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Natural Gas in Europe

The Potential Impact of Disruptions to Supply

Gabriel Di Bella, Mark Flanagan, Karim Foda, Svitlana Maslova, Alex Pienkowski, Martin Stuermer and Frederik Toscani

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Natural Gas in Europe: The Potential Impact of Disruptions to Supply

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ABSTRACT: This paper analyzes the implications of disruptions in Russian gas for Europe's balances and economic output. Alternative sources could replace up to 70 percent of Russian gas, allowing Europe to avoid shortages during a temporary disruption of around 6 months. However, a longer full shut-off of Russian gas to the whole of Europe would likely interact with infrastructure bottlenecks to produce very high prices and significant shortages in some countries, with parts of Central and Eastern Europe most vulnerable. With natural gas an important input in production, the capacity of the economy would shrink. Our findings suggest that in the short term, the most vulnerable countries in Central and Eastern Europe — Hungary, Slovak Republic and Czechia — face a risk of shortages of as much as 40 percent of gas consumption and of gross domestic product shrinking by up to 6 percent. The effects on Austria, Germany and Italy would also be significant, but would depend on the exact nature of remaining bottlenecks at the time of the shutoff and consequently the ability of the market to adjust. Many other countries are unlikely to face such constraints and the impact on GDP would be moderate—possibly under 1 percent. Immediate policy priorities center on actions to mitigate impacts, including to eliminate constraints to a more integrated gas market via easing infrastructure bottlenecks, to accelerate efforts in defining and agreeing solidarity contributions, and to promote stronger pricing pass through and other measures to generate greater energy savings. National responses and RePowerEU contains many important measures to help address these challenges, but immediate coordinated action is called for, with specific opportunities in each of these areas.

JEL Classification Numbers:	E23, F51, L71, L95, Q02, Q41
Keywords:	Energy supply; natural gas; production output

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WORKING PAPERS

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Contents

Executive Summary

Russia's invasion of Ukraine has placed natural gas supply in Europe at risk. Russia has been Europe's largest supplier of natural gas and distribution networks are geared towards Russian supply. Russian pipeline flows to Europe have been dropping since the second half of 2021 and following recent cuts in deliveries, Russian exports to the EU are now down roughly 60 percent compared to June 2021. As of early July, Russian gas has ceased or been significantly reduced to a growing list of countries, beginning with Poland and now including the Netherlands, Germany, Austria and Italy, among others.

Fully replacing Russian gas imports may prove difficult in the short-term. So far, Europe has been able to offset reductions in Russian deliveries and build up storage to reach average historical levels in June. However, with the recent reductions in deliveries the situation has escalated further. Alternative gas and power sources—including higher non-Russian pipeline gas imports, an increase in LNG imports and fuel energy switching in power generation—could likely replace some two-thirds of Russian gas over the next 12 months. Nevertheless, there is uncertainty about global supply, and countries' and firms' ability to switch between energy sources. Moreover, transmission constraints limit the ability to transport gas from alternative sources across some regional distribution systems and even within some countries, leaving several countries in Central and Eastern Europe, including Germany, and Italy, which are heavily reliant on Russian gas, particularly vulnerable. Demand compression in response to high energy prices will help reduce supply gaps. On aggregate, Europe could avoid shortages if Russian deliveries continue at the current reduced levels or in the event of a temporary but full disruption through the summer. A full and longer disruption through the peak winter season, however, could lead to costly regional shortages, very high prices, and rationing in some countries.

Disruptions in the gas markets are likely to have important impacts on the overall economy. The impact would depend on complex supply-side factors, most prominently on how gas is used in production, how much it can be substituted for by other inputs, how initial impacts in heavily affected sectors cascade through the economy. These supply-side mechanisms would also interact with additional demand side developments (e.g., confidence) and cross-country spillovers. Reflecting this complexity, the recent literature uses a wide range of techniques to assess the impact of a Russian natural gas shut-off. In this paper we look at two approaches designed to capture different disruption contexts: an approximation to a general equilibrium approach—best for situations when prices can adjust the system, which is likely to be the case for countries that are not highly reliant on Russian gas and do not face infrastructure bottlenecks, such as Spain and the UK. And a production-function based approach—which can be useful for countries where technical constraints, notably infrastructure bottlenecks, fragment the gas market. Additional demand side impacts, not fully captured by either model, could exacerbate the output decline.

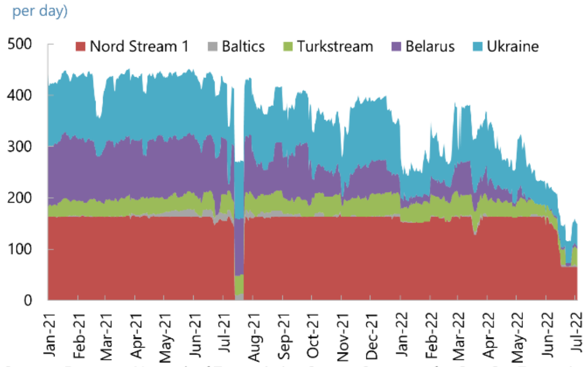
The GDP impact of a full Russian gas shutoff is likely to depend on the extent to which shortages emerge and gas markets fragment. When calculating the GDP impact, we focus on the loss in output over a 12-month period relative to a benchmark case in which total European gas supplies would be at "normal" levels (with 2021 used as a base on which to build the calculation). As such, the estimates in this paper cannot simply be added to recent projections (which may assume partial shut offs). In a full shutoff scenario, severe shortages would likely emerge in some countries in Central and Eastern Europe and these countries could see a strong negative impact on GDP of up to 6 percent. The effect on Austria, Germany and Italy would also be significant, but would depend on the policy response and exact nature of remaining bottlenecks and other frictions at the time of the shutoff and consequently the ability of the market to adjust. In contrast, many countries in the EU are unlikely to face such constraints and the impact on GDP would be moderate. Once Europe can fully overcome adjustment frictions, and demand and supply fully adjust to prices in an integrated market, output effects could be much smaller for the EU as a whole and heterogeneity in the country level impact would also be reduced.

Immediate further action is needed to mitigate these risks. Our analysis suggests that addressing bottlenecks to increase import capacity and transport gas from different sources (e.g., enabling reverse flows from Western to Eastern Europe) would support gas storage accumulation over the summer and reduce the risk of shortfalls in the winter. And securing solidarity across countries would help mitigate the impact of a shut-off in the most vulnerable countries. The EU and national responses have been swift and comprehensive to date, and many countries have also already begun to source alternative energy supplies and to develop contingency plans. Immediate policy priorities center on stronger actions to eliminate infrastructure bottlenecks and other constraints to an integrated gas market, accelerated efforts in defining and agreeing solidarity contributions, and stronger efforts to reduce demand, including by pursuing greater energy efficiency initiatives and allowing pricing mechanisms to work to a fuller extent than has been the case so far.

I. Introduction

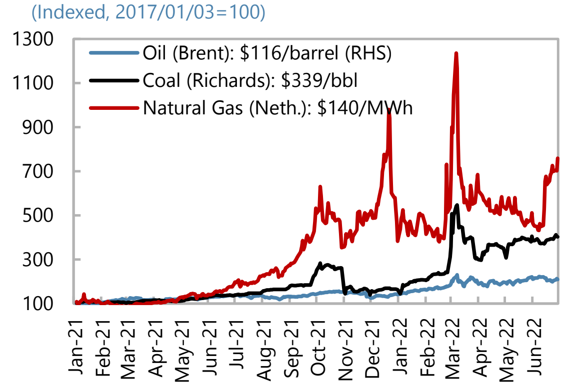
The war in Ukraine has created risks for Europe's energy supply. Russia is Europe's largest supplier of natural gas, oil, and coal, and has become ingrained in distribution networks. Europe decided to stop purchases of Russian coal and oil, and Russian gas pipeline flows to Europe have been falling since the second half of 2021, with total flows in the first six months of 2022 35 percent below the 2021 levels. Following recent cuts in deliveries, mainly through the Nord Stream pipeline, Russian pipeline exports to the EU are now down roughly 60 percent compared to June 2021. Additional risks to supply could come via potential wartime destruction of energy transmission infrastructure, further sanctions on Russian energy exports by European policymakers, or embargoes on exports by Russia. To date, disruptions to gas, oil and coal trade—and concerns over future supply—have led to large spikes in energy prices.

Russian Pipeline Gas Supplies to EU by Route (Million cubic meters per day)



Sources: European Network of Transmission System Operators for Gas; Gas Transmiss
Note: Last data point is 7/3. Recent data are provisional.

Fossil Fuel Prices
(Indexed, 2017/01/03=100)



Source: Bloomberg Financial L.P.

This paper sets aside the precise reason for gas supply disruptions and explores scenarios to illuminate potential impacts on gas supply and GDP. The focus on natural gas market disruptions reflects technical constraints that could prevent a full replacement of supply. In contrast, coal and oil markets are likely better able to adjust to disruptions through trade diversion (with some country exceptions), although diversion could be costly nevertheless. We focus on analyzing the impact of a full interruption of Russian gas supplies to Europe that starts at end-June 2022 and lasts through the 2022–23 winter. The scenario is compared to a counterfactual no shock scenario, with consumption extrapolated from 2021 (but adjusted for current high prices). High and low demand scenarios are also considered. The analysis focuses on the major gas importers in Europe[1].

This paper adds to a growing literature on the economic impact of a disruption to Russian energy supply (Table 6). A key contribution of this paper is to discuss how the European gas market could evolve and fragment under a full gas shut off, and how different economic models can be applied to better capture the resulting context. We flag and analyze uncertainty around estimates both for the potential gas shortages and GDP losses, focusing on the role of adjustment frictions in worsening the GDP outcome. By taking this pan-European view our policy recommendations focus on minimizing collective losses, as well as mitigating the impact at a country level.

The remainder of this paper is organized as follows. Section II provides background on natural gas markets in Europe. Section III considers avenues through which the energy sector might adjust in the event of disruptions. Section IV considers specific disruption scenarios, looking at whether adequate storage is achieved by the beginning of the heating season, how the market might adjust, and whether and where shortages would emerge. Section V looks at the potential impact on output, enumerating channels of impact, surveying approaches to modeling the shock, and putting forward estimates based on two calibrated models. Section VI draws out some key messages and examines policy options to mitigate potential problems.

II. Background

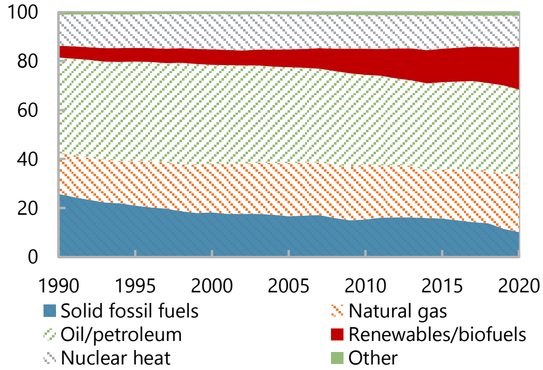
Europe relies mainly on hydrocarbons sources from outside the EU, with heavy reliance on Russia (Figure A1). This dependency varies significantly across different types of energy. For all forms of energy, the share of net imports in gross inland consumption for the EU in 2020 was 57.5 percent. While gas is mostly used for energy generation and for heating, it is also a key input into production processes in some industries (e.g., chemicals). For natural gas, import dependency from outside of the EU was 84 percent in 2020. Russia has been the largest supplier of gas to the EU: in particular, in 2020, more than 40 percent of total imports of natural gas came from Russia. The dependence on Russia for overall energy natural gas varies significantly across countries.

[1] The full sample includes Austria, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Luxembourg, Lithuania, the Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Türkiye, and the United Kingdom.

Figure 1. Sources of Energy in Europe

The importance of gas has increased in the EU…

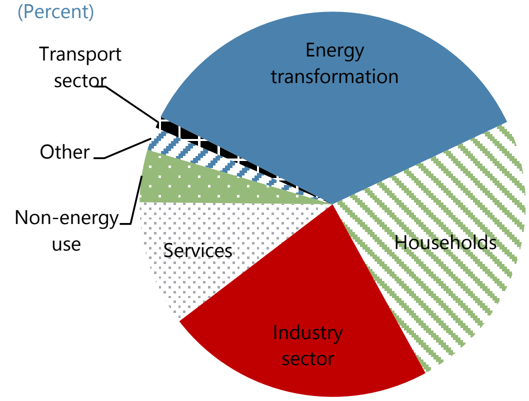
EU: Energy by Source
(Percent of total)



Source: Eurostat.

..where it is mostly used for energy generation

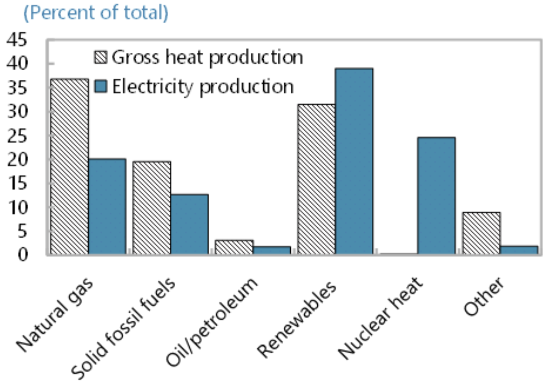
EU: Gross Inland Natural Gas Consumption, 2020
(Percent)



Sources: Eurostat; and IMF staff calculations.

Gas plays a large role in heat and electricity production.

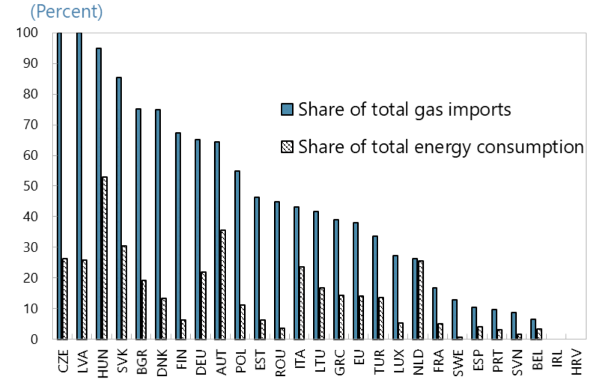
EU: Heat and Electricity Production by Energy Source
(Percent of total)



Sources: Eurostat and IMF staff calculations.

And Russia has been a key supplier

Russian Gas Dependance, 2020
(Percent)



Source: Eurostat, Gazprom and staff calculations.
Note: Some countries may re-export Russian gas, which could affect Russia's share in total imports and energy consumption.

The European natural gas market is not fully integrated:

- Pipeline gas flows arrive to Europe through Russia, Norway, the United Kingdom, Northern Africa, and the Caspian region (see map). Russian pipelines enter Europe through Germany (Nord Stream I), Poland (Yamal), Ukraine and Türkiye. Norwegian gas enters via Germany, the Netherlands, Belgium, the UK, and Denmark upon completion of the Baltic Pipe (to Poland) towards the end of this year.[2] Gas from Northern Africa and Azerbaijan enter through Spain, Italy, Türkiye, and Greece. Türkiye also receives gas from Iran. In total, non-Russian pipelines currently account for 30 percent of total gas import capacity, while Russian pipelines account for 42 percent and LNG import terminals for another 28 percent of import capacity. Pipeline capacity utilization was at 81 percent from Norway and 50-60 percent from other non-Russian

[2] Poland plans to use this pipeline to fully offset its Russian gas imports (10 bcm) starting January 2023.

countries in 2021 (Table 1). Since pipelines typically do not run at 100 percent capacity for the entire year due to maintenance closures, *de-facto* capacity may be less than stated capacity.

- LNG is imported through several LNG import and regasification terminals (see map). LNG import capacity accounts for 28 percent of the total gas import capacity and was utilized to about 39 percent of stated capacity in 2021. However, not all of the stated capacity is usable (due to technical constraints such as seasonal demand draw, maintenance, and system redundancies) and some of the capacity is effectively not connected to central Europe (e.g., LNG import terminals in Spain and Portugal). LNG imports have substantially increased over the last couple of months. In April 2022, 66 percent of declared daily total LNG send-out capacity was used on average in Europe, and 78 percent outside of Spain.

Table 1. EU Gas Import Capacity and, Supply by Source 2021

EU Gas Import Capacity and Supply by Source (bcm), 2021

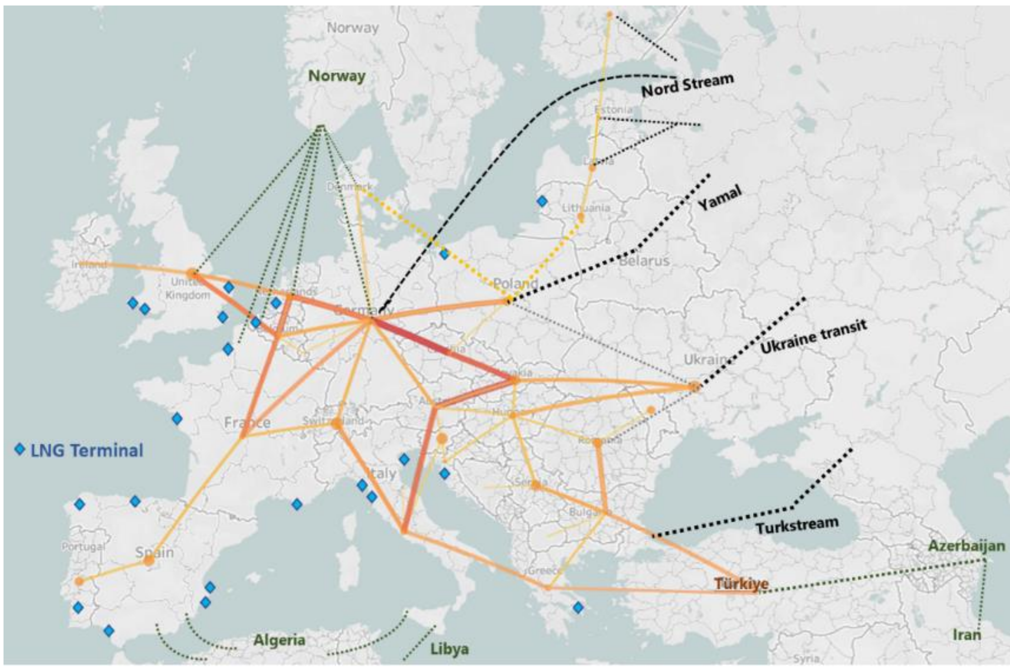
Billion cubic meters	Annual Capacity	2021 Flow	Spare Capacity	Utilization Rate
		Pipeline Flows		
Russia	276	153	123	55%
Norway	109	88	21	81%
North Africa	79	40	38	51%
Azerbaijan	13	8	5	62%
Total pipelines	**477**	**289**	**188**	**61%**
		LNG Import Terminals		
Spain	69	19	50	27%
France	43	18	26	41%
Italy	20	10	10	50%
Belgium	17	4	13	24%
Netherlands	14	8	6	57%
Greece	7	2	5	29%
Portugal	7	6	1	86%
Poland	6	4	2	67%
Lithuania	4	2	2	50%
Croatia (as of Dec. 2021)	3	-	-	-
Total LNG	**187**	**72**	**115**	**39%**
excluding Spain	**117**	**53**	**64**	**45%**
Total	**663**	**361**	**302**	**54%**
Russia	276	153	123	55%
Non-Russia	387	208	179	54%

Source: Bruegel (2022) based on ENTSOG, GIIGNL, GIE, NPD

- Existing infrastructure can accommodate partial interruptions of Russian gas to specific countries. Russian gas deliveries have already been stopped to Poland, Bulgaria, Finland, Denmark, and the Netherlands, and reduced to Germany, Italy, France and others. Poland has been able to replace Russian imports with LNG imports under a new interconnector with Lithuania's Klaipeda LNG terminal and interconnections with other EU countries, notably Germany. Bulgaria has the capacity to increase gas imports from Azerbaijan and LNG imports via Greece and Türkiye. Finland expects a newly leased floating LNG terminal to fully offset Russian imports by end year, Denmark is receiving most of its flows from Germany, and the Netherlands has been able to import from suppliers with continued access to Russian gas.

- However, transmission within Europe is subject to some technical limitations, meaning that larger disruptions could partially fragment the market. Spain, the EU's largest LNG hub with over 35 percent of its import capacity, can only export 10 percent of its import capacity to France. France, in turn, cannot transmit to most neighboring gas systems given bottlenecks in north-south transmission within France, the time needed to reverse flows in pipelines from Germany (gradually up to a year), and regulatory and technical constraints linked to odorization.[3] North-South bottlenecks in both Germany and Italy could not only limit sharing within these countries, but constrain imports into Central and Eastern Europe (in the latter case constraining potential rerouting of Spanish LNG imports through North Africa along existing pipelines). Finally, transmission from Greece and Italy into southeastern Europe is in both cases limited in capacity.

Europe: Cross-Border Transmission Capacities and Import Points

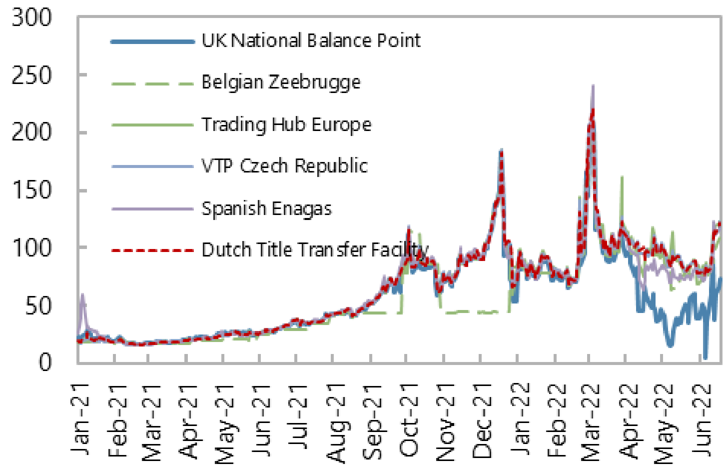


Sources: IMF staff based on ENTSOG (System Development Map, 2021, and Transparency platform)
Notes: Thicker and darker lines represent larger transmission capacities as of December 2021. Direction of flows within EU and individual pipelines not shown. Dotted lines represent import pipelines into Europe. Dashed yellow lines represent pipelines expected to come online in the next twelve months.

- With Russian flows already down by around 35 percent year-to-date relative to last year, infrastructure bottlenecks are in fact starting to bite. Capacity to get natural gas into Europe from the UK and pipelines through Belgium is at 100 percent of capacity and European wholesale prices have started to diverge over the past months (as of June 20, the Dutch TTF price is trading €48/MWh above UK prices).[4]

[3] French gas contains additives, principally chemicals, to give gas an odor to help people identify leaks. These are not added to German gas as they are incompatible with certain industrial processes.
[4] The Dutch Title Transfer Facility (TTF) is the key European benchmark prices.

European Wholesale Natural Gas Prices by Hub
(EUR/MWh)

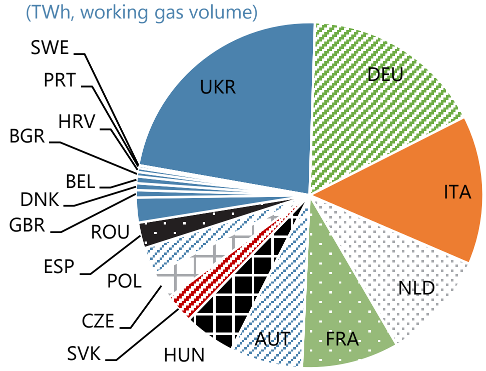


Source: Bloomberg Finance L.P.

Natural gas storage can in principle help smooth natural gas market disruptions and seasonal fluctuations in demand, but inventory levels vary considerably:

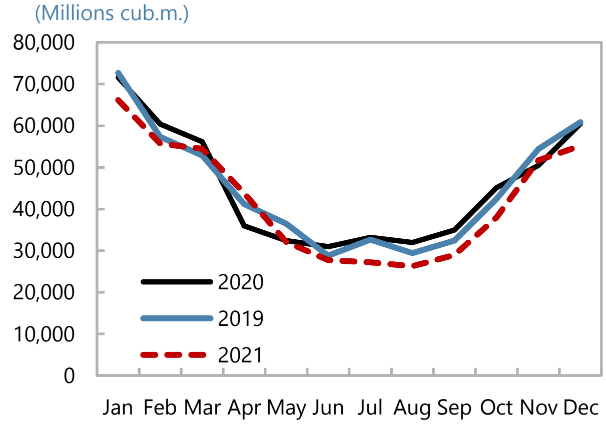
- Storage capacity is significant, but unevenly distributed. Outside of Russia and Belarus, Ukraine and Germany have the largest gas storage capacity, summing to about 40 percent of total European capacity. Some countries store gas for others, and this could become inaccessible in disruption scenarios. Gazprom also owns major storage facilities in Germany and Austria, accounting for 7 percent of EU storage capacity (and 4 percent of current inventories), and these are assumed to be available in a crisis, as they fall under European legal jurisdiction.[5]

Gas Storage Capacity
(TWh, working gas volume)



Sources: Gas Infrastructure Europe (GIE) AGSI+ Storage Transparency Platform.

Gas Consumption in Europe
(Millions cub.m.)

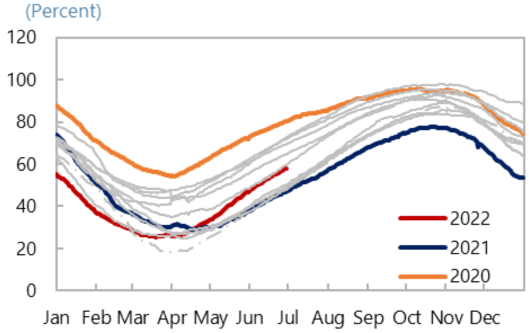


Source: Eurostat.

[5] Gazprom did not fill these facilities before last winter, dragging down the aggregate European average fill levels that were otherwise within historical norms. In April 2022, the German energy regulatory took Gazprom Germania under trusteeship, effectively taking operational control over the company.

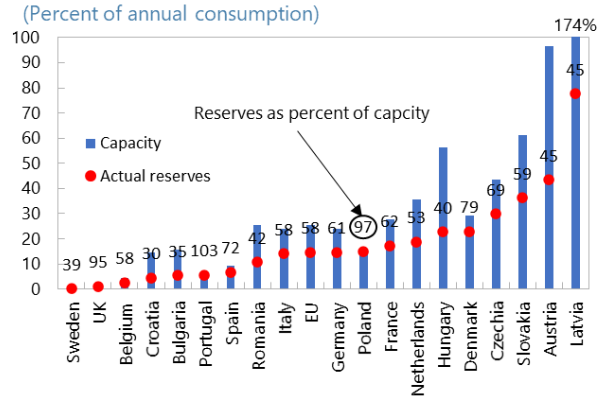
○ Storage in Europe was at historical lows during the Winter of 2022 but accumulation of storage since April has been rapid. As of end-June, gas storage facilities in the EU are at 58 percent of capacity, close to the average level over the past decade. However, the variation across countries and regions is large both in terms of how high storage is as a share of available capacity and how high capacity is as a share of annual consumption. Gas reserves as a share of annual consumption are very low in countries that are well-connected to international LNG markets (i.e., the UK, Belgium, Portugal, and Spain). Those countries that have less scope to access international LNG supply options—including Austria, Hungary, and Slovakia have higher reserve capacity relative to consumption.

Europe: Gas Storage Filling
(Percent)



Sources: Gas Infrastructure Europe (GIE) AGSI+ Storage Transparency Platform..
Note: Thin grey lines denote storage filling in 2011-2019.

Stored Gas Reserves and Capacity, end-June
(Percent of annual consumption)



III. Short-Term Adjustment to a Potential Gas Supply Shock

The market would adjust to gas supply disruptions by accessing new supplies where feasible, using alternative sources of energy, and via demand reductions. In 2021, the EU imported around 155 bcm of gas from Russia, while Türkiye and the UK imported around 16bcm and 3bcm, respectively. Our analysis suggests that, in aggregate, there is scope for Europe to reduce this reliance considerably in 2022, with further gains likely beginning in H1 2023.

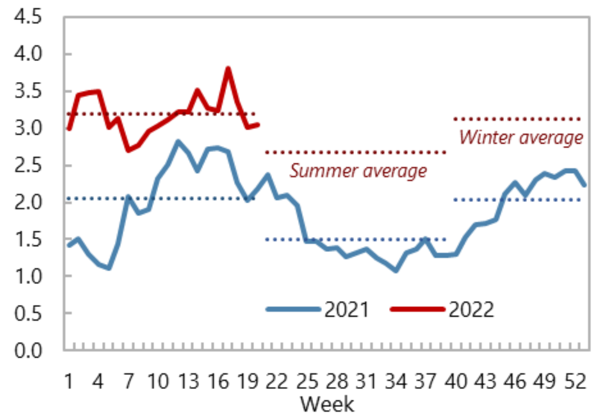
Supply

At the maximum, and assuming gas prices remain at current levels, our estimates suggest that alternative sources of energy could replace around 80 bcm of Russian gas in 2022, (and even more over the next 12 months) largely through higher LNG imports (Table 2):

○ Higher non-Russian pipeline flows could provide some additional gas, perhaps 15 bcm during 2022. While there is substantial excess capacity (Table 1) in non-Russian pipelines, production constraints would limit the magnitude of additional flows from Norway, Africa, and Azerbaijan to about 10 bcm this year (assuming modest increases in production; IEA 2022). The scheduled completion and early operation of The Baltic Pipe linking Norway and Poland in Q4-2022 will bring an additional 10 bcm in 2023.[6]

- Sustained high LNG imports could provide around 55 bcm more in gas in 2022. Higher LNG imports early this year are likely to continue. The seasonally lower demand pull in the summer—which would reduce LNG imports versus recent levels—is likely to be partly offset by mandates to refill storage. A number of factors instill a notable degree of uncertainty around this estimate, including competition from Asia, summer maintenance needs for LNG terminals and vessels as well as the timing of US export capacity expansions. Given the structure of the LNG market, this higher level of LNG imports would likely need LNG prices to remain at or near the high levels of the past months (Box 1). In the coming winter LNG capacity will be expanded slightly, allowing LNG imports to rise further in H1 2023.[7] A recently announced agreement between the EU, Israel and Egypt could modestly increase EU LNG imports this year and next year, with more significant volumes expected thereafter.[8] Expansion in LNG export capacity would require long-term contracts with customers.

EU: Weekly LNG Imports, 2022 actual and projected
(Billion cubic metres)



Source: Bruegel and authors' estimates

Export Capacities of Key LNG Producers

USA	Committed to provide Europe with an additional 15 bcm of LNG this year. Export terminals this year have been operating at 95 percent capacity. In early June, a fire at an export processing terminal in Texas forced a temporary closure. New terminals later this year will increase export capacity by 14-21 percent. Additional engineering measures could increase capacity of existing terminals by 10 percent in the short-term. 1/
Qatar	Qatar has signaled that it can lift its exports to Europe by perhaps 10-15 percent (or 8-12 bcm), but it not reported whether this would be achieved via increased production or by diverting existing non-Europe exports towards Europe.
Australia	Australia's export capacity utilization is high at over 90 percent and is not expected to significantly increase this year.
1/ See EIA, 2022. https://www.eia.gov/naturalgas/U.S.liquefactioncapacity.xlsx for data on US export terminals.	

- Domestic EU production could also increase. For example, the Netherlands could delay the closure of its Groningen gas field, which it has currently ruled out for now (FT, June 20). Fracking in Europe is not considered as a short-term measure due to high investment needs, lengthy project timelines, regulatory barriers, and notable opposition.

[6] Assumed to be already contracted and included in Norway's production.

[7] The German government has leased four floating storage and regasification units that will further expand its import capacity. These are expected to come online in December 2022 (7.5 bcm/year), January 2023 (5 bcm/year), August 2023 (5 bcm/year) and January 2024 (5 bcm/year). Finland and Estonia have jointly leased an LNG floating terminal set to provide 5 bcm per year after end-2022. Greece and Bulgaria jointly expect a new floating LNG import terminal to begin operations in end-2023 with capacity of 5.5 bcm per year.

[8] An agreement was signed on June 15 for the Egypt to liquify and export Israeli gas to the EU, with 2-4 bcm possible in the next year (FT, June 15)

Alternative sources of energy could help further reduce gas import needs (however, constraints to the electricity grid limit full electricity sharing within Europe):

- Nuclear power. Increased nuclear power production could provide the equivalent of 7 bcm of gas in 2022, reflecting a new nuclear plant in Finland that is set to begin operations this June (IEA 2022). The German authorities considered the possibility of prolonging use of nuclear power plants but rejected this in view of perceived technical constraints and political feasibility and thus such actions are not assumed here.[9]
- Renewable energy. The EU's output of power from wind and solar was expected to increase by 15 percent compared to 2021, equivalent to about 17 bcm (IEA, 2022). The IEA argues that a concerted policy effort to install new solar and wind power facilities could replace another 6 bcm of natural gas in 2022, although there are strong indications that manufacturing bottlenecks could prevent this.

Table 2. Russian Gas Replaced Over 12- Months

Billion cubic meters	EC Estimates (2022)	IEA Estimates (2022)	Authors' Estimates (2022)	Authors' Estimates (next 12 months) 1/
Energy Supply	**87.5**	**53**	**80**	**90**
Higher LNG Imports 2/	50	20	55	60
Higher non-Russian pipeline imports 2/	10	10	15	20
Power sector	23.5	19	10	10
More solar rooftops and heat pumps	4	4	na	na
Additional potential from fuel switching (mainly coal)	-	*28*	*12*	*14*
Energy Demand	**14**	**12**	**17**	**17**
Energy efficiency	4	2	na	na
Demand compression 3/	10	10	17	17
Households	*10*	*10*	*4*	*4*
Industry	*na*	*na*	*13*	*13*
Total	101.5	65	97	107
Share of 2021 Russian Imports	**66%**	**42%**	**63%**	**70%**
Share of 2021 Russian Imports *(with fuel switching)*	**-**	**61%**	**71%**	**79%**
Supply replacement ratio	**57%**	**35%**	**52%**	**59%**
Supply replacement ratio *(with fuel switching)*		**53%**	**60%**	**68%**

1/ From H2 2022 through H1 2023. Includes additional LNG, pipeline gas, and increased fuel switching anticipated to occur over winter 2022-2023.
2/ Authors' estimate includes expected flows from Germany's floating LNG terminals and from the Baltic Pipe linking Norway and Poland, announced after EC and IEA proposals were published in March 2022, and expected to become operational in Q4-2022.
3/ Estimates based on demand elasticity calculations for households and industry above.
Note: Supply replacement ratio expressed as a percent of 2021 Russian imports. EC and IEA proposals as of March 2022. Authors' assessment as of June 2022.

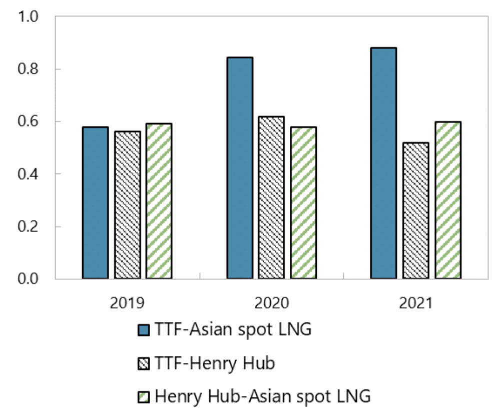
[9] Three plants were shut down in end-2021 and last three plants are expected to be phased out in end-2022, with cumulative capacity of 9.5 GW.

Box 1. Short-Term Contracts in the LNG Market

A tight market and responsive prices are producing rising short-term LNG trade. The share of spot and short-term contracts in total LNG trade increased from 25 percent in 2017 to nearly 40 percent in 2021.[a] This includes both direct short-term contracts between producers and end-consumers as well as short-term trades from buyers (traders or other consumers) who buy LNG from producers under long-term contracts and re-sell at higher prices on spot markets.[b] Short-term contracts drove 67 percent of the increase in LNG trade last year, led by demand from China and Europe and largely met by supply from the US, the largest provider of spot and short-term LNG contracts. Long-term LNG contracts with the US are based on Henry Hub prices, which are several times below European (TTF) and Asian spot prices due to bottlenecks in US export capacity. This provides a benefit to trading houses and other end-consumers from re-routing LNG towards Europe and Asia on spot markets.

Competition may intensify price pressures but could also encourage substitution elsewhere (freeing volumes). China's LNG demand has been rising among end-users and traders, and Japan has experienced heightened supply needs amidst low storage levels. On the other hand, if nuclear power accelerates in both China and Japan in response to high LNG prices, price pressures may potentially ease. Overall, given the competition for LNG, European and Asian spot gas prices are higher and more strongly correlated than European and US Henry Hub prices. The latter are currently at levels seen before the outbreak of the war on February 23, while European prices are currently 36 percent higher than before.

Correlation between regional benchmarks
(squared correlation coefficient)



Sources: Bloomberg, IEA Gas Market Report January 2022, and IMF staff calculations.

[a] IEA Gas Market Report (2022), GIIGNL (2021). Two factors have driven the increase in spot and short-term contracts. One is the uncertainty among buyers in Europe on long-term gas use given the energy transition. The other is long-term LNG contracts that do not restrict end-users, allowing traders to buy long and sell on spot markets.
[b] Typically, around 80 percent of LNG production is based on long-term contracts in order to finance capacity expansion.

- Substitution by other hydrocarbon energy sources. Gas-to-coal switching has already been underway in Europe, led primarily by Germany and the Netherlands, though it is expected to slow down with the recent surge in coal prices and diminished switching capacity in parts of the EU, including Spain and Italy.[10] We estimate that gas-to-coal switching can reduce gas demand by 9 bcm and gas-to-oil switching for power generation can reduce demand by another 3 bcm in 2022, with continued fuel switching into early 2023 winter months.[11]

Inventories could be used up to a point. However, storage outflow rates drop as zero storage is approached, and in any event, countries would likely want to maintain some storage buffer. Assuming countries targeted a minimum inventory capacity of 10 percent, as of end-May, a maximum of 40 bcm could be available to cover temporary supply shortfalls over the succeeding 12 months.

[10] IEA Gas Market Report (Q1 2022), IEA Electricity Market Report (January 2022).
[11] Based on modifications to IEA technical estimates. Modifications consider the large price response and varying abilities for oil refineries to handle multiple grade types of oil.

Demand

Only some demand compression is likely from the household sector in the short run. Many European countries regulate consumer gas and electricity prices, partly to protect vulnerable households. Indeed, since prices began to increase last year additional measures to partially shield consumers have been implemented. Such measures typically require suppliers to be compensated, either directly through a subsidy or through the promise of higher prices in the future. Importantly, such measures do not set the necessary incentives to reduce demand. In any event, household demand for gas is thought to be highly inelastic, with short-run estimates ranging from -0.08 to -0.25[12]. Assuming an average elasticity of -0.15 (i.e., abstracting from any new energy efficiency campaigns) and assuming average pass-through from wholesale to consumer prices of 20 percent (broadly consistent with regulation and rates seen to date in 2022), the recent increase in gas prices will reduce household consumption by only about 4bcm for the remainder of the year. Of course, individual countries might have more or less compression to the extent their pass-through and adaptation exceed the average, and one would expect pass-through and savings to rise going forward.

The existing high prices would lead to some demand reduction in the industrial sector. While on average demand is quite price-inelastic, there is some heterogeneity both within industries and within countries. Natural gas demand from industries such as metals and chemicals—which are exposed to global competition—may be more sensitive to an increase in the cost of gas, and thus more likely to reduce production and gas use. Anecdotal evidence suggests that this is already occurring (Box 2). Moreover, in some industries where gas is used directly as a production input (e.g., chemicals), substitution can be all but impossible. Estimated average elasticities by industry range from - 0.15 for chemicals to -0.09 for textile and leather. Using these elasticities and using the IMF's World Economic Outlook natural gas price forecasts (IMF, 2022) suggests a reduction in industrial natural gas demand of 13 bcm for the remainder of 2022.

Short Run Own-Price Elasticities for Natural Gas

Country	Chemical/ Petrochem.	Non-metallic minerals	Mining and quarrying	Food and tobacco	Paper, pulp and printing	Textile and leather	***Country mean***
Finland		-0.101		-0.112	-0.117		***-0.110***
France		-0.134		-0.183		-0.108	***-0.142***
Italy	-0.149	-0.130	-0.077	-0.071	-0.059	-0.060	***-0.091***
UK	-0.152	-0.134		-0.115	-0.099	-0.106	***-0.121***
Industry Mean	***-0.151***	***-0.125***	***-0.077***	***-0.120***	***-0.092***	***-0.091***	

Source: Andersen et al (2011)

[12] See Asche et al (2008), Auffhammer and Rubin (2018), Nilsen et al (2012) and EIA (2021).

Box 2. Examples of Industrial Demand Compression

- Norwegian fertilizer company Yara has temporarily reduced production at two plants in Italy and France.
- ArcelorMittal, Europe's largest steel producer (40 mt, about 2 percent of global output) announced that it would operate its all its electric arc furnaces in "stop-start mode" to avoid peak electricity prices. This comes on top of output reductions at other steel producers.
- Aluminum smelters in Europe have curbed 900,000 mt of aluminum production capacity, about 1.3 percent of global output.
- Finally, Zinc smelting capacity has been reduced by 700,000 mt, roughly 5 percent of global production.

Overall, at present and projected gas prices, the potential supply and demand adjustment is estimated to be nearly 100 bcm during 2022, perhaps rising by an additional 10 bcm when considering the 12 months beginning in June 2022 (Table 2). The 2022 estimate is in line with the European Commission (EC, 2022) and above the IEA (IEA, 2022). Differences with the EC and IEA largely center around the scope for alternative power sources, the degree of demand compression and the horizon over which the assessment is made. On energy supply, we project higher LNG imports on account of a high volume of observed flows through June. We take a more conservative view on the scope to scale up other forms of electricity generation due to political and technical constraints (i.e., nuclear), supply bottlenecks (green energy), and insufficient financial incentives (i.e., bioenergy plants). On the demand side, EC and IEA estimates reflect broad assumptions/targets (especially on the household side) while our analysis reflects observed prices applied to estimates of demand elasticity for households and industry.

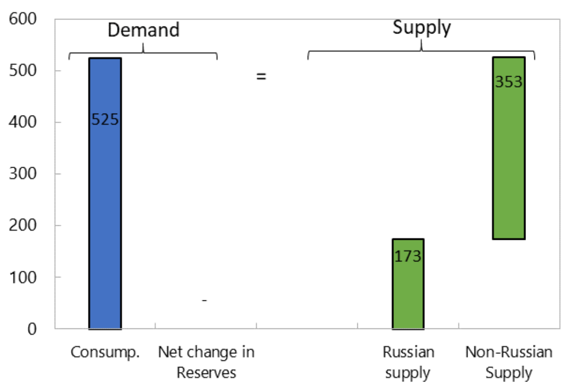
IV. Scenarios and Likely Adaptation

The focus of this paper is the impact of a full and prolonged shut-off of Russian gas to Europe. This would go well beyond the recent partial gas supply disruptions, which if they continue would be manageable with some risks in the event of a cold winter.[13] These simulations also go beyond the temporary shut-off assumed in ENTOSOG's recent work.[14] This scenario is calibrated against a stylized counterfactual with no interruption of Russian flows (see Box 3), which helps in cleanly modeling the output effects of the shut-off shock. The scenario allows for adjustment to the limits identified in Section III, and then assesses storage and shortage problems that could arise, and their potential timing. The 'full shut-off' scenario begins from end-June 2022 and is modelled through to end-June 2023.

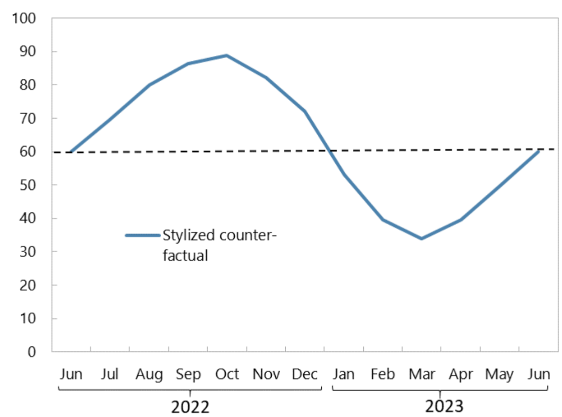
Box 3. Stylized Counter-Factual with No Disruption to Russia Gas Supply

The shut-off scenario is calibrated against a stylized counter-factual. This counterfactual is built up from 2021 supply and consumption patterns and takes end-June 2022 gas storage levels (which are close to median levels in past years) as given. It assumes that Russian and non-Russian supplies are sufficient to build storage to levels consistent with the EC's target of at least 80 percent of storage capacity by end-summer. During the 2022–23 winter, these inventories would be drawn down following the normal seasonal pattern. Demand would moderate relative to the trend established in 2021, given higher prices witnessed to date in 2022. As shown in Table 2, household and industrial demand is expected to decline by 4bcm (5 percent) and 13bcm (15 percent), respectively in 2022, given already elevated gas prices. Under this counterfactual, there would be no gas shortages. Even during a cold winter, new supplies or additional inventory draw-down would prevent shortages.

Gas Flows: Stylized Counter-Factual (bcm)



Gas Balance (Inventories) (Percent of Storage Capacity)



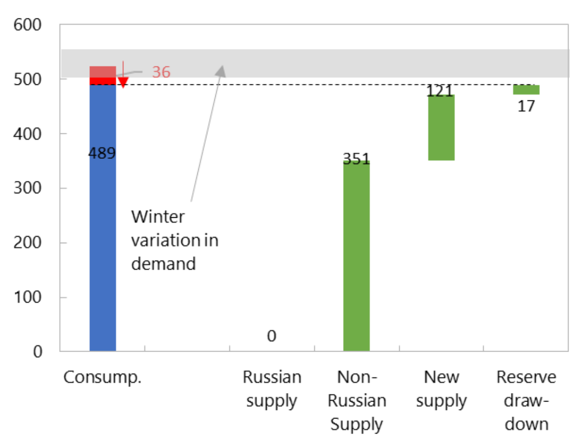
[13] It is beyond the scope of this paper to build a 'real time' projection based on the latest gas flows. However, our initial assessment is that a continuation of such flows would not lead to wide-spread gas shortages in Europe, but would make it difficult to build gas storage to normal pre-winter levels. And during the winter, storage levels may need to be depleted to very low levels in some countries, with the situation particularly difficult in case of a cold winter.

[14] The European Network of Transmission System Operators for Gas (ENTSOG), an association of 42 EU gas pipeline operating companies, most recent Summer Supply Outlook includes a simulation of the impact on gas storage levels from a Russian shut-off on April 1. The exercise—which projects up to October 1, 2022—shows that several countries would see storage levels significantly below normal seasonal levels. If the shut-off started on April 1, EU storage levels of natural gas would be 45 percent on October 1. For every additional 4 weeks of supplies from Russia, the storage levels increase by about 10 percentage points.

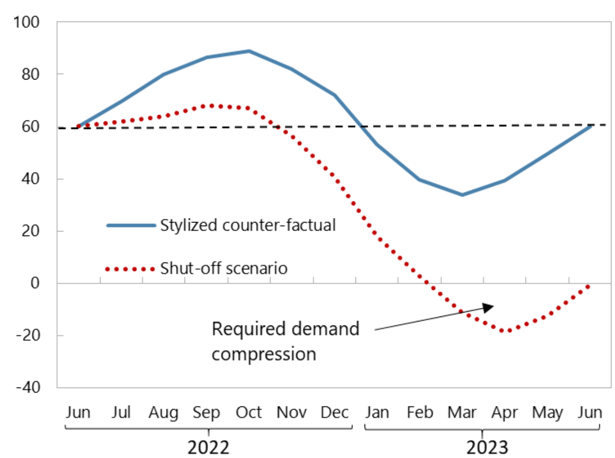
Under the 'full shut-off' scenario, there would be substantial shortages of gas and adjustments to consumption would be necessary in many parts of Europe. The simulations suggest:

- *Adjustment needs and limits*: Assuming that around 70 percent of the Russian shortfall is covered by alternative gas and energy sources (per Table 2), a shortfall would remain over the winter months, when seasonal demand is high.
- *Storage levels:* Some reserves could be built over the summer—accumulating to around 65 percent of capacity in aggregate--but the drawdown of these reserves over the winter to minimum levels would not be enough to meet demand in all countries. Furthermore, at end-June 2023, storage levels would be well- below seasonal averages, indicating that problems would continue into the winter of 2023/24.
- *Implied demand compression:* The shortfall in supply would mean that 'winter' (early-November to end-March) consumption would need to decline by around 12 percent (7 percent annually) or 36 bcm. Given price-inelastic demand, markets would clear at a higher price (with the extent of country-level price increase dependent on whether connection to world markets for marginal supply could be maintained). A particularly cold winter would force an additional 30 bcm of demand compression. Policymakers could choose to protect household consumption, essential services and strategic industries, but this would force higher demand compression on unprotected industries.

Gas Flows: Shut-Off Scenario (bcm)



Gas Balance (Percent of Storage Capacity)



Under this full shut off scenario, the impact on the natural gas market would likely differ across regions (reflecting their different alternative supply possibilities). To illustrate, we abstract from "full solidarity"—which the EU has not yet defined—and assume only that each country shares their "excess" inventories (i.e., those above the assumed minimum 10 percent level) with neighboring countries:

- *UK, Ireland, Spain, Portugal, Sweden, and Denmark.* With little reliance on Russian gas, these countries could adjust to such a supply disruption. Given their low storage capacity, any inventory build-up or draw-down in these countries would have little impact on the rest of Europe.

- *France, the Netherlands, and Belgium.* These countries have some reliance on Russian gas, but they also have direct access to LNG import capacity and alternative pipeline supply routes, and can also adjust. In these countries inventories are reduced to minimal levels to help support "protected consumption" in neighboring countries (Germany and CEE).

- *Türkiye.* Türkiye is a gas-intensive economy with a relatively high reliance on Russian gas (34 percent of total imports in 2020). However, it appears to have the import infrastructure to meet most of any Russian shortfall, especially through LNG imports.

- *Finland, Latvia, Lithuania, Estonia.* Although historically reliant on Russian gas, these countries have existing and soon-to-be-launched alternative import capacity, which should allow them to adjust and avoid physical shortages. Given the new floating LNG import terminal in Finland and opening of a new pipeline to Estonia, these countries will be able to export an additional 2bcm of gas to other countries.

- *Poland.* While around half of natural gas was imported from Russia in 2020, Poland's economy is not particularly gas intensive, with a greater historic reliance on coal. A new pipeline from Norway via Demark will open in October, with an initial import capacity of 2-3bcm per year, rising to 10bcm per year by January 2023. This, in combination with LNG imports from Lithuania, should allow for full substitution of Russian gas in the event of a full shut-off .

- *Bulgaria, Romania, Croatia, Slovenia.* This group of countries could also avoid shortfalls. In Bulgaria, while the share of Russian gas is high relative to total gas consumption, gas plays a less important role in the overall energy mix. It also has alternative supply routes via Greece and Türkiye. Romania is a significant domestic producer of gas, which could cover most of its domestic consumption needs. Croatia is not dependent on Russian gas, and is assumed to support supplies to Slovenia, which also has a pipeline via Italy.

- *Germany and Austria.* Both countries are highly reliant on Russian gas. Although they have relatively strong pipeline networks with neighboring countries, bottlenecks exist including within Germany. We approximate non-Russian gas import flows based on analysis by ENTSOG (2022) taking into account the bottlenecks with neighboring countries.[15] Using this approach, a shortfall of around 15 percent of consumption (15bcm) would occur.

- *Italy.* The authorities have stated that they will only be able to replace around two-fifths of Russian gas over the next 12-months, and have agreed new gas import deals consistent with this. This assumption is also consistent with implied import capacity implicit in the simulations conducted by ENTSOG (2022). Taking this as given, and assuming inventories are reduced, a shortfall of around 15 percent of annual consumption would remain.

- *Czechia, Slovakia, Hungary.* These countries have a high reliance on Russian gas, and the main alternative supply routes go through constrained countries (Germany, Austria, Italy). This would limit their inflows. It is likely that significant shortages would emerge and that the price needed to clear this regional market would be extremely high.

[15] ENTSOG's analysis shows that in the event of a full Russian gas shut off, if non-Russian import infrastructure operates at maximum capacity, then Germany and Austria should still be able to build modest gas inventories over the summer. This helps to establish the non-Russian import capacity constraints for these countries. Combining this with the seasonal increase in gas consumption allows the potential gas shortfall to be estimated. In addition, this analysis assumes that 'reverse flows' from France are not possible given differences in the additives in each country. Overcoming this barrier could increase import capacity to Germany.

Table 3: Gas Flows in Adverse Scenario (BCM)

	Consumption	Russian supply	Non-Russian supply	Reserve draw down	Demand Compression*	Percent of annual consumption
Europe	**525**	**0**	**472**	**17**	**-36**	**-7%**
UK and Ireland	76	0	76	0	0	0%
Spain and Portugal	38	0	38	0	0	0%
Sweden and Denmark	4	0	4	0	0	0%
France, Netherlands, Belgium	98	0	96	2	0	0%
Türkiye	57	0	57	0	0	0%
Finland, Latvia, Lithuania, Estonia	6	0	6	0	0	0%
Poland	23	0	22	1	0	0%
Bulgaria and Romania	15	0	14	1	0	0%
Croatia and Slovenia	4	0	4	0	0	0%
Other Europe	7	0	7	0	0	0%
Germany and Austria	99	0	78	6	-15	-15%
Italy	73	0	58	4	-11	-15%
Czechia, Slovakia, Hungary	25	0	12	3	-10	-40%

*Required reduction in demand in order to meet available supply. This could be achieved through market-based price adjustment and/or government rationing schemes

Note: The columns of the table should be read in the same way as the gas flow charts, above. For Italy, for example, consumption without a gas shut-off would be around 73bcm over the next 12-months. Alternative non-Russian gas supplies are around 58bcm . This could be supplemented with an additional 4bcm draw-down of reserves, net over the year (draw-down may be higher at peak demand). This leaves a potential shortfall of 11bcm, representing 15 percent of annual consumption.

V. Economic Impact of a Prolonged Shut-Off

Disruptions in the gas markets are likely to have important impacts on the overall economy. The impact would depend on complex supply-side factors, most prominently on how gas is used in production, how much it can be substituted for by other inputs, and how initial impacts in heavily affected sectors cascade through the economy. These supply-side mechanisms would also interact with additional demand side developments and cross-country spillovers. Reflecting this complexity, the recent literature includes examples using a wide range of techniques to assess the impact of a Russian natural gas shut-off.

Conceptual Framework

The gas market disruption under analysis can be characterized as a persistent supply shock. A key question is how the production network would adjust to this shock. In this regard, there are a few issues to consider (see Appendix II for a model-based elaboration):

- *The role of gas in the production function.* For certain sectors (e.g., petrochemicals, glass production) natural gas is an essential production input, while for other sectors it is less so, or its use is indirect, e.g., through the use of gas in the production of electricity. It is thus important to consider: (i) the capacity of a sector/firm to substitute gas as a direct input; and; (ii) the ability to substitute gas as an input in the production of other forms of energy, like electricity.
- *How energy interacts with other inputs/factors of production*. For instance, if models allow for substitution between energy and capital but also between natural gas and other sources of energy. In this regard, a high relative price of natural gas would incentivize firms to substitute away from gas. Some models also allow for substitution of intermediate goods that use substantial amounts of gas within and across sectors, which can be another important margin of adjustment.

- *Downstream linkages*. As different sectors experience output losses, it becomes necessary to understand how downstream sectors will also be affected. The ability of downstream sectors to substitute affected inputs (with similar imported inputs, or with other inputs) will be crucial.
- *Market structure*. Typically, if a supply shock hits a market, prices incentivize households and firms to adjust consumption and production. However, in the extreme case when markets become totally segmented due to a supply shock, it may not be possible to access gas, or to even find substitutes for it in production.
- *Time horizon.* Production technologies are less flexible in the short run implying lower elasticities of substitution leading to larger supply-side effects. Over time, production can adjust to a much larger degree to a change in the availability of inputs. For example, in the chemical and petrochemical industry, Andersen et al. (2011) report that the short-run own-price elasticity of natural gas is estimated to be -0.15, but-0.62 in the long-run.

Aggregate demand effects are likely to amplify the GDP impact, but depend also on the policy response:

- *Reduced private demand*. For energy importers an increase in the price of natural gas represents a negative terms of trade shock. Households' income will be affected because the prices they pay for energy will reduce their real income and because production (and employment) will suffer. Negative confidence effects would also encourage higher precautionary saving. Firms' investment plans would be negatively affected because of the shock to profits, and also because of deteriorated expectations and sentiment. These effects would propagate more in economies with more nominal rigidities. For gas producers, higher prices would feed through to higher corporate profits and dividend payments, buffering terms of trade and private demand impacts.

- *External demand*. As most European countries would experience a similar shock simultaneously, demand from European trading partners will decrease, magnifying the negative impact of the shock. And with many European countries locked into exchange rate arrangements, this adjustment channel would offer little offset.

- *Policy response*. Fiscal support would act through automatic stabilizers and potentially additional measures (where fiscal space is available) to mitigate the impact of rising food and energy prices, ideally focusing on the most vulnerable households and businesses (IMF Fiscal Monitor, 2022). Within any support package, the design of measures could also have the potential to either attenuate or magnify the impact of the shock. Policy interventions that persistently distort price signals (keeping gas demand high) or that impede the necessary supply-side adjustment to persistently higher energy prices are likely to magnify the cost of the shock. In terms of monetary policy, a tighter stance could constrain demand and growth above and beyond the direct impact of the shock if the inflation impact has a persistent component, and policymakers are unable to 'look through it'.

Modeling the Economic Impact of the Supply Shock

We illustrate the impact of a full Russian gas shutoff—persisting through June 2023—through two approaches, a *multisector partial equilibrium model with demand spillovers* and a *multisector open-economy general* *equilibrium model*.[16] This allows us to consider the different market environments that could arise from a gas shut-off across countries. The first approach can illuminate the economic impact when gas markets are fragmented, outright physical shortages exist and the gas market cannot adjust to prices. And the second approach illustrates economic impacts when markets are integrated and there is complete price-pass through. In the following we describe the main assumptions and their differences (see also Table 4).

Table 4: Key Features of the Models

Feature	*Multi-sector model with demand spillovers*	*Baqaee and Farhi (2019) multisectoral general equilibrium model based sufficient statistic*[17]
Substitutability of energy and other factors of production	Perfectly inelastic for capital; Cobb-Douglas for labor	Quite inelastic, 0.084 for industry, 0.136 for power sector, 0.24 for households
Choice of production function	Nested CES (Cobb-Douglas parameterization)	By-country, sectoral CES production functions with constant returns to scale in labor and intermediate inputs.
Indirect sectoral substitution at the production level	No	Yes
Sectoral coverage	Disaggregated by 21 industries and households	Disaggregated by household, power, industry, and other sectors
Size of the market	EU (gas substitution derived in Section III)	EU+LNG (Asia)
Assumes market-clearing through prices	Not applicable	Yes
Demand side effects	Yes	No
Domestic and international downstream linkages	Yes	Yes
Endogenous policy response	No	No
Uncertainty effects	No	No
Accounts for domestic production?	No	Yes
Captures cross-country trade spillovers	Yes	Yes
Demand side: captures adverse confidence effects?	No	No
Suitable for…	Potential gas shortages (no market-clearing price), predominance of firms where gas is an essential input, incomplete price pass through to end-user	Global LNG and EU market price clears market, diversified industrial sector, high pass-through of prices to end-user

Multisector model with demand spillovers. The first approach, which assumes that gas markets are fragmented, takes the adjustment assumptions in the full Russian gas shut-off scenario as given and assesses the economic impact of the remaining gas short-fall (Table 3). We use a multi-sector model, where natural gas is assumed complementary to capital in production (see Atkinson and Kehoe (1999), Gerarden et. al (2015), and

[16] Different approaches have been used in this context including DSGE models (ECB, 2022, Bundesbank, 2022), multi-sectoral general equilibrium models (Bachman et al, 2022, Baqaee et al, 2022, and Chepeliev et al, 2022) and partial equilibrium approaches (OECD, 2022).

[17] See Bachman et al (2022) for the derivation of the sufficient statistic.

Kormilitsina (2016)). The model covers 21 sectors and differentiates between gas as an explicit input into the production function, and its use to generate electricity.[18] A simple Keynesian framework like that in Frenkel and Razin (1996) is used to capture demand spillovers. In this regard, initial cross-country output losses are calibrated to ensure that the propagation of the shock through demand and trade channels results in a regional natural gas contraction that is in line with the shut-off scenario. This stylized model attempts to capture quantity adjustments that would occur under rationing, and thus, the price channel is assumed away.

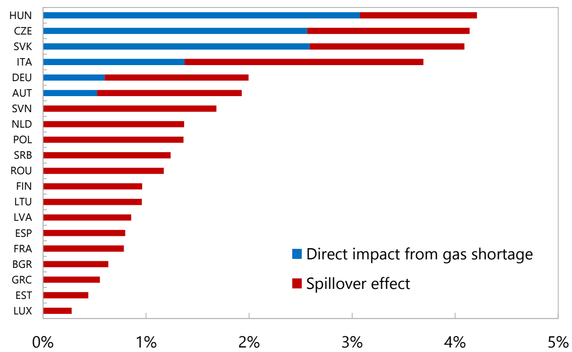
Multisector General Equilibrium Model. The second approach, which assumes integrated gas markets, employs an LNG market model in conjunction with an approximation of a sectoral open economy general equilibrium model.[19] Considering the global LNG market as a buffer for the supply shock, the LNG market model derives the price effect and the adjusted gas consumption and production. These are used to compute the import share of natural gas in the economy and its change due to the supply shock. With these inputs the sufficient statistic of the multi-sectoral, open economy GE model by Baqaee and Farhi (2019) calculates the output impact of a natural gas import shock, following Bachman et al (2022) and Baqaee et al (2022). The model assumes that flexible prices clear an integrated gas market, and as such sets a benchmark for measuring impacts once all adjustments have worked their way through the system. The model accounts for substitution of natural gas and other factors of production, but does not account for international trade spillovers.

Due to the supply bottlenecks described above that are likely to constrain adjustment in a full Russian gas shut-off scenario, it is useful to first examine illustrative results from the multi-sector model with demand spillovers (Table 5, columns 1–3). As discussed above, impacts are measures against the stylized counter-factual with no Russian gas disruption (avoiding the complication of accounting for recent partial shutdowns):

- The results from apply the model suggest that losses would be relatively large, and more significant in countries where infrastructure constraints result in large decreases in gas supply. Sectors with higher natural gas intensity would suffer the most. In Hungary, Czechia, and Slovakia, the direct impact on. In production would be largest, given the significant gas shortages expected. These would be further exacerbated by trade spillovers, leading to an aggregate GDP loss of about 4 percent in the baseline in each country over the next twelve months. In Italy, a high reliance on gas for electricity production and a sizeable spillover component would lead to an aggregate GDP loss of around 3½ percent. The aggregate GDP loss in Germany and Austria is estimated to be about 2 percent each. The model suggests that countries primarily facing a price shock without physical shortages could see modest impacts ranging up to 1 percent of GDP (Spain, France).

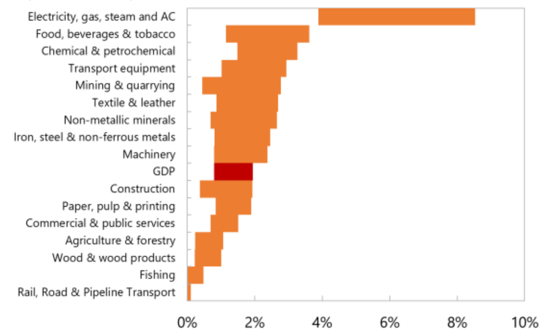
[18] Kemfert (1998) analyzes aggregate and sectoral industrial data for Germany and finds that at the aggregate industrial level, a nested CES production function with a nest of capital and energy describes the data well.
[19] See Albrizio et al (2022) for a full set of assumptions and description of the model.

Output Loss
(Percent of GDP)



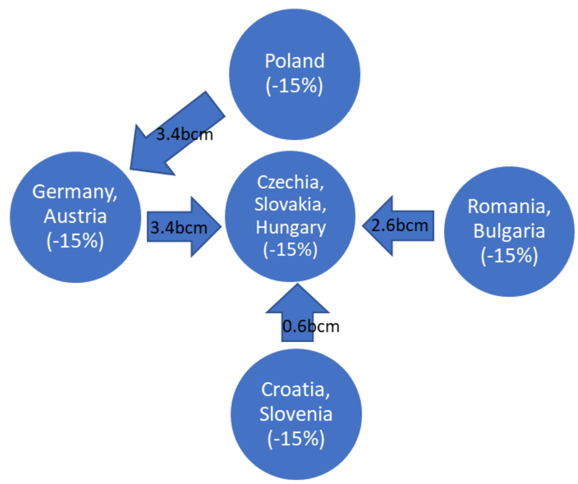
Source: IMF staff calculations.

Sectoral Output Loss
(Percent of GDP)



Source: IMF staff calculations.

- Greater gas sharing—consistent with the EU aim to achieve additional solidarity agreements—could significantly reduce the potential impact on the hardest hit countries. An ilustrative scenario shows how Germany, Austria, Poland, Romania, Bulgaria, Croatia and Slovenia could share gas with the hardest hit countries –Czechia, Slovakia, and Hungary. All would face a 15 percent shortfall in gas consumption, sharing the burden of adjustment more widely. Using these assumptions in the multi-sector approach with demand spillovers model, results in output losses falling meaningfully in these beneficiary countries, while increasing slightly in countries giving up gas use (Table 5). Note that this would likely be beneficial overall for the EU given tight supply chain connections, but such non-linearities are difficult to model in this framework.



- The degree of protection to the household sector will have implications for the impact on output. Indeed, most countries do protect households and essential services.[20] There are clearly broadly defined welfare gains from protecting households, and these would also apply to protecting critical household services (e.g., health care). But by protecting households from any substantial decline in gas consumption, a larger decline in gas would be passed on to industry and services, which would exacerbate the supply shock. While households would be insulated from a larger decline in real disposable income (which would support consumption and growth), the supply-side effect from lower production would dominate. To illustrate the impact of protecting households, we use a simplifying assumption that household consumption remains constant. This would be consistent with some combination of underlying policies—price restraints, taxes, subsidies/transfers, etc.—that make sure the consumer's decision problem does not change. Our results show that full protection of households can increase the output costs of the full gas shut off by nearly 50 percent, with the overall GDP impact thus as high as 6 percent in the most affected countries

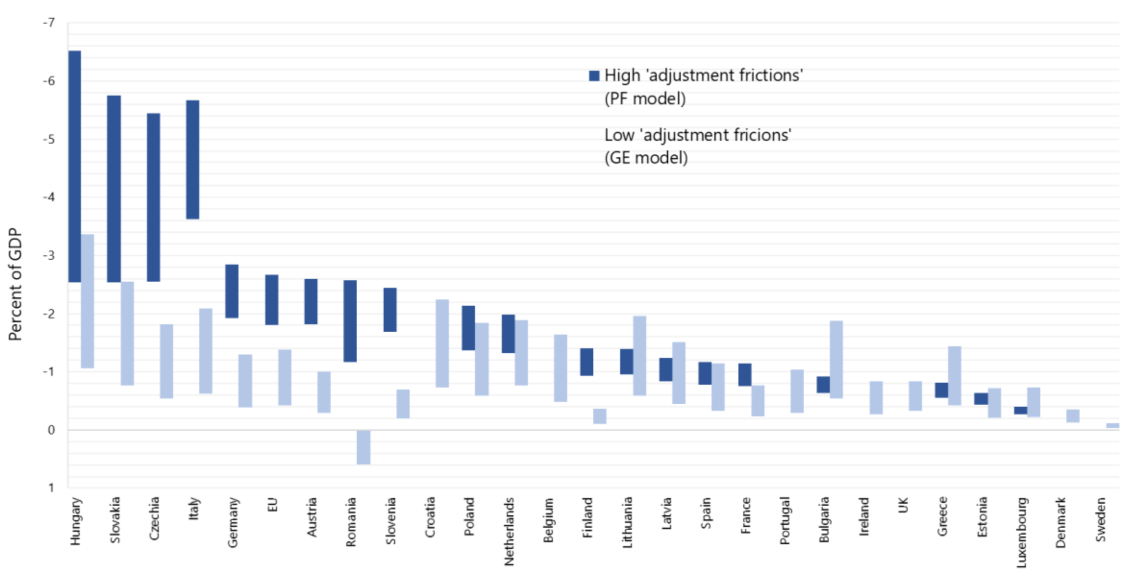
[20] Protection of households is based on different rules across countries. They typically imply that gas companies are not allowed to stop delivering gas to households, but households could face some regulated price increases.

Since a number of countries will likely primarily face a price shock (with no physical shortages), it is also important to consider illustrative results from the modeling approach that assumes flexible prices and competitive and fully integrated markets: the multisector general equilibrium model. Under these assumptions, a full cessation of Russian gas exports to Europe would lead to 110 percent price increase compared to Q1 2022 in both the global LNG market and in the EU. This would lead to demand adjustments in major LNG importing countries outside the EU, helping to allow for rerouting of natural gas, mitigating the impact in the EU while at the same time creating negative economic spill-overs to these other countries. At the point when full adjustment holds, the EU wide aggregate output effect would be -0.4 percent of gross national expenditure (GNE) based on first round supply side effects alone (Table 5). Aggregate demand side effects could double the estimate. Looking at individual countries--based on the expenditure share of gas in their GDP—Hungary, Slovakia, the Netherlands, and Croatia would take the largest hits based on the model, but for all countries impacts would be modest.

In the event that the European gas market would become completely cut off from the global LNG market, there would be no gas demand response in the rest of the world and no rerouting of LNG from Asia to Europe. This would imply a greater degree of demand compression in the EU, and even with full adjustment and no market fragmentation within the EU, output losses are estimated to increase to -1.4 percent of GDP.

Overall, the results emphasize the importance of accounting for the diverse environments in different countries that could arise during a full gas shut-off. Major driving factors are adjustment frictions and the policies in place that affect consumption between sectors and sharing between countries. As a Russian gas shut-off would be an unprecedented event, it is highly uncertain how these factors play out.

Output Losses Associated with a Russian Gas Supply Shut-Off (Percent of GDP)



Source: IMF staff estimates

Notes: PF model refers to multisector production function containing higher adjustment frictions, with ranges including baseline, solidarity, and protected households scenarios. GE model refers to multisector general equilibrium model containing lower adjustment frictions, with ranges including full or no EU integration with global LNG market.

Table 5. Output Losses Associated with a Russian Supply Shut-Off: 12-month Ahead (Percent)

Country	High 'adjustment frictions'			Low 'adjustment frictions'	
	Multi-sector production function model*			Multisectoral general equilibrium model	
	Baseline	Solidarity	Households protected	EU integrated in global LNG market	EU not integrated in global LNG market
EU	**-1.8**	**-1.8**	**-2.7**	**-0.4**	**-1.4**
UK	...	...	...	-0.3	-0.8
IRL	...	...	...	-0.3	-0.8
ESP	-0.8	-0.8	-1.2	-0.3	-1.1
PRT	...	...	...	-0.3	-1.0
SWE	...	...	...	0.0	-0.1
DNK	...	...	...	-0.1	-0.4
FRA	-0.8	-0.8	-1.1	-0.2	-0.8
NLD	-1.4	-1.3	-2.0	-0.8	-1.9
BEL	...	...	...	-0.5	-1.6
FIN	-1.0	-0.9	-1.4	-0.1	-0.4
LVA	-0.9	-0.8	-1.2	-0.4	-1.5
LTU	-1.0	-1.0	-1.4	-0.6	-2.0
EST	-0.4	-0.4	-0.6	-0.2	-0.7
POL	-1.4	-2.1	-2.0	-0.6	-1.8
BGR	-0.6	-0.9	-0.9	-0.5	-1.9
ROU	-1.2	-2.6	-1.7	-0.5	0.1
HRV	...	...	...	-0.7	-2.2
SVN	-1.7	-1.9	-2.4	-0.2	-0.7
GRC	-0.6	-0.6	-0.8	-0.4	-1.4
LUX	-0.3	-0.3	-0.4	-0.2	-0.7
DEU	-2.0	-1.9	-2.8	-0.4	-1.3
AUT	-1.9	-1.8	-2.6	-0.3	-1.0
ITA	-3.7	-3.6	-5.7	-0.6	-2.1
CZE	-4.1	-2.6	-5.4	-0.5	-1.8
SVK	-4.1	-2.5	-5.7	-0.8	-2.6
HUN	-4.2	-2.5	-6.5	-1.1	-3.4

*No estimates for individual countries with no or minor Russian gas imports. However, for these countries, the 'trade spillover' impact would likely range between 0 and -0.8 percent of GDP.

Note: The multisectoral general equilibrium model assumes a full shut-off of Russian pipeline gas exports to the EU, namely -142 Bcm. This shortfall represents a supply shock of -16.8% if the EU is fully integrated in the global LNG market and 34.7% if not. The scenarios use price elasticities of demand that are weighted by the sectoral composition of gas consumption in each country. The price elasticity of supply is assumed to be 0.06 (Krichene, 2002). We assume that the law of one price holds and use the Dutch TTF as reference price. We compute the results for each country separately based on the model, but the open-economy characteristics take implicitly into account cross-country substitution. See Albrizio et al (2022) for the full set of assumptions and results.

Aggregate demand effects are likely to raise output losses beyond those estimated above. While the multisector model with demand spillovers captures some demand-side elements, neither can capture policy channels, confidence effects, and the wage and price rigidities which may further propagate shocks. These would need to be ‘layered-on’ to any estimate of the impact, and this process is country-specific. Recent background analysis for the 2022 Germany Article IV consultation (Lan et al, 2022) extends the production function approach of Bachmann et al. (2022) and accounts for the curtailment of Russian gas flows to Germany through Nord Stream 1 in June 2022. Assuming that households and the transmission sector are protected, the supply-side impact for Germany is estimated to be within the broad range of estimates presented above. If the remaining Russian gas supplies are shut off, and incorporating adverse uncertainty, Germany's real GDP is estimated to fall below its baseline path by 1.5 percent in 2022, 2.7 percent in 2023, and 0.4 percent in 2024 with no catch-up effects in later years due to deferred economic activity.[21] In this scenario, the authors estimate that inflation could be about 2 percentage points higher on average in 2022 and 2023.

The range of overall output losses flagged by the two approaches presented above falls into the lower end of the range in the literature. Estimates for the marginal impact on output range from near zero to over -5 percent (Table 6). Higher output losses are assessed in analytical settings where the economic structure is taken as being more rigid and demand effects are more fully modeled (e.g., Bundesbank, 2022). Some of the studies also include other Russian energy exports or even a broader set of exports and are therefore not fully comparable to our sole focus on natural gas.

Table 6. Summary of Studies on the Output Effects of a Russian Gas or Energy Shut-Off

Study	Analytical Approach	GDP impact (EU/EA)	GDP impact (DEU)
Bachmann et al. March 2022	Computable general equilibrium - "sufficient statistic"		-0.5%
Baquee et al. April 2022	Computable general equilibrium - "sufficient statistic"	-0.2 to -0.3%	-0.5%
Bundesbank April 2022	NiGEM, semi-structural, input-output table		-5%[a]
Bundesbank June 2022	Sectoral input-output table and semi-structural (BbkM- DE)		-6.8%[a]
Chepeliev et al. March 2022 (VoxEU)	Computable general equilibrium	-0.3 to -0.6%	
ECB, March 2022	Multiple models	-0.5%	
ECB, June 2022	Multiple models	-0.6% to -2.3%[b]	
European Commission, May 2022	DSGE: Commission's Global Multi-Country	-2.6%[c]	
German Council of Economic Experts March 2022	Partial equilibrium (input-output table)		-2.0%
German Council of Economic Experts April 2022	Computable general equilibrium - "sufficient statistic"		-2.0% to -2.4%
Joint Economic Forecast, 2022	Multiple models		-6.5%[d]
Krebs, May 2022	Multiple models		-3.2% to -12%
Lan et al, July 2022	Partial equilibrium (input-output table)		-2.7%
OECD, March 2022	NiGEM global macroeconomic model, input-output tables	-1% to -1.4%	
Oxford Economics March 2022	Not disclosed	-2.2%	
Schnittker et al, March 2022	Partial equilibrium (demand reduction to minimise GVA loss)	-0.9% to -2.8%	

[a]Includes impact of cuts to Russian grain exports. [b]Impact in 2023 from production cuts beginning Q3-2022. [c]Includes other war-related channels, of which half, or 1.3%, is due to cuts in gas supply. [d]Over 2022-23.
Note: Some studies include additional war-related shock, including to other energy flows and prices.

[21] To estimate the impact of heightened uncertainty on demand m, the historic relationship between two measures of uncertainty and GDP is constructed. Assuming a jump in these uncertainty measures (to the 95th percentile of the historical distribution) the confidence effects on output are estimated at -0.8 percent of GDP in 2022.

VI. Policy Discussion

Overall, the gas supply simulations and output modelling illustrate the economic importance of minimizing frictions to adjustment (especially alleviating infrastructure bottlenecks), securing adequate gas sharing and supplies, and incentivizing lower demand for natural gas. Where frictions are more binding—like infrastructure bottlenecks or insufficient adjustment by some sectors— the scale of output effects can be high. If these frictions are minor, then the multisectoral general equilibrium model may provide a good approximation to this supply shock and would suggest lower impacts. Importantly, policymakers have some control over the scale of these frictions, and how much demand is curtailed, a point we now turn to.

The EC has proposed the REPowerEU package to reduce Russian energy import dependency and facilitate progress towards achieving full energy independence from Russia by 2030. Overall, REPowerEU is an important step forward with several key initiatives that will help address the issues identified in this paper. It covers four inter-related dimensions: (i) reducing energy consumption (including via efficiency campaigns); (ii) diversifying supplies; (iii) accelerating the green transition (both through a push on solar photovoltaic technology, as well as developing alternatives to natural gas such as green hydrogen and biomethane); and (iv) improved connectivity within Europe – with many important initiatives (see Appendix IV for details). The EC has also put forward regulation mandating minimum gas storage levels of 80 percent by November 1, 2022, with an increased target of 90 percent from 2023 onwards. Moving forward expeditiously and in a coordinated way is a priority, to optimize the investment undertaken (and avoid stranded assets).

Many countries have already made large strides towards the goals set by REPower EU and the storage mandate. As noted above, alternative sources of LNG supply have been procured and further efforts are ongoing. At the EU average level—and for major economies such as Germany, France, Italy and Spain—significant progress has been made at achieving the target of 80 percent stored capacity by October (90 percent for Germany). In Poland and Portugal, storage facilities were more than 90 percent full in late June. However, in a couple of countries—Croatia and Sweden—filling in storage facilities was less than 30 percent of the working gas volume. The progress has been facilitated by incentives. Germany in June extended a 15bn Euro credit line via the state development bank KfW to the gas market operator Trading Hub Europe to incentivize gas storage. Similar or related measures to incentivize maximum gas storage amid high prices might be warranted in other countries going forward.

Several individual countries have also launched campaigns to encourage household and government energy savings (e.g., Italy, with its campaign to reduce indoor temperature settings) while Germany intends to develop a mechanism to compensate firms for reducing their gas consumption. Preliminary data available for the first half of 2022 suggest that some demand adjustment is happening.

Nevertheless, there is ample rationale for the EU to accelerate efforts further with a view to mitigate potential shortages in the winter of 2022-23 and rebuild what could be very precarious storage levels during the summer of 2023. The focus should be on addressing adjustment frictions, encouraging stronger demand adjustment, and securing better sharing arrangements:

- ***Infrastructure bottlenecks***. Pillar III of the REPowerEU plan clearly lays out bottlenecks that need to be addressed to achieve a fully supplied and integrated European natural gas market in the absence of

Russian gas. Some larger investments in infrastructure will be needed, but there are also some more technical solutions that could be targeted to improve security of supply in the near-term. These would include the ability to reverse flows from West to East and solving the difficulty in sending French gas to Germany due to different standards on gas additives (which would also open the possibility of improving pipeline connections to the Iberian Peninsula where there is excess LNG import capacity). These projects and the technical preparations to support them could be accelerated with payments and subsidies, as well as regulatory measures.

- ***Demand adjustment: Price pass through, regulation and information campaigns*** The REPowerEU plan acknowledges that it will be crucial to maintain price signals to allow for endogenous demand adjustment. However, many current policy initiatives in member countries go against this principle, stopping or substantially reducing price pass-through. Governments in the EU, could target higher pass-through, with the precise amount varying depending on the strength of the social safety net, extent of existing energy subsidies, and fiscal space.[22] Where social safety nets are strong and pass through higher, they should follow best practices on compensation mechanisms and target vulnerable and low-income households.[23] The EU should continue to promulgate such practices and flag major deviations from best practice. Energy saving campaigns can also be used to reduce the pain of price increases (and if successful can directly reduce the risk of shortages). Past successful examples from international experience include Japan (Honjo and Ashina, 2017).

- ***Shortfalls in sharing gas amongst members***. Solidarity in the EU is defined as an obligation to support other members in meeting the demand of their protected consumers (including households and essential services; i.e., hospitals, schools etc.). However, not all countries have fully defined in law who is to be protected and only six bilateral solidarity agreements between countries have been finalized to date.[24] Accelerating the conclusion of solidarity agreements is important, since optimizing supply distribution in a shortfall scenario would not be a simple task and would likely involve some technical adjustments to the pipeline network to overcome bottlenecks (e.g., from west to east and from north to central regions). It would also be helpful for these solidarity agreements to extend beyond gas sharing (e.g., additional cross-border electricity sharing could mitigate the impact of gas shortages).

At the same time, with important bottlenecks likely to remain even after extra measures, and thus shortages likely in some countries, the Commission should also consider the guidance it intends to issue on how to prioritize gas supplies. This may well have implications for the green transition and being able to maintain a competitive industrial base. Outright gas shortages may accelerate the relocation of energy and natural gas intensive industries such as fertilizers, chemical industries, metals, machinery etc. to other continents. This risks carbon leapfrogging (the move of emissions to other places with lower prices and regulation). A starting point would be to require detailed contingency plans for large industrial users in regions facing potential gas shortages. Since supply chains extend across countries, solidarity agreements could also cover sharing to protect critical industrial clusters along with households.

[22] See (Amaglobeli et al, 2022).

[23] April 2022 Fiscal Monitor (IMF, 2022).

[24] It is encouraging that three out of the six solidarity agreements were signed in the weeks since March 10, 2022 (https://energy.ec.europa.eu/topics/energy-security/secure-gas-supplies_en#:~:text=The%20first%20bilateral%20solidarity%20agreement,April%202022%3B%20Finland%20and%20Estonia).

VII. Conclusion

Gas supply disruptions pose a significant economic risk to Europe at the present juncture. During a prolonged full shut-off of Russian gas, the most vulnerable countries in Central and Eastern Europe could face outright gas shortages and see GDP losses of as much as 6 percent. Italy would also face significant impacts due to its high reliance on gas in electricity production, although it has greater potential to secure alternative gas supplies. The effects on Austria and Germany would be less severe but still significant, depending on the availability of alternative sources and the ability to lower household gas consumption.

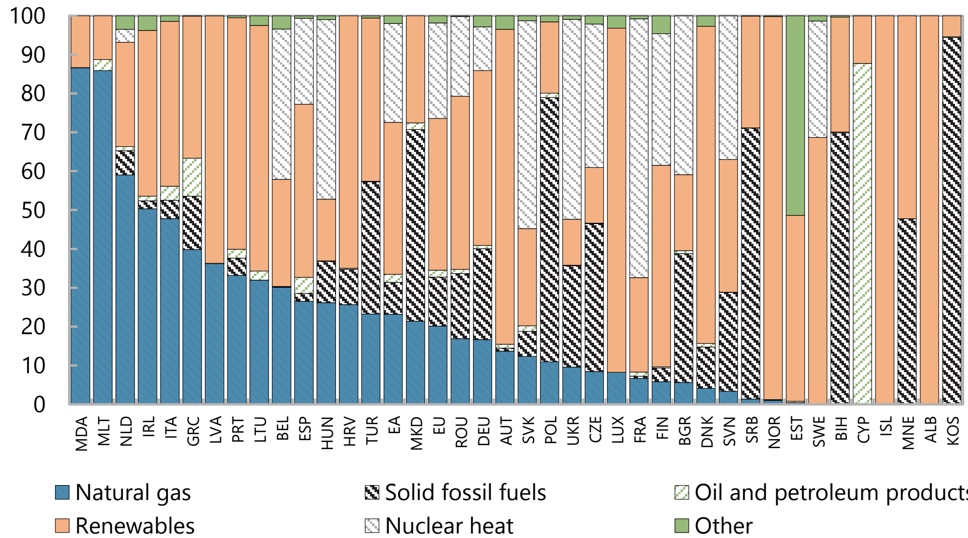
The European Union has made substantial progress in beginning to address these risks with the REPowerEU plan, the gas storage mandate, and initiatives by individual member countries. From historic winter lows, gas reserves have increased substantially, while infrastructure bottlenecks—such as LNG import capacity and within-Europe pipelines—are starting to be addressed. However, in the event of a prolonged and full Russian gas shut-off, gas shortages could be substantial particularly in parts of Central and Eastern Europe, including Germany, and Italy, generating sizable output losses in the near term.

Policies can deliver more. The priorities are to focus on overcoming infrastructure bottlenecks that prevent a more integrated 'gas union' within Europe; on settling solidarity agreements before a full gas shut-off begins, and on coordinated measures to induce lower gas consumption, notably by allowing prices to work to a greater extent, while protecting the most vulnerable households.

This paper provides some perspective on these issues, but further analytical work would also support preparedness. Simulations, like those undertaken by ENTSOG (2022), but covering the winter period and including market-based endogenous adjustment would be hugely beneficial. Quantifying the uncertainty in potential gas demand due to deviations in winter weather is another field of exploration. More analysis on the 'second-round' effects from a shut-off, such the supply-chain impact or the effect on financial conditions and uncertainty, would also be useful. This would help inform country-specific macroeconomic policy design, especially fiscal policy.

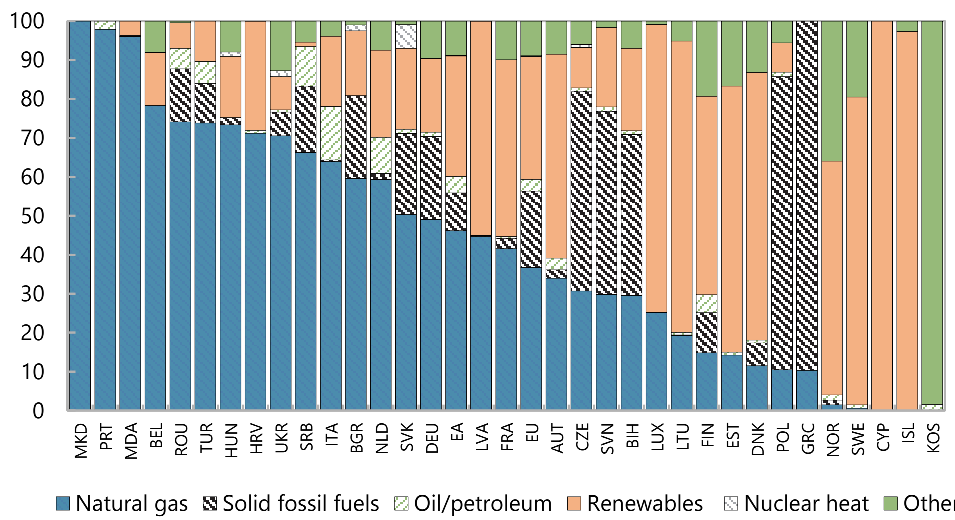
Appendix I

Gross Electricity Production, 2020
(Percent)



Sources: Eurostat; and IMF staff calculations.

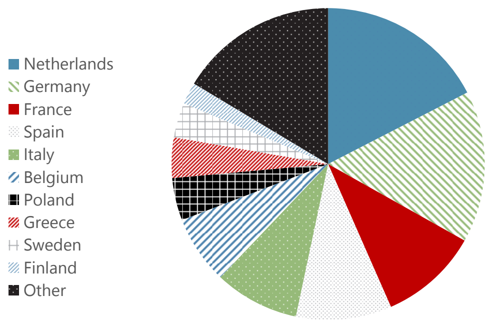
Gross Heat Production, 2020
(Percent)



Sources: Eurostat; and IMF staff calculations.

EU: Imports of Oil and Petroleum Products

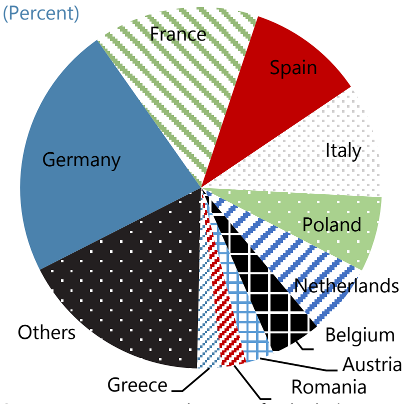
(in percent; by partner country; in 2020)



Sources: Eurostat; and IMF staff calculations.

EU: Consumption of Oil and Petroleum Products, 2020

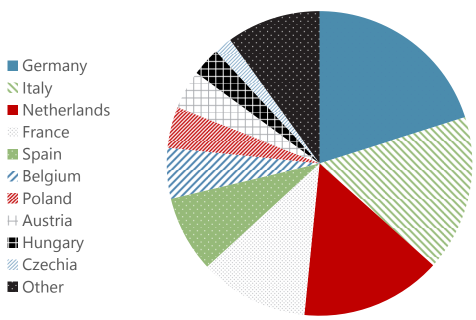
(Percent)



Sources: Eurostat, and IMF staf calculations.

EU: Imports of Natural Gas

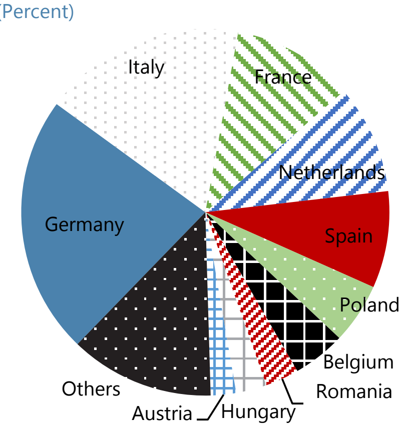
(in percent; by partner country; in 2020)



Sources: Eurostat; and IMF staff calculations.

EU: Consumption of Natural Gas, 2020

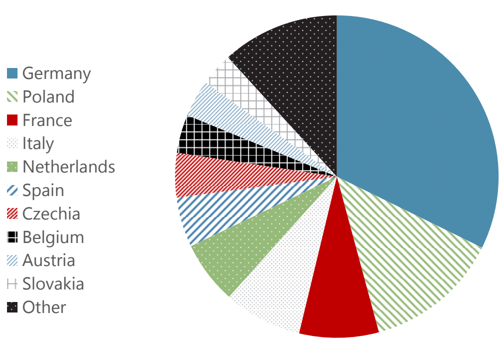
(Percent)



Sources: Eurostat, and IMF staf calculations.

EU: Imports of Solid Fossil Fuels

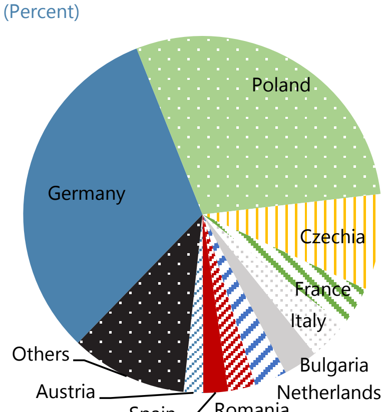
(in percent; by partner country; in 2020)



Sources: Eurostat; and IMF staff calculations.

EU: Consumption of Solid Fossil Fuels, 2020

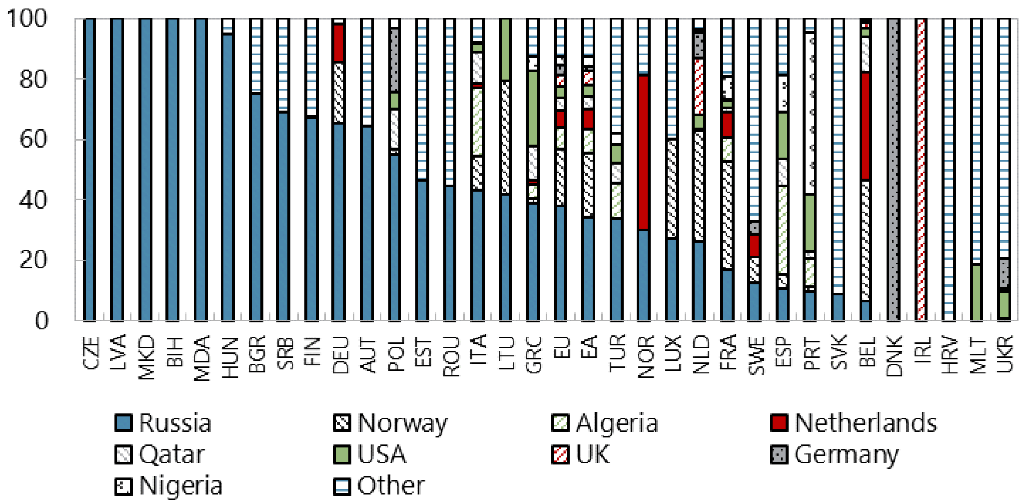
(Percent)



Sources: Eurostat, and IMF staf calculations.

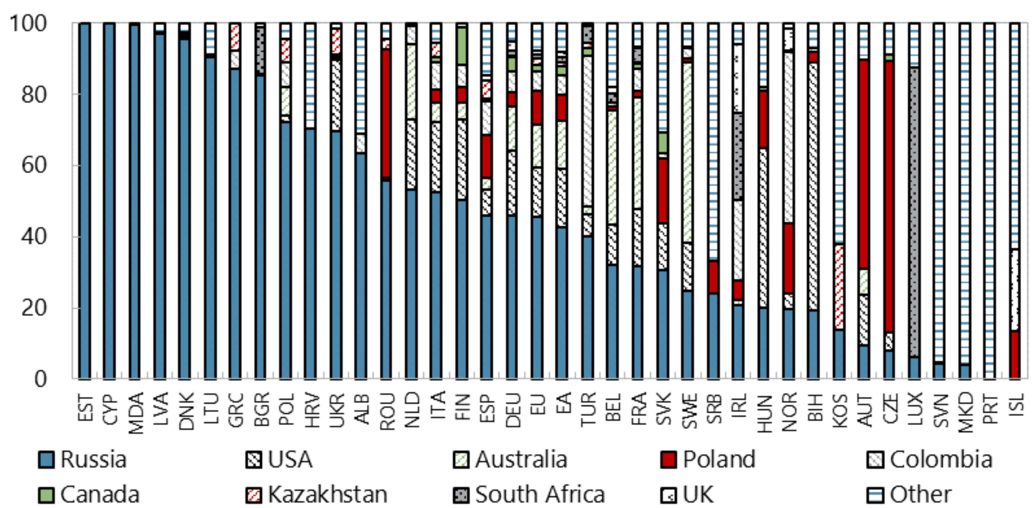
Import of Natural Gas, 2020

(Percent)



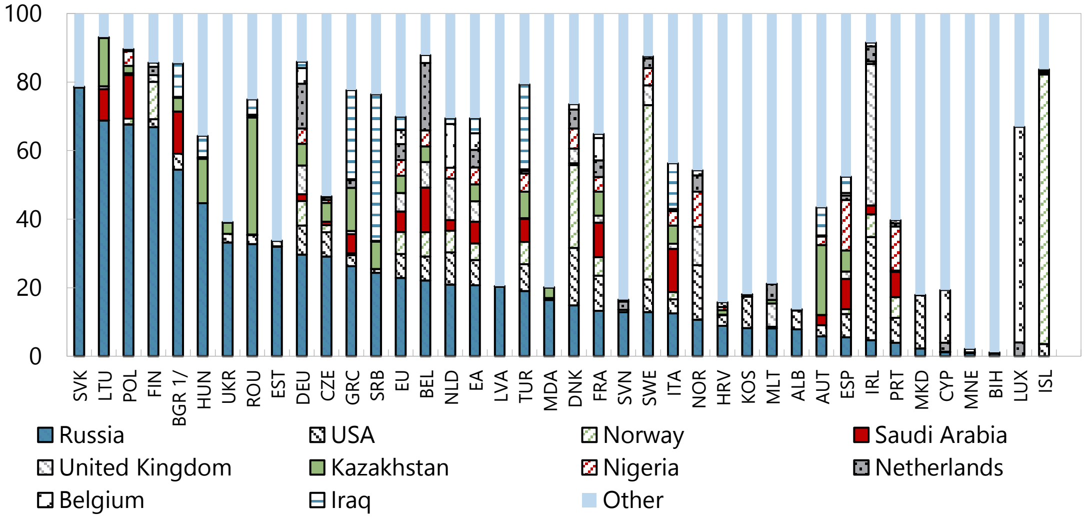
Imports of Solid Fossil Fuels, 2020

(Percent)



Imports of Oil and Petroleum Products, 2020

(Percent)



Source: Eurostat. 1/ Data for Bulgaria is for 2019.

Appendix II

Section I: General Framework

This section proposes a simple model that can be used to inform one's intuition about the possible impact of a sudden decrease in the supply of natural gas (or a large increase in natural gas prices). The economy is assumed to be small and open, takes prices as given, and imports all energy. The model features a representative household that maximizes utility with leisure (l) and consumption (c) as arguments, and where $\eta > 0$, denotes the curvature of the consumption function.

$$U(c,l) = \frac{c^{1-\eta}-1}{1-\eta} + ln(l) \tag{1}$$

Consumption is described by a nested CES aggregator composed of $N-1$ goods (with, $N \geq 2$) and energy (E_H), where $0 < a_i < 1$, are consumption weights and $g > 0$ is the elasticity of substitution between different goods.

$$c = \left[\sum_{i=1}^{N-1} a_i \, c_i^{\,1-\frac{1}{g}} + \left(1 - \sum_{i=1}^{N-1} a_i\right) E_H^{\,1-\frac{1}{g}}\right]^{\frac{1}{1-\frac{1}{g}}} \tag{2}$$

In turn, the household's energy demand is described by a CES aggregator with natural gas G_H and other forms of energy N_H as arguments, where $0 < b < 1$, are energy consumption weights and $s > 0$ is the elasticity of substitution between different types of energy.

$$E_H = \left[b G_H^{\,1-\frac{1}{s}} + (1-b) N_H^{\,1-\frac{1}{s}}\right]^{\frac{1}{1-\frac{1}{s}}} \tag{3}$$

The household's available time (T) is allocated between leisure and labor L_i, $T \geq \sum_{i=1}^{N-1} L_i + l$ in the $N-1$ production activities. The household's budget constraint is given by,

$$p_i \sum_{i=1}^{N-1} y_i - p_{E,i} \sum_{i=1}^{N-1} E_i \geq pc \tag{4}$$

In (4), p_i denotes the price of good i, y_i denotes the output of good i, $p_{E,i}$ is the energy price paid in the production of good i, E_i is the amount of energy used to produce good i, and p denotes the consumer price index. Good i is produced with nested CES technology of the form:

$$y_i = A_i \left[\alpha_i K_i^{\,1-\frac{1}{\gamma_i}} + (1-\alpha_i) L_i^{\,1-\frac{1}{\gamma_i}}\right]^{\frac{1}{1-\frac{1}{\gamma_i}}} \tag{5}$$

In (5), A_i is a scale factor affecting the firm's size, K_i is effective capital used in the production of good i, α_i denotes capital intensity, and γ_i denotes the elasticity of substitution between primary factors of production. Firms will differ on capital intensity, energy intensity, size, on the elasticity of substitution between capital and labor, and between different types of energy. In turn the capital stock used in the production of good i is given by,

$$K_i = \left[\theta_{K,i} \overline{K}_i^{\,1-\frac{1}{\delta_i}} + \theta_{E,i} E_i^{\,1-\frac{1}{\delta_i}}\right]^{\frac{1}{1-\frac{1}{\delta_i}}}, \tag{6}$$

where $\theta_{i,K}, \theta_{i,E} > 0$ are technology parameters, $\overline{K}_i$ denotes physical capital, which is assumed to be fixed as the analysis will be focused in the short-term, and δ_i denotes the elasticity of substitution. Expression (6) suggests that energy and physical capital are complementary, or that in broad terms, that energy use determines the utilization rate of a given physical capital; this is in line with several examples in the literature (e.g., Kormitsilina (2016)). Energy use in the production of good i is given by a CES aggregator of the form:

$$E_i = \left[\beta_i {G_i}^{1-\frac{1}{\sigma_i}} + (1-\beta_i){N_i}^{1-\frac{1}{\sigma_i}}\right]^{\frac{1}{1-\frac{1}{\sigma_i}}} \tag{7}$$

In (7) natural gas is denoted by G_i and other forms of energy are denoted by N_i; $0 < \beta_i < 1$ are energy consumption weights and $\sigma_i > 0$ is the elasticity of substitution between different types of energy.

The $2(N-1)$ first order conditions are given by,

$$\frac{p_i}{p} {A_i}^{1-\frac{1}{\gamma_i}}(1-\alpha_i)\left(\frac{y_i}{L_i}\right)^{\frac{1}{\gamma_i}}\left(\frac{1}{c^\eta}\right) = \frac{1}{l} \tag{8}$$

$$p_i {A_i}^{1-\frac{1}{\gamma_i}}\alpha_i \left(\frac{y_i}{K_i}\right)^{\frac{1}{\gamma_i}}(1-\theta_i)\left(\frac{K_i}{E_i}\right)^{\frac{1}{\delta_i}} = p_{E,i} \tag{9}$$

Expression (8) shows that in an interior equilibrium, the real value of the marginal product of labor multiplied by the marginal utility of consumption should be equal to the marginal utility of leisure. In turn, expression (9) shows that the value of the marginal product of energy needs to be equal to the price of energy.

Given that consumption and energy demand (both for households and in production) are CES aggregators, their price levels will also be CES. In expressions (10)-(12), p_G and p_N denote the international price of natural gas, and that of other forms of energy, respectively.

$$p = \left[\sum_{i=1}^{N-1} {a_i}^g {p_i}^{1-g} + \left(1-\sum_{i=1}^{N-1} a_i\right)^g {p_{E,H}}^{1-g}\right]^{\frac{1}{1-g}} \tag{10}$$

$$p_{E,i} = [{\beta_i}^{\sigma_i} {p_G}^{1-\sigma_i} + (1-\beta_i)^{\sigma_i} {p_N}^{1-\sigma_i}]^{\frac{1}{1-\sigma_i}} \tag{11}$$

$$p_{E,H} = [{b_i}^{s_i} {p_G}^{1-s_i} + (1-b_i)^{s_i} {p_N}^{1-s_i}]^{\frac{1}{1-s_i}} \tag{12}$$

Finally, natural gas demands will be given by,

$$G_i = E_i {\beta_i}^{\sigma_i}\left(\frac{p_G}{p_{E,i}}\right)^{-\sigma_i} \tag{13}$$

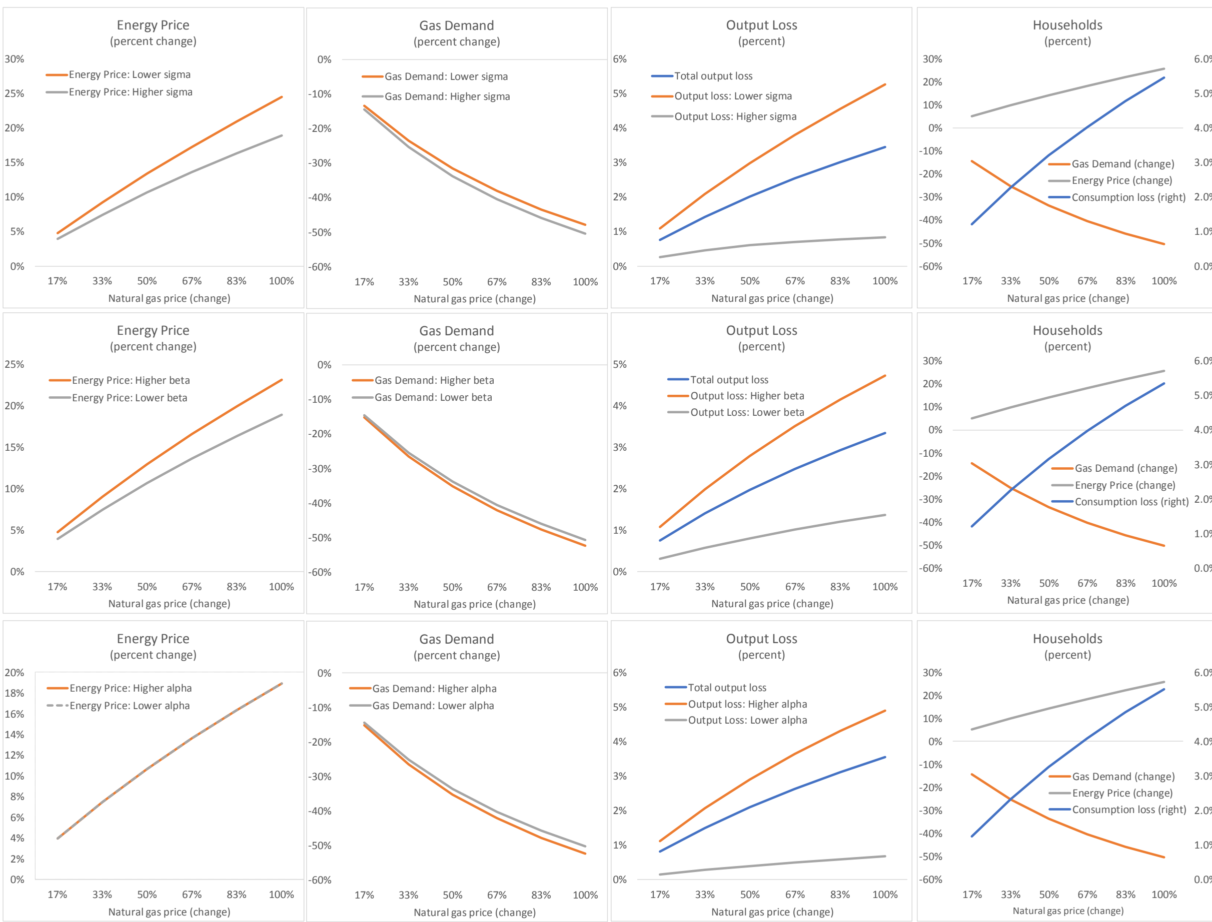
$$G_H = E_H {b_i}^{s_i}\left(\frac{p_G}{p_{E,H}}\right)^{-s_i} \tag{14}$$

Expression (13) denotes natural gas demand for the production of good i, with $i = \{1,2,..N-1\}$, while expression (14) denotes the natural gas demand by the representative household. The economy's total gas demand will then be given by $G = G_H + \sum_{i=1}^{N-1} G_i$.

Impact of a Natural Gas Price Increase

A higher natural gas price would lead to an increase of energy prices for both households and firms. For households, the increase in the overall energy price will depend on the importance of gas in the energy consumption basket, and on the ability of households to substitute natural gas for other forms of energy. Analogously for firms, the increase in the overall energy price that each of them faces will depend on their ability to substitute for other forms of energy (σ_i) and on the firm's gas intensity (β_i): Firms with lower σ_i, and higher β_i will face a higher price of energy. Accordingly, gas demand will decrease more in firms with higher σ_i, and higher β_i, but also in firms with higher capital intensity α_i. In line with this, the value marginal product of labor will decrease more in firms with lower σ_i, and higher β_i, and α_i. Symmetrically, the value of the marginal product of capital will be lower in this type of firms. As a result, these firms will experience a larger decrease in both energy and labor demand, and a higher output loss. Panel xx shows some of these results. The size of the output loss will also depend on the size of different firms: if firms that are more vulnerable to an increase in the natural gas price constitute a significant portion of overall output, then the total output loss will be larger than in a case where vulnerable firms represent a relatively small share of total output.

Sensitivity to Natural Gas Price Increases under alternative calibrations: Select Variables



Source: Authors' calculations

In the case of households, the increase in the natural gas price will result in a higher overall price level, while the decrease in the marginal value product of labor would result in a lower remuneration for work; overall, the higher energy prices will result in a decrease in disposable income and a decline in consumption. Consumption losses will depend on the ability of households to substitute natural gas for other types of energy, and on the capacity to reallocate labor to less vulnerable sectors to attenuate total output losses.

Section II: Specification for Output Estimates

In line with the model in described above, capital and energy are assumed to be complements in production, but to simplify matters, γ_{ij}, δ_{ij}, $\theta_{ij,K}, \theta_{ij,E}$ are all assumed to be equal to one. This results in a Cobb-Douglas production function of the form:

$$y_{ij} = \left(\bar{K}_{ij} E_{ij}\right)^{\alpha_{ij}} L_{ij}{}^{1-\alpha_{ij}}, \tag{15}$$

where y_{ij} denotes output for sector i in country j, $E_{ij} = G_{ij} + R_{ij} + N_{ij}$, and R_{ij} is final electricity demand by sector i in country j. A decline in natural gas supply would then affect available energy directly and indirectly through the use of natural gas in the production of other forms of energy, like electricity.

The impact of a Russian natural gas shut-off on available energy will depend on a given's country capacity to replace Russian natural gas with gas from other sources. In other words, domestic gas supply for country j, $G_j = G_j{}^{RUS} + G_j{}^{other}$; if Russian natural gas imports cease, the change in natural gas supply will be $\widehat{G_j} = \varphi_j{}^{RUS}(\rho_j - 1)$, where $0 \leq \rho_j \leq 1$ is the replacement ratio of Russian imports for country j and $\varphi_j{}^{RUS}$ is the share of Russian natural gas imports in domestic gas supply. Moreover, assuming that the percentage change in natural gas as an input in the production of other forms of energy and for final demand are the same, the change in electricity supply will be equal to $\widehat{R_j} = \varphi^G_{R,j} \widehat{G_j}$, where $\varphi^G_{R,j}$ is the share of natural gas-based electricity generation for country j. The change in energy supply due to an interruption of natural gas imports from Russia would then be given by,

$$\hat{E}_{ij} = \varphi^G_{E,ij} \widehat{G_j} + \varphi^R_{E,ij} \widehat{R_j}\ , \tag{16}$$

where in (16), $\varphi^G_{E,ij}$ represents the share of natural gas in total energy demand by sector i in country j, and $\varphi^R_{E,ij}$ denotes the share of electricity in total energy demand by sector i in country j. Finally, the output loss of an interruption of natural gas imports from Russia for country j will be given by,

$$\hat{y}_j = \sum_{i=1}^{21} \varphi_{ij}\, \alpha_{ij} \hat{E}_{ij}\ , \tag{17}$$

where in (17), φ_{ij} denotes sector's i share in country j's GDP.[25]

We use Eurostat's Supply-Use and Gross value-added data for 2019 to calibrate φ_{ij} and α_{ij}, and Eurostat's energy balance data for 2019 to calibrate $\varphi^G_{E,ij}$, $\varphi^R_{E,ij}$, and $\varphi^G_{R,j}$, as well as Eurostat import data to calibrate $\varphi_j{}^{RUS}$.

Demand spillovers

While the formulation above focuses on the impact of a decline in natural gas supply on output, it does not capture losses due to demand spillovers. Then, to supplement the analysis above, we consider a simple setting with a Keynesian flavor similar to that in Frenkel and Razin (1996):

$$\Delta y_j = \mu_j\left(\Delta X_j + l_j\right)\ , \tag{18}$$

[25] The output loss for the sector "electricity, gas, water and air conditioning" also captures the decline in consumption of gas and electricity by households, which is assumed to be affected to the same extent as that of productive sectors.

where in (18) Δy_j represents the change in output of country j, ΔX_j are the change in exports by country j, l_j denotes the initial output loss due to a decline in natural gas supply, and $\mu_j = 1/1 - c_j + m_j$ is the demand multiplier with c_j being the propensity to consume and m_j the propensity to import. In turn,

$$\Delta X_j = \sum_{i=1}^{N} m_i \phi_{ij} \Delta y_i \qquad (19)$$

In (19), ϕ_{ij} represents the share of imports by country i from country j and N is the number of countries (or regions) in the world. Expressions (18) and (19) result in a system of N equations with N unknowns of the form $\Gamma\, \mathbf{\Delta y} = \mathrm{l}$, where $\mathbf{\Delta y}$ is a Nx1 vector of output changes, l is a Nx1 vector of initial output losses, and Γ is a NxN matrix where $\Gamma_{ii} = 1 - c_i + m_i$ and $\Gamma_{ij} = -m_j \phi_{ji}$.
Total output losses would be given by $\mathbf{\Delta y} = \Gamma^{-1}\,\mathrm{l}$, where the contribution of demand spillovers to output loss would be $\Delta y_j - l_j$.

To assess demand spillovers, we calibrate c_i , m_i and ϕ_{ij} using Eurostat and Comtrade data for 2019 for the 20 select European countries in our sample, plus two regional aggregates (the “rest of Europe” and the “rest of the world”). We further calibrate l to be a uniform fraction, $0 < \vartheta < 1$, of the output loss vector resulting from (17) such that $\mathbf{\Delta y}\, \mathbf{g}'$ is equal to the projected regional decline in natural gas, where $\mathbf{g}$ is a Nx1 vector composed by the natural gas intensities for all countries, g_i.

Appendix III

Table A.IV.1: Aggregate Output Effects for Individual EU Countries and the Aggregate EU Based on the First Approach (12-month percentage point deviation from the baseline)

Aggregate Output Effects (Percent)

Country	Scenario 1 Substitution of LNG across ROW, weighted elasticity	Scenario 2 Substitution of LNG across ROW, minimum elasticity	Scenario 3 No LNG substitution, weighted elasticity	Scenario 4 No LNG substitution, minimum elasticity
Austria	-0.3	-0.4	-1.0	-2.1
Belgium	-0.5	-0.6	-1.6	-3.1
Bulgaria	-0.5	-0.7	-1.9	-4.0
Croatia	-0.7	-0.9	-2.2	-4.5
Czech Rep.	-0.5	-0.6	-1.8	-3.4
Denmark	-0.1	-0.2	-0.4	-0.8
Estonia	-0.2	-0.3	-0.7	-1.4
Finland	-0.1	-0.2	-0.4	-0.8
France	-0.2	-0.3	-0.8	-1.4
Germany	-0.4	-0.4	-1.3	-2.4
Greece	-0.4	-0.5	-1.4	-2.9
Hungary	-1.1	-1.2	-3.4	-6.3
Ireland	-0.3	-0.4	-0.8	-1.8
Italy	-0.6	-0.7	-2.1	-3.9
Latvia	-0.4	-0.5	-1.5	-3.0
Lithuania	-0.6	-0.6	-2.0	-3.4
Lux.	-0.2	-0.2	-0.7	-1.4
Malta	-0.3	-0.5	-1.2	-2.6
Netherland:	-0.8	-1.0	-1.9	-4.0
Poland	-0.6	-0.7	-1.8	-3.7
Portugal	-0.3	-0.4	-1.0	-2.3
Romania	-0.5	-0.7	0.1	0.7
Slovakia	-0.8	-0.8	-2.6	-4.6
Slovenia	-0.2	-0.3	-0.7	-1.6
Spain	-0.3	-0.4	-1.1	-2.5
Sweden	0.0	0.0	-0.1	-0.2
EU	-0.4	-0.5	-1.4	-0.7
UK	-0.3	-0.4	-0.8	-1.9

Source: Albrizio et al (2022). Notes: These results are derived from the global LNG model in conjuncture with the Baqaee and Farhi (2019) multisectoral general equilibrium model and its sufficient statistic. Scenarios 1 and 2 assume a -16.8 percent supply shock to the global LNG market, while Scenarios 3 and 4 assume -34.5 percent supply shock based on the scope of the EU market only. Scenarios 1 and 3 employ sector weighted demand elasticities. Scenarios 2 and 4 use the minimum sectoral demand elasticity (0.084 for manufacturing) for all sectors. Scenario 1 implies a 111 percent increase in natural gas prices compared to Q1 2022, Scenario 2 a 221 percent rise, Scenario 3 a 367 percent increase, and Scenario 4 a 1,011 percent increase.

Appendix IV

Table A.V.1. Energy Savings and Costing of Measures to Reduce Dependence on Russian Gas in addition to the Fit-for-55 Package

Measure	Natural Gas Saving (bcm, 2030)	Investment (EUR bn, 2022-2030)
All Fit-for-55 measures by 2030	116	
Short-term preparedness		
Diversification (additional LNG using existing infrastructure)	50	
Diversification of pipeline imports using existing infrastructu	10	
Delayed phase-out and more operating hours for coal	24	2
Abandoned phase-out nuclear plants	7	0.5
Fuel switch in the residential and service sectors	9	
EU Save: Demand measures (behavior)	(10)	
EU Save: Industry curtailment		
Medium-term (until 2027)		
New LNG infrastructure and pipeline corridors		10
Additional investments in the power grid and storage		39
Biomass in power generation	1	2
Energy Efficiency and Heat Pumps	37	56
Photovoltaic and wind	21	86
Sustainable biomethane	17	37
Reduced use in industry	12	41
Long-term (by 2027 and beyond)		
Renewable hydrogen	27	27
Total	310	300

Source: European Commission, REPowerEU Plan.

Table A.V.2. Overview of REPowerEU Plan

Pillar	Specific Measures
Reducing energy consumption	In the near-term, the Commission envisages a 5 percent reduction in gas and oil consumption from a new 'Playing My Part' public information campaign, aimed at households.
	Over the medium term, regulatory measures to improve the energy efficiency of buildings and to enhance product sustainability are expected to lead to further savings. Concretely, the EC proposes to increase the planned energy demand reduction by 2030 (relative to 2020) in the energy efficiency directive from 9 to 13 percent.
Diversifying supplies	A new EU Energy Platform has been established to support voluntary joint purchases of gas, LNG, and hydrogen. Operationally, the platform primarily supports information sharing between members states.
	The EC is considering a voluntary 'joint purchasing mechanism' to negotiate gas import contracts on behalf of multiple countries.
Accelerating the green transition: *The EC proposes to increase the EU's target for renewable energy generation from 40 to 45 percent of total energy production by 2030. This would also offset the impact of higher coal use in the near-term: GHG emissions will be unchanged in 2030 relative to Fit for 55.*	Solar is a key pillar of the more ambitious renewable roll-out, with the EC aiming to double installed capacity by 2025 from today and again by 2030. Likewise, wind energy rollout is to be accelerated by significantly streamlining permitting.
	Accelerate the heat pump rollout, with an accompanying push to increase domestic European production networks.
	An ambitious target for green hydrogen production and imports of a total of 20 million tonnes by 2030 was set. This will require investments in the order of 25-50 billion Euros. Detailed infrastructure needs will be mapped by March 2023.
	Biomethane gas production is planned to ramp up to 35 bcm, at a cost of 37 billion Euros by 2030.
	National permitting procedures are to be significantly facilitated in line with guidance provided by the EC,
Improved connectivity within Europe	Ongoing infrastructure improvements (e.g., the gas interconnector between Poland and Lithuania and the Baltic pipeline between Denmark and Poland) will add transmission capacity in 2022. Recently acquired floating LNG terminals in Germany and Finland will ease infrastructure bottlenecks during 2023.
	Additional priority projects at a cost of €10bn were identified (e.g., capacity for flows from France and Belgium into Germany) which would remove internal infrastructure bottlenecks over the next few years.
	Investment is also planned in the electrical power grid (€39bn), consistent with a greater reliance on renewable power generation.

Emergency preparedness	To prepare for a possible disruption scenarios the following steps are proposed: (i) swift adoption of the proposed storage regulation (mandating minimum 80 percent storage levels by October 1), (ii) short-term energy savings efforts, (iii) member states update contingency plans; (iv) ask transmission systems operators (TSOs) to fast-track technical measures which can increase the reverse flow capacities from west to east by next winter and (v) conclude outstanding bilateral solidarity agreements.

References

Albrizio, Silvia, John Bluedorn, Christoffer Koch, Andrea Pescatori, and Martin Stuermer (2022). “Market size and supply disruptions: Sharing the pain from a potential Russian gas shut-off to the European Union.” IMF Working Paper.

Amaglobeli, David, Emine Hanedar; Gee Hee Hong; Celine Theveno (2022). Fiscal Policy for Mitigating the Social Impact of High Energy and Food Prices. MF Notes No 2022/001

Andersen, T. B., Nilsen, O. B., and Tveteras, R. (2011). How is demand for natural gas determined across European industrial sectors? *Energy Policy*, 39(9):5499–5508.

Asche, Frank, Odd Bjarte Nilsen and Ragnar Tveterås. 2008. “Natural Gas Demand in the European Household Sector.” *The Energy Journal* 29 (3): 27–46.

Atkeson, Andrew and Patrick Kehoe (1999), “Models of Energy Use: Putty-Putty versus Putty-Clay”, The American Economic Review, Vol. 89, No.4, September.

Auffhammer, Maximilian, and Edward Rubin. 2018. “Natural Gas Price Elasticities and Optimal Cost Recovery Under Consumer Heterogeneity: Evidence from 300 Million Natural Gas Bills.” NBER Working Paper 24295, National Bureau of Economic Research, Cambridge, MA.

Bachmann, R., Baqaee, D., Bayer, C., Kuhn, M., Loeschel, Peichl, A., Pittel, K., Moll, B., and Schularick, M. (2022). “What if? The economic effects for Germany of a stop of energy imports from Russia”. ECONtribute Policy Brief, 28.

Baqaee, D. and Farhi, E. (2019). “Networks, barriers, and trade”. Working Paper 26108, National Bureau of Economic Research.

Baqaee, D., Moll, B., Landais, C., and Martin, P. (2022). “The economic consequences of a stop of energy imports from Russia”. Conseil d’Analyse Economique Focus, 84.

Bundesbank 2022a. ‘Additional disruptions to the German economy in the event of an energy embargo”. Monthly Report, April.

_____ 2022b. ‘Possible development of the German economy in an adverse risk scenario”. Monthly Report, June.

Chepeliev, M., Hertel, T., and van der Mensbrugghe, D. (2022). “Cutting Russia’s fossil fuel exports: Short-term pain for long-term pain’. VoxEU Blog, March 9.

ENTSOG, 2022. “Summer Supply Outlook, April 11”.

European Central Bank, 2022a (March). ‘Natural gas dependence and risks to euro area activity”. Box 4, Economic Bulletin, Issue 1/2022. Prepared by Vanessa Gunnella, Valerie Jarvis, Richard Morris and Máté Tóth.

_____, 2022b (June). “A downside scenario related to the economic impact of Russia’s military aggression in Ukraine”. Box 3, Eurosystem staff macroeconomic projections for the euro area.

European Commission. 2022. “Secure Gas Supplies: EU Legislation Helps to Prevent and Respond to Potential Gas Supply Disruptions.” Brussels, Belgium. April 2022.

_____. 2022. “European Economic Forecast: Spring 2022”,

European Network of Transmission System Operators for Gas (ENTSOG). 2022. “ENTSOG Summer Supply Outlook.” Brussels.

Frenkel, Jacob and Assaf Razin (1996), Fiscal Policies and Growth in the World Economy. Third Edition. MIT Press.

Gerarden, Todd, Richard Newell, and Robert Stavins (2015), “Deconstructing the Energy-Efficiency Gap: Conceptual Frameworks and Evidence”, The American Economic Review, Vol. 105, No.5, Papers and Proceedings, May.

German Council of Economic Experts, 2022a. “Effects of a possible end to energy supplies from Russia on energy security and economic output”. Economic Outlook, March. Wiesbaden.

German Council of Economic Experts, 2022b. “A potential sudden stop of energy imports from Russia: Effects on energy security and economic output in Germany and the EU”. Working Paper 01/202. April 2022.

Honjo, Keita, & Ashina, Shuichi (2017). “Impacts of the 2011 Tohoku earthquake on electricity demand in Japan State space approach.” Proceedings of the 33rd conference on energy, economy, and environment, (p. 620). Japan

International Emergency Agency (IEA). 2022. “Gas Market Report, Q1-2022.” France.

_____ 2022. “Electricity Market Report.” France.

International Monetary Fund (IMF). 2022. *Fiscal Monitor: Fiscal Policy from Pandemic to War*. Washington, DC, April.

Joint Economic Forecast, 2022. From Pandemic to Energy Crisis: Economy and Politics under Permanent Stress. Spring Joint Economic Forecast No. 1-2022. Prepared by the German Institute for Economic Research (DIW Berlin), the ifo Institute (Munich), the Kiel Institute for the World Economy (IfW Kiel), the Halle Institute for Economic Research (IWH), and RWI (Essen).

Kemfert, Claudia (1998), “Estimated substitution elasticities of a nested CES production approach for Germany”, Energy Economics 20, pp. 249-264.

Kormilitsina, Anna (2016) “An amplification mechanism in a model of energy”, The Canadian Journal of Economics, Vol. 49, No.4, November.

Krebs, T. (2022), “Auswirkungen eines Erdgasembargos auf die gesamtwirtschaftliche Produktion in Deutschland”. Nr. 79 , Mai 2022, Hans-Böckler-Stiftung

Kurmayer, Nikolaus J. "Germany Rules Out Prolonging its Nuclear Power Plants."

Lan, T., G. Sher, and J. Zhou (2022). “The economic impacts of a potential shutoff in Russian gas”. *IMF Working Paper*, International Monetary Fund.

OECD, 2022 (March). “Economic and Social Impacts and Policy Implications of the War in Ukraine”, OECD Economic Outlook, Interim ReportLan, Ting., Galen Sher and Jing Zhou, 2022. “THE ECONOMIC IMPACTS OF A POTENTIAL SHUTOFF IN RUSSIAN GAS”, Selected Issues Paper, Germany 2022 Article IV Consultation

Naftogaz Ukrtransgaz. 2022. “Natural Gas Storage in Ukraine, BCM (as of 01.02.2022).” Kyiv.

Reuters. 2022. “Netherlands Nearly Doubles Estimated Groningen Gas Output to Secure Supply.” Amsterdam.

Schnittker, Christian, Shirley Feng, Alexandre Stott, 2022. “The Impact of Gas Shortages on the European Economy”, Goldman Sachs Economics Research.

U.S. Energy Information Administration (EIA). 2021. “Price Elasticity for Energy Use in Buildings in the United States.” Washington, DC.