8
Germany	100	64	8,7	100	68	1,2
Greece	100	1	8,6	100	1	1,5
Hungary	100	27	14,8	100	68	1,7
Ireland	0		0	0		0
Italy	100	64	14,3	100	57	16,7
Latvia	0		0	0		0
Lithuania	100	1	74,1	100	1	72,4
Luxemburg	100	64	7,7	100	68	8,8
Netherlands	0		0	0		0
Poland	100	1	47,7	100	1	24,7
Portugal	0		0	0		0
Romania	100	73	0,3	100	65	0,5
Slovakia	100	64	12,0	100	69	8,2
Slovenia	100	3	37,9	100	50	19,8
Spain	0		0	0		0
Sweden	0		0	100	21	6,7
Switzerland	100	66	27,4	100	74	18,7
United Kingdom	0		0	0		0
Bosnia	100	1	100	100	52	28,5
Serbia	100	1	75,2	100	56	13,7
Croatia	0		0	0		0
Former Yugoslav Republic of Macedonia	100	1	100	100	1	100

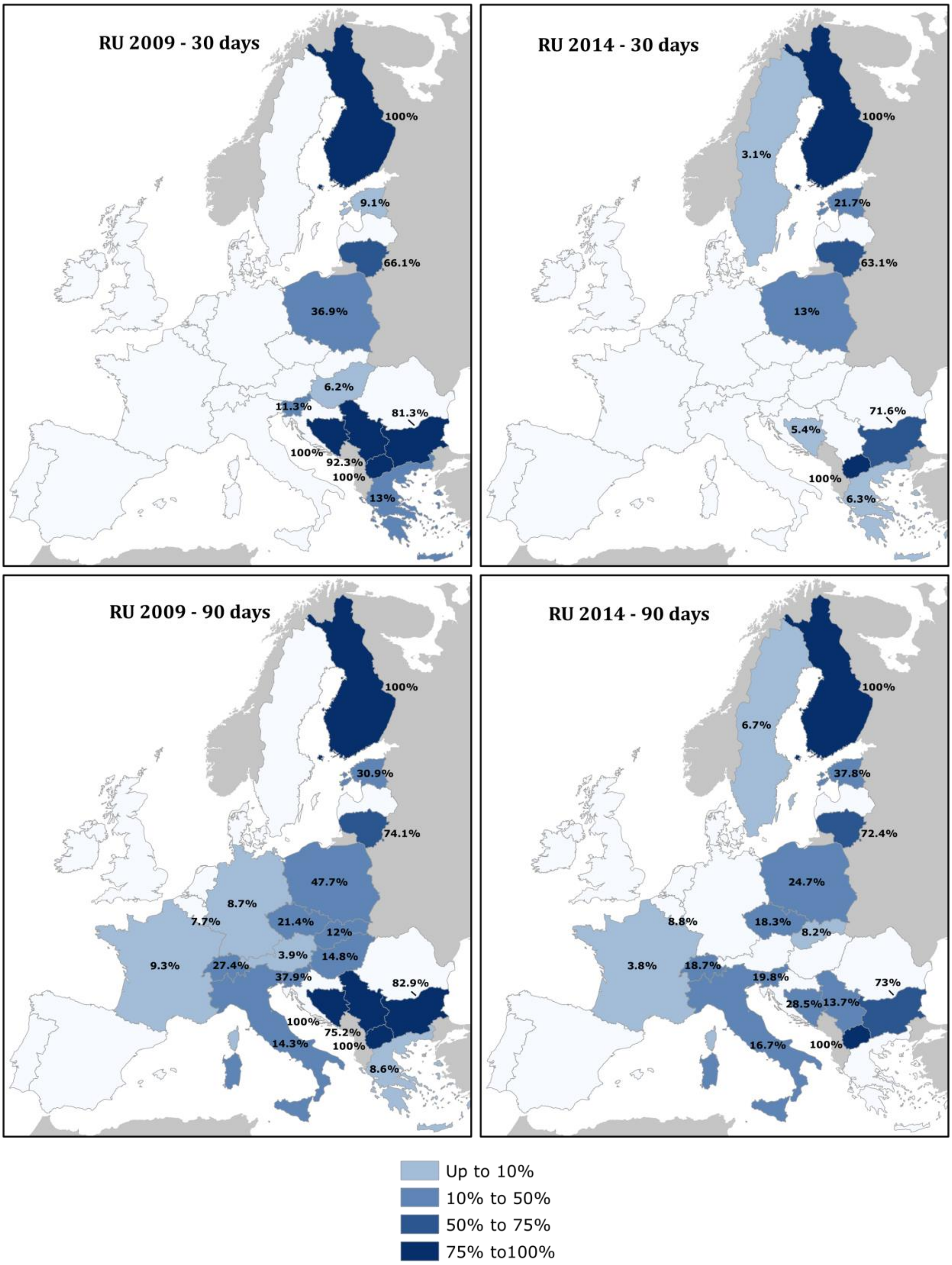

Figure 12. Comparison of average percentage of unserved gas for the two scenarios of 30 (top) and 90 (bottom) days crisis for a total disruption of gas from Russia between 2009 (left) and 2014 (right).

4. CONCLUSIONS

This report provides a first assessment of the effects and magnitude of the improvements – from the infrastructure point of view – implemented between 2009 and 2014 in the European high pressure grid system. The developments achieved in the European natural gas system can be traced back to the adoption by the European Commission of the third package of legislative proposals for electricity and gas markets, to the application of Regulation (EC) 994/2010 on security of supply, to the increased liquidity of the market (though still regionally in many cases) and the flexibility of European TSOs.

Relevant investments promoted by many TSOs and strategically supported by the European Commission as "Projects of Common Interest" (PCI) [33] have created the conditions to boost the technical performance of the European gas grid to start to solve some still open challenges of the on-going transition of the European energy system. In particular, major steps forward have been accomplished in the direction of completing an internal energy market.

Between 2009 and 2014 the EU gas system has experienced the following improvements:

- The EU high pressure grid has grown on average 6% regarding pipeline infrastructure within and between MS. In addition the ability to transport gas has improved by increasing the total installed compressor power.
- The number of EU LNG terminals has increased by four units in the period and the nominal annual aggregated send-out capacity increased by 41% from 134 to 189 Bcm per year. Such changes provide the opportunity for many MS to reduce their dependence from a single supplier. However the EU LNG market has experienced a substantial reduction since 2011 due to, among other factors, the decrease in gas demand.
- The number of UGS facilities and the working storage capacity have increased 11% and 21% respectively, with a total of 143 sites and a capacity of 100 Bcm. In line with the European energy policy, UGS are playing more and more a strategic role in providing reliable sources during crises or exceptional conditions, as it can react quickly to sudden peaks and it can be geographically near to the consumption areas.
- Reverse flow has been substantially implemented within the EU as the number of interconnection points increased from 24% to 40% and the overall capacity at cross-border points has improved as a whole by 10,6% from 2.997 Mcm/d to 3.315 Mcm/d. However some relevant bottlenecks still exist in the EU grid (e.g., the South-East corridor, interconnections between France and Spain or France and Germany and Belgium) and some member States are still poorly or not connected to the main EU system (e.g., the Baltic Region and Finland, Croatia, Bulgaria and Greece).
- The infrastructure standard, introduced by Regulation 994/2010, quantifies the ability of MS, in terms of available infrastructure, to satisfy total gas demand in the event of disruption of the single largest gas infrastructure. The value of the N-1 indicator increased on average 19 percentage points between 2012 and 2014. This is primarily linked to the general improvements in the EU gas infrastructure and reinforced by a reduction of the demand in peak conditions.

The second part of the report focuses on the use of a mass-balance simulation tool – GEMFLOW – to assess the effects of the infrastructural improvements on the overall behaviour of the European natural gas high pressure system under specific crisis scenarios. The simulation tool can quantify in statistical terms probability and impact of failure for each country by considering all the links and interactions of the key components of the EU gas system. In addition GEMFLOW can help to understand where possible cross-border bottlenecks are and where actions could be addressed.

Two scenarios were analysed, the partial cut of supply from Russia through Ukraine and the total cut of gas from Russia during a period of 30 and 90 days. The results show that in all cases the overall amount of unserved gas in 2014 decreased at EU level and, in general, at MS level. This reveals that the incorporation of new infrastructure, including the availability of reverse flow, has provided more flexibility to better support shortages of supply from Eastern Europe pipeline routes. However the impact of the simulated gas crises could still be severe for some European Countries, which are isolated or dependent on a single supply source, such as the case of Bulgaria, Former Yugoslav Republic of Macedonia, Finland or the Baltic Region. For this region and for Poland the situation will improve because of the new felicity and capacity provided by the start of commercial operations of the LNG terminal of Klapédia (Lithuania) in January 2015 and the up-coming new LNG facilities of Świnoujście (Poland) in 2016. On the other hand, the changes in the South-Eastern corridor (i.e., Romania – Bulgaria – Greece) along with the new improvements in Hungary have provided better options for the region to cope with a relevant shortage of supply. Other changes in the EU infrastructure, such as the increased storage capacity in Poland and Germany, and the increment of LNG send-out capacity in France and the Netherlands, are important upgrades to moderate the impact of the Russian crisis in 2014 scenarios.

Further research should be carried out to reach a better understanding of the key components and mechanisms of the European gas system to react to shocks or scenarios of disruption. In this respect the Institute of Energy and Transport of the Joint Research Centre is acting in multiple directions. On one side GEMFLOW is under continue development as to better integrate into the simulation time dependent parameters (like variable supply profiles from interconnections with non EU Countries or consumption profiles for Member States), protected customers and fuel switching effects from the gas-driven electricity facilities. On the other side, the JRC is completing the EUGas project. The "European Gas assessment" tool (EUGas) [34] is a full hydraulic model of the transmission and transit grids of the European Union describing the geography, topology and properties of each relevant component of the national systems (i.e., production sites, storage facilities, LNG terminals, compressor stations, cross-border points and consumption off-takes). EUGas allows simulating the physics of natural gas transmission – seeking a steady state solution – and also allows assessing the behaviour of a grid under different consumption states or disruption scenarios. Finally, looking only at the natural gas system gives precious insights, but without a vision of the complex behaviour and interactions among sectors and energy sources, it is hard to understand impacts and trends in the entire energy system. Energy system models like the JRC Energy Trade Model [35, 36] should be used to frame a sectorial analysis and to understand how competition among energy sources could perform.

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ANNEX 1

The websites of TSOs have been checked to assess nature and type of the information concerning capacities and flows provided to the public based on the application of Regulation (EC) No. 715/2009. Capacities and flows data are classified into three categories: "one value" when only an overall figure is provided; "By categories" when users or flow categories are available or "By off-take point" when data are published by major exit point. Data are further categorised based on the type of the flow/capacity (i.e., consumption, production, storage, LNG, import/export through cross-border points or linepack), unit of measure (i.e., energy or volume units), time granularity (i.e., hourly, daily or monthly figures)

The survey has been carried out from January 2015 till March 2015.

		DATA TYPE																			
				CAPACITIES			FLOWS			TYPE						U.M.		TIME			
Member State	**TSO**	No data available	Only total amount	One value	By categories	By off-take point	One value	By categories	By off-take point	Consumption	Production	Cross-border point	Storage Facility	LNG Facility	Linepack	Energy (kWh)	Volume (m^3)**	monthly	daily	hourly	**WWW link**
Austria	GAS CONNECT – BOG m.b.H.				y							y	y	n		y	y			y	https://mgm.gasconnect.at/gca_mgm/mgm/data.do
	TAG				Y			y		y		y		n		y	y		y		http://www.taggmbh.at/allsite_prod1/ContentView/3/FrontEnd?pageId=20136
Belgium	FULXYS				y			y		y	n	y	y	y		y	y		y	y	https://gasdata.fluxys.com/?sc_lang=en
Bulgaria	Bulgartransgaz					y		y		y		y	y	n			y		y		http://www.bulgartransgaz.bg/en/pages/kapacitet1-98.html
Czech Rep.	NET4GAS					y			y	y		y	y	n	y	y	y		y		http://extranet.net4gas.cz/gas_flow.aspx
Croatia	Plinacro	y									n			n							http://www.plinacro.hr
Denmark	Energinet.dk						y			y				n		y				y	https://www.energinet.dk/EN/GAS/Gasdata-og-kvalitet/Sider/Gas-leveret-i-Danmark.aspx
Estonia	EG Võrguteenus								y		n	y	n	n			y		y		http://www.egvorguteenus.ee/en/public-information/gas-supply/
Finland (*)	Gasum	y							y		y	y	n	n			y			y	http://www.gasum.com/transmission-portal/Finlands-gas-network/
France	GRTgaz				y			y		y		y	y	y	y	y	y	y	y		http://www.smart.grtgaz.com/en
	TIGF				y			y	y			y	y	y	y	y	y		y		http://tetra.tigf.fr/SBT/public/PointsCommerciaux.do?action=liste
Germany	OPEN GRID EUROPE				y			y		y	y	y	y	n		y	y		y		https://www.open-grid-europe.com/cps/rde/xchg/open-grid-europe-internet/hs.xsl/2100.htm
	ONTRAS				y			y		y	y	y	y	n		y			y		https://www.ontras.com/cms/transparenz/transparenz-tool/?L=2
	GASCADE							y				y	y	n		y			y		https://gascade.biz/ivo/
	GASUNIE Deutschland				y			y			y	y	y	n		y	y		y	y	http://transparenz.gasunie.de/mts.web/netzkarte/Index?lang=en&inst=gud
	GRTgaz Deutschland			y			y					y	y	n		y			y	y	http://www.grtgaz-deutschland.de/en/networkaccess/networkdata
	Bayernets					y			y	y		y	y	n		y			y		http://www.bayernets.de/start_en.aspx
Greece	DEFSA								y	y	n	y	n	y		y	y		y	y	http://www.desfa.gr/default.asp?pid=223&la=2
Hungary	FGSZ					y			y	y	y	y	y	n	y	y	y		y		http://tsodata.fgsz.hu/en/pub_data
Ireland	Gaslink					y			y			y	y	n		y			y		http://web1.bgegtms.ie/
Italy	Snamretegas				y			y		y	y	y	y	y		y	y		y	y	http://www.snamretegas.it/it/servizi/Quantita_gas_trasportato/1_Dati_di_oggi/
Latvia	Dabsgaze	y									n			n							http://www.lg.lv/

		DATA TYPE																			
				CAPACITIES			FLOWS			TYPE						U.M.		TIME			
Member State	**TSO**	No data available	Only total amount	One value	By categories	By off-take point	One value	By categories	By off-take point	Consumption	Production	Cross-border point	Storage Facility	LNG Facility	Linepack	Energy (kWh)	Volume (m^3)**	monthly	daily	hourly	**WWW link**
Lithuania	Amber Grid					**y**			**y**		**n**	**y**	**n**	**y**			**y**		**y**		http://www.ambergrid.lt/en/capacity
Luxemburg	Creos	**y**									**n**		**n**	**n**							http://www.creos-net.lu/
the Netherlands	GASUNIE				**y**			**y**		**y**	**y**	**y**	**y**	**y**		**y**	**y**		**y**		http://www.gasunietransportservices.nl/en/transportinformation/dataport
Poland	Gaz System					**y**			**y**	**y**	**y**	**y**	**y**	**n**		**y**	**y**		**y**		http://en.gaz-system.pl/strefa-klienta/krajowy-system-przesylowy/zdolnosc-przesylowa/
Portugal	REN – Gasodutos		**y**					**y**			**n**		**y**	**y**		**y**			**y**		https://www.ign.ren.pt/web/guest/existencias
Romania	Transgaz					**y**			**y**	**y**	**y**	**y**	**y**	**n**		**y**	**y**		**y**		http://www.transgaz.ro/en/informa%C8%9Bii-clien%C8%9Bi/operational-data
Slovakia	EUStream					**y**			**y**	**y**		**y**		**n**		**y**	**y**		**y**		https://tis.eustream.sk/TIS/#/?nav=rd.flw
Slovenia	Plinovodi				**y**	**y**		**y**	**y**	**y**	**n**	**y**	**n**	**n**		**y**	**y**		**y**		http://www.plinovodi.si/en/for-users/network-information
Spain	Enagas				**y**			**y**		**y**		**y**	**y**	**y**	**y**	**y**	**y**		**y**	**y**	http://www.enagas.es/enagas/en/Gestion_Tecnica_Sistema/DemandaGas/Demanda_Tiempo_Real
Sweden	SwedeGas					**y**			**y**	**y**	**n**	**y**	**y**	**y**		**y**			**y**		http://www.swedegas.se/vara_tjanster/gasinformation/statistik/
United Kingdom	National Grid				**y**	**y**		**y**	**y**	**y**		**y**	**y**	**y**	**y**	**y**	**y**		**y**	**y**	http://www2.nationalgrid.com/uk/industry-information/gas-transmission-operational-data/

* Data are not available due to the renewal of network´s control system (30/03/2015).

** For some web-sites it was unclear if volumes were expressed using normal or standard conditions.

ANNEX 2

The diagram presented in Figure 6 was obtained by aggregating the data published in "The European Natural Gas Network 2014 – Capacities at cross-border points on the primary market" (version June 2014[14]) by ENTSOG and in "The European Natural Gas Network 2009 – Capacities at cross-border points on the primary market" by Gas Transmission Europe (GTE). In few cases, figures from other versions of the NETSOG maps, notably version "June 2010", were used.

Conversion from GWh/d to mcm/d (i.e., millions of normal cubic meters per day) is carried out assuming a gross-calorific value of 11.18 (kWh/Nm^3 at combustion temperature of 25 °C). No difference between high- or low-calorific content is made.

For interconnection points, numbers in brackets refer to the identification number of the interconnection point used in the ENTSOG 2014 capacities map.

Figures concerning firm capacities at cross-border points were calculated by considering only main interconnections among national high pressure grids. The following interconnections were not considered: Bizzarone (n. 66), Jura (n. 68), Tegelen (n. 70), Haanrade (n. 63), VIP Kiefersfelden-Pfronten (n. 69), Iasi – Ungheni (operational during 2014 but not reported by ENTSOG).

Underground gas storages were not considered as contributing capacity to interconnection points. The values reported in the ENTSOG map for 2014 for Dolni Bojanovice / Brocké (n. 59), Láb (SK) / Láb IV (n. 60), Haiming 2 7F / Haiming 2-7F (OGE) (n. 61) and Haidach (AT) / Haidach USP (DE) (n. 62) were not used.

Though reported in the ENTSOG map, the interconnection of Ruse – Giurgiu (n. 64) was excluded as not operational in 2014.

The capacity for 2009 of the interconnection point at Vlieghuis (n. 14) was estimated using the value published in the ENTSOG map for 2011.

The interconnection at Hermanowice (n. 65) has been considered as a brand new point.

The reverse flow to Ukraine from Hungary has been considered as belonging to one single aggregated point Beregdaróc – Beregovo (n. 219). The reverse flow has been estimated using the firm interruptible capacity at Beragdaróc in March 2014.

Because GTE map for 2009 reports an aggregated figures for the exit Emden (i.e., EPT1 n. 202 and NPT n. 203), such values has been split using the ratio for Gasunie DTS and Gasunie TS from the ENTSOG map for 2011.

The interconnection Estonia – Russia at Narva (n. 225) has been fixed to its maximum theoretical capacity for the year 2009. The interconnection Latvia – Russia at Korneti (n. 212) has been fixed for 2009 to the same value used for 2014 for the export to Russia.

The reverse flow in Gorizia – Šempeter (n. 29) or in Negru Voda I (n. 53) have not been considered as the first was activated at the end of 2014, and the second was only technically available on the Bulgarian side at the end of 2014.

The interconnection between Slovakia and Hungary at Balassagyarmat – Veľké Zlievce (constructed with a bidirectional design) was not operational in 2014 and it was not accounted for.

The interconnection between Slovakia and Ukraine at Budince started operations in October 2014. The export to Ukraine was estimated in 17,6 Mcm/d based on the values of firm capacity published by the TSO from October to December 2014.

All improvements in the Netherlands to the high pressure grid did not turn out in an increase of firm capacity – mainly – with Germany.

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[14] Available at http://www.entsog.eu/maps/transmission-capacity-map

ANNEX 3

The following tables provide the reference data used to create the feature data set used to model each national gas system for each scenario.

The variable PROD, LNG and STO are set to zero in order to start all simulation with the same condition and to help the comparison of results by focusing the analysis on maximum technical capacities.

It should be noted that the new LNG terminal of Klapédia (Lithuania) has not been taken into account in the simulations because it started commercial operations in January 2015.

Data for the 30 days crisis for 2009

COUNTRY	Cons	Min. Cons	PROD	Max. PROD	LNG	Max. LNG	STO	Max. STO	STO Inventory	STO Max. Inventory
Austria	40.3	40.3	0	4.3	0	0.0	0	48.9	2961.0	4230.0
Belgium	71.1	71.1	0	0.0	0	28.6	0	22.8	478.8	684.0
Bulgaria	14.2	14.2	0	0.2	0	0.0	0	3.3	245.0	350.0
Czech Rep.	45.5	45.5	0	0.4	0	0.0	0	50.7	2153.9	3077.0
Denmark	21.8	21.8	0	23.2	0	0.0	0	15.7	700.7	1001.0
Estonia	3.6	3.6	0	0.0	0	0.0	0	0.0	0.0	0.0
Finland	18.8	18.8	0	0.0	0	0.0	0	0.0	0.0	0.0
France	232.7	232.7	0	2.5	0	46.2	0	328.5	8578.5	12255.0
Germany	438.3	438.3	0	42.2	0	0.0	0	507.5	14562.8	20804.0
Greece	11.8	11.8	0	0.0	0	8.7	0	0.0	0.0	0.0
Hungary	59.4	59.4	0	7.2	0	0.0	0	51.0	2604.0	3720.0
Ireland	18.3	18.3	0	2.4	0	0.0	0	2.6	161.0	230.0
Italy	348.0	348.0	0	21.5	0	7.4	0	253.0	10034.5	14335.0
Latvia	8.9	8.9	0	0.0	0	0.0	0	24.0	1624.0	2320.0
Lithuania	14.6	14.6	0	0.0	0	0.0	0	0.0	0.0	0.0
Luxemburg	5.1	5.1	0	0.0	0	0.0	0	0.0	0.0	0.0
Netherlands	236.4	236.4	0	265.2	0	0.0	0	177.2	3554.6	5078.0
Poland	71.1	71.1	0	13.2	0	0.0	0	33.8	1102.5	1575.0
Portugal	12.3	12.3	0	0.0	0	15.1	0	7.0	105.0	150.0
Romania	48.7	48.7	0	23.6	0	0.0	0	25.1	1885.8	2694.0
Slovakia	34.3	34.3	0	0.5	0	0.0	0	34.4	1925.0	2750.0
Slovenia	3.6	3.6	0	0.0	0	0.0	0	0.0	0.0	0.0
Spain	109.0	109.0	0	0.6	0	111.1	0	14.8	1942.5	2775.0
Sweden	7.0	7.0	0	0.0	0	0.0	0	1.0	6.0	8.5
Switzerland	17.5	17.5	0	0.0	0	0.0	0	0.0	0.0	0.0
United Kingdom	403.5	403.5	0	203.2	0	81.7	0	77.6	2835.7	4051.0
Bosnia	1.5	1.5	0	0.0	0	0.0	0	0.0	0.0	0.0
Serbia	10.0	10.0	0	0.5	0	0.0	0	0.0	0.0	0.0
Croatia	9.5	9.5	0	5.4	0	0.0	0	5.8	387.1	553.0
FYROM	0.6	0.6	0	0.0	0	0.0	0	0.0	0.0	0.0

Data for the 30 days crisis for 2014

COUNTRY	Cons	Min. Cons	PROD	Max. PROD	LNG	Max. LNG	STO	Max. STO	STO Inventory	STO Max. Inventory
Austria	40.3	40.3	0	3.6	0	0.0	0	94.4	5716.2	8166.0
Belgium	71.1	71.1	0	0.0	0	28.6	0	15.0	490.0	700.0
Bulgaria	14.2	14.2	0	0.7	0	0.0	0	4.2	385.0	550.0
Czech Rep.	45.5	45.5	0	0.5	0	0.0	0	57.4	2447.9	3497.0
Denmark	21.8	21.8	0	18.2	0	0.0	0	16.2	698.6	998.0
Estonia	3.6	3.6	0	0.0	0	0.0	0	0.0	0.0	0.0
Finland	18.8	18.8	0	0.0	0	0.0	0	0.0	0.0	0.0
France	232.7	232.7	0	1.5	0	65.7	0	347.0	9075.5	12965.0
Germany	438.3	438.3	0	31.0	0	0.0	0	643.2	16696.4	23852.0
Greece	11.8	11.8	0	0.0	0	8.7	0	0.0	0.0	0.0
Hungary	59.4	59.4	0	5.1	0	0.0	0	80.1	4431.0	6330.0
Ireland	18.3	18.3	0	1.9	0	0.0	0	2.6	161.0	230.0
Italy	348.0	348.0	0	16.4	0	35.6	0	290.5	11630.5	16615.0
Latvia	8.9	8.9	0	0.0	0	0.0	0	24.0	1624.0	2320.0
Lithuania	14.6	14.6	0	0.0	0	0.0	0	0.0	0.0	0.0
Luxemburg	5.1	5.1	0	0.0	0	0.0	0	0.0	0.0	0.0
Netherlands	236.4	236.4	0	280.3	0	27.7	0	220.4	3764.6	5378.0
Poland	71.1	71.1	0	12.9	0	0.0	0	43.5	1766.8	2524.0
Portugal	12.3	12.3	0	0.0	0	22.7	0	7.1	167.3	239.0
Romania	48.7	48.7	0	22.9	0	0.0	0	24.3	2170.0	3100.0
Slovakia	34.3	34.3	0	0.2	0	0.0	0	45.1	2194.5	3135.0
Slovenia	3.6	3.6	0	0.0	0	0.0	0	0.0	0.0	0.0
Spain	109.0	109.0	0	0.1	0	115.3	0	31.5	2872.1	4103.0
Sweden	7.0	7.0	0	0.0	0	0.0	0	1.0	6.0	8.5
Switzerland	17.5	17.5	0	0.0	0	0.0	0	0.0	0.0	0.0
United Kingdom	403.5	403.5	0	124.7	0	116.0	0	108.2	3389.4	4842.0
Bosnia	1.5	1.5	0	0.0	0	0.0	0	0.0	0.0	0.0
Serbia	10.0	10.0	0	1.0	0	0.0	0	5.0	315.0	450.0
Croatia	9.5	9.5	0	5.2	0	0.0	0	5.8	387.1	553.0
FYROM	0.6	0.6	0	0.0	0	0.0	0	0.0	0.0	0.0

Data for the 90 days crisis for 2009

COUNTRY	Cons	Min. Cons	PROD	Max. PROD	LNG	Max. LNG	STO	Max. STO	STO Inventory	STO Max. Inventory
Austria	35.7	35.7	0	6.1	0	0.0	0	48.9	2961.0	4230.0
Belgium	65.5	65.5	0	0.0	0	28.6	0	12.0	478.8	684.0
Bulgaria	14.2	14.2	0	0.3	0	0.0	0	3.3	245.0	350.0
Czech Rep.	39.8	39.8	0	0.6	0	0.0	0	50.7	2153.9	3077.0
Denmark	20.2	20.2	0	33.2	0	0.0	0	15.7	700.7	1001.0
Estonia	3.6	3.6	0	0.0	0	0.0	0	0.0	0.0	0.0
Finland	17.5	13.9	0	0.0	0	0.0	0	0.0	0.0	0.0
France	211.3	211.3	0	3.6	0	46.2	0	328.5	8578.5	12255.0
Germany	393.3	393.3	0	60.4	0	0.0	0	509.9	14562.8	20804.0
Greece	11.2	11.2	0	0.1	0	8.7	0	0.0	0.0	0.0
Hungary	52.3	52.3	0	10.3	0	0.0	0	51.0	2604.0	3720.0
Ireland	17.8	17.8	0	3.5	0	0.0	0	2.5	152.6	218.0
Italy	320.7	320.7	0	30.7	0	25.9	0	253.0	10034.5	14335.0
Latvia	8.9	8.9	0	0.0	0	0.0	0	24.0	1624.0	2320.0
Lithuania	14.6	14.6	0	0.0	0	0.0	0	0.0	0.0	0.0
Luxemburg	4.8	4.8	0	0.0	0	0.0	0	0.0	0.0	0.0
Netherlands	193.2	193.2	0	378.9	0	0.0	0	146.0	3500.0	5000.0
Poland	63.6	63.6	0	18.8	0	0.0	0	33.8	1102.5	1575.0
Portugal	11.9	11.9	0	0.0	0	15.1	0	7.0	105.0	150.0
Romania	48.7	48.7	0	33.7	0	0.0	0	25.1	1885.8	2694.0
Slovakia	29.2	29.2	0	0.7	0	0.0	0	34.4	1925.0	2750.0
Slovenia	3.6	3.6	0	0.0	0	0.0	0	0.0	0.0	0.0
Spain	104.9	104.9	0	0.8	0	111.1	0	14.8	1942.5	2775.0
Sweden	6.4	6.4	0	0.0	0	0.0	0	0.6	6.0	8.5
Switzerland	15.5	15.5	0	0.0	0	0.0	0	0.0	0.0	0.0
United Kingdom	373.8	373.8	0	290.4	0	99.3	0	77.6	2835.7	4051.0
Bosnia	1.5	1.5	0	0.0	0	0.0	0	0.0	0.0	0.0
Serbia	10.0	10.0	0	0.8	0	0.0	0	0.0	0.0	0.0
Croatia	9.5	9.5	0	7.8	0	0.0	0	5.8	387.1	553.0
FYROM	0.6	0.6	0	0.0	0	0.0	0	0.0	0.0	0.0

Data for the 90 days crisis for 2014

COUNTRY	Cons	Min. Cons	PROD	Max. PROD	LNG	Max. LNG	STO	Max. STO	STO Inventory	STO Max. Inventory
Austria	35.7	35.7	0	5.1	0	0.0	0	94.4	5716.2	8166.0
Belgium	65.5	65.5	0	0.0	0	28.6	0	15.0	490.0	700.0
Bulgaria	14.2	14.2	0	1.0	0	0.0	0	4.2	385.0	550.0
Czech Rep.	39.8	39.8	0	0.7	0	0.0	0	57.4	2447.9	3497.0
Denmark	20.2	20.2	0	26.0	0	0.0	0	16.2	698.6	998.0
Estonia	3.6	3.6	0	0.0	0	0.0	0	0.0	0.0	0.0
Finland	17.5	17.5	0	0.0	0	0.0	0	0.0	0.0	0.0
France	211.3	211.3	0	2.1	0	65.7	0	347.0	9075.5	12965.0
Germany	393.3	393.3	0	44.4	0	0.0	0	643.2	16696.4	23852.0
Greece	11.2	11.2	0	0.0	0	8.7	0	0.0	0.0	0.0
Hungary	52.3	52.3	0	7.2	0	0.0	0	80.1	4431.0	6330.0
Ireland	17.8	17.8	0	2.7	0	0.0	0	2.6	161.0	230.0
Italy	320.7	320.7	0	23.5	0	35.6	0	290.5	11630.5	16615.0
Latvia	8.9	8.9	0	0.0	0	0.0	0	24.0	1624.0	2320.0
Lithuania	14.6	14.6	0	0.0	0	0.0	0	0.0	0.0	0.0
Luxemburg	4.8	4.8	0	0.0	0	0.0	0	0.0	0.0	0.0
Netherlands	193.2	193.2	0	400.4	0	27.7	0	220.4	3764.6	5378.0
Poland	63.6	63.6	0	18.5	0	0.0	0	43.5	1766.8	2524.0
Portugal	11.9	11.9	0	0.0	0	22.7	0	7.1	167.3	239.0
Romania	48.7	48.7	0	32.8	0	0.0	0	24.3	2170.0	3100.0
Slovakia	29.2	29.2	0	0.3	0	0.0	0	45.1	2194.5	3135.0
Slovenia	3.6	3.6	0	0.0	0	0.0	0	0.0	0.0	0.0
Spain	104.9	104.9	0	0.2	0	115.3	0	31.5	2872.1	4103.0
Sweden	6.4	6.4	0	0.0	0	0.0	0	1.0	6.0	8.5
Switzerland	15.5	15.5	0	0.0	0	0.0	0	0.0	0.0	0.0
United Kingdom	373.8	373.8	0	178.1	0	116.0	0	108.2	3389.4	4842.0
Bosnia	1.5	1.5	0	0.0	0	0.0	0	0.0	0.0	0.0
Serbia	10.0	10.0	0	1.4	0	0.0	0	5.0	315.0	450.0
Croatia	9.5	9.5	0	7.4	0	0.0	0	5.8	387.1	553.0
FYROM	0.6	0.6	0	0.0	0	0.0	0	0.0	0.0	0.0

LIST OF ABBREVIATIONS AND DEFINITIONS

ACER	Agency for the Cooperation of Energy Regulators
Bcm	billion cubic meter (i.e., 10^9 m^3)
EC	European Commission
ENTSOG	European Network of Transmission System Operators for Gas
EU	European Union
EUGas	European Gas Assessment tool
GLE	Gas LNG Europe
GSE	Gas Storage Europe
GTE	Gas Transmission Europe
IEA	International Energy Agency
JRC	Joint Research Centre
LNG	Liquefied Natural Gas facility
Mcm	million cubic meter (i.e., 10^6 m^3)
Mcm/d	million cubic meter per day
MS	Member State
PCI	Projects of Common Interest
TSO	Transmission System Operator
UGS	Underground Gas Storage facility

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JRC Mission

As the Commission's in-house science service, the Joint Research Centre's mission is to provide EU policies with independent, evidence-based scientific and technical support throughout the whole policy cycle.

Working in close cooperation with policy Directorates-General, the JRC addresses key societal challenges while stimulating innovation through developing new methods, tools and standards, and sharing its know-how with the Member States, the scientific community and international partners.

Serving society
Stimulating innovation
Supporting legislation

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