May 24, 2022

CSH Policy Brief

Austria without Russian natural gas?

Expected economic impacts of a drastic gas supply shock and mitigation strategies

As the war in Ukraine continues, there is an increasing threat of a drastic reduction of Russian gas supply to the European Union (EU). A sudden drop in gas trade between EU countries and Russia could arise from an EU-imposed import embargo, a Russian export embargo or by pipeline malfunction due to the military conflict. Natural gas imports from Russia account for 80% of Austria's annual gas consumption, and for roughly 38% of the EU's gas consumption. This policy brief discusses the likely short-term impacts on the Austrian economy resulting from an immediate import stop of Russian natural gas, as well as possible actions for mitigation and their effects.

Approach. *We assume a total stop of Russian gas exports to the EU starting on June 1, 2022 and analyze the resulting impacts on Austria's economy. Our results are based on three modeling steps.*

(1) Detailed analysis of the possible countermeasures on the supply and demand side to mitigate the immediate shortfall in Russian gas supply.

(2) Mapping the net reduction in gas supply to industrial sectors to quantify direct economic shocks and expected relative reductions in gross output.

(3) Use these direct economic shocks to initialize a dynamic out-of-equilibrium macroeconomic input-output model to estimate overall economic impacts (direct shocks + indirect effects through supply relations between industry sectors).

We distinguish and analyze two opposing scenarios on how the shortfall in Russian gas supply is dealt with: (A) EU-wide cooperation and (B) an uncoordinated scenario.

Results. *The main results are presented in Table 1.*

- ***Total consumption.*** *In 2021 Austria consumed 9.34 billion cubic meters (bcm) of natural gas. A Russian gas supply stop would mean an 80% decrease in availability of 7.47 bcm to 1.87 bcm for Austrian consumption. See Section 1.*
- ***Additional imports.*** *In Scenario A, 5.20 bcm (corresponding to 55.7% of annual consumption) could be imported from alternative sources other than Russia to Austria within the next year. In Scenario B only 2.65 bcm (28.4%) could be imported additionally. See Sections 2.1.*
- ***Storage.*** *We estimate total storage levels of the EU and Austria to be 58.02 bcm and 3.56 bcm, respectively, on June 1 when the hypothetical Russian import stop starts. In Scenario A, Austria would be allocated 0.64 bcm of the gas extracted from its storage (6.9% of annual consumption), while it might extract 1.40 bcm (15%) in Scenario B. See Section 2.2.*
- ***Aggregate gas shock.*** *Taking additional imports and storage extraction into account, the total aggregate gas shock is reduced from –80% to –17.4% and –36.6% in Scenario A and Scenario B, respectively.*
- ***Fuel switching.*** *Independent of the scenario, there is a high potential to reduce gas*

consumption by switching gas power plants to oil in the short-term, possibly in the order of 10.5% of Austria's annual gas consumption (0.98 bcm). See Section 2.3.

- ***Other savings.*** *Behavioral changes, like a 1°C reduction in average room temperature in households, have the potential of saving around 0.11 bcm of gas demand. Reduced supply of natural gas also reduces gas needs for operating pipeline infrastructures by another 0.05 bcm and 0.11 bcm in Scenario A and B, respectively. See Sections 2.4–2.5.*
- ***Total gas shortfall after demand and supply side measures.*** *In total this means a reduction of gas availability for Austria over the coming year of 0.49 bcm (5.2% of annual consumption) in Scenario A, and 2.21 bcm (23.7%) in Scenario B. See Section 2.6.*
- ***Industry gas supply reduction.*** *After serving protected customers, such as households and power plants, the remaining gas is allocated to the industry. For Scenario A we observe a reduction of 10.4% of gas supply for the Austrian industry, due to a strong and coordinated policy response. For Scenario B we find a 53.3% reduction of industry gas supply compared to normal levels. See Section 2.7.*
- ***Direct economic output shock.*** *The 10.4% gas supply reduction to industry in Scenario A amounts to a direct aggregate output shock of –1.1%. In Scenario B the direct aggregate output shock amounts to –5.6%. For industry-specific output shocks, see Section 3.1.*
- ***Total economic impact.*** *Taking into account indirect effects, we arrive at an estimate of –1.9% for total aggregate output reduction in Scenario A. In Scenario B the total aggregate output reduction is –9.1%. See Section 3.2.*

Our results are subject to several limitations which are discussed in Section 4.

	Scenario A EU-cooperation	**Scenario B Uncoordinated**
Annual gas consumption (Austria 2021)	**100% (9.34 bcm)**	
– Russian import stop	–80% (–7.47 bcm)	
+ Additional imports	55.7% (5.20 bcm)	28.4% (2.65 bcm)
+ Storage	6.9% (0.64 bcm)	15.0% (1.40 bcm)
Aggregate gas shock	**–17.4% (–1.63 bcm)**	**–36.6% (–3.42 bcm)**
+ Fuel switching (electricity and CHP)	10.5% (0.98 bcm)	
+ Savings heating (excluding industry)	1.2% (0.11 bcm)	
+ Savings from operating pipelines	0.5% (0.05 bcm)	1.2% (0.11 bcm)
Gas shortfall after demand and supply measures	**–5.2% (–0.49 bcm)**	**–23.7% (–2.21 bcm)**
Industry gas supply reduction	**–10.4% ***	**–53.3%***

Direct aggregate output shock	**–1.1% ****	**–5.6%****
Total aggregate output impact	**–1.9% ****	**–9.1%****

Table 1. Summary of scenarios and results. Reported percentages are expressed with respect to annual gas consumption when deriving aggregate gas supply reductions. *Percentages of *Industry gas supply reduction* refers to the relative reductions in industry gas supply after room heating-related measures have been considered. **Economic impacts in % refer to relative reductions in aggregate gross output from the pre-shock state. CHP is short for combined power and heat.

Conclusions

Our results suggest that in the EU-cooperation Scenario A, losses for the Austrian economy are noticeable, but manageable. Overall economic impacts result in a decrease of gross output of 1.9% which translates to 1.11 billion EUR per month. These losses are significantly smaller than the economic impact of the first wave of the Covid-19 pandemic, where GDP in the second quarter of 2020 was –14% smaller compared to pre-shock levels. In the uncoordinated Scenario B, economic impacts are more severe, resulting in a 9.1% reduction of Austrian gross output. This amounts to a loss of about 5.31 billion EUR in gross output per month. We point out, however, that losses could be substantially larger, if no strong measures are put in place to mitigate the initial gas supply shock.

The amount of natural gas that can be supplied to industry in the scenario of a 100% loss of Russian gas imports is highly sensitive with respect to the aggregate gas supply reduction after alternative sources are considered. For a wide range of plausible scenarios, an additional reduction in aggregate gas availability of 1% translates into an additional 2.2% reduction in industry gas supply.

Impacts on aggregate gross economic output are sensitive with respect to aggregate gas supply reductions. For modest aggregate shocks to gas supply (below 12%) we observe no adverse impact on gross output, given the implementation of adequate countermeasures. For plausible ranges of gas shocks an additional 1% reduction in gas supply leads to a 0.3% reduction of aggregate gross output.

The expected economic impacts resulting from a Russian gas import stop strongly depend on the mitigation measures that will be put in place. These results highlight the importance of EU-wide cooperation and the wide range of specific policy measures that mitigate adverse economic consequences. We list several policy implications below and discuss them in detail in Section 5.2.

1. *Need of EU-wide coordination in gas supply policies*
2. *Prepare for fuel switching of power plants over the summer wherever possible*
3. *Incentivize changing production processes to less gas intensive production*
4. *Incentivize changing heating systems to heat pumps, and geothermal heating and biomass*
5. *Incentivize investments in renewable energy technologies and storage*
6. *Encourage the population to actively engage in gas saving behavior*
7. *An embargo on Russian gas could be economically viable given the immense costs of war*

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Acknowledgements

We greatly appreciate the continuous support of Maria del-Rio Chanona and Christian Diem whose inputs substantially improved this policy brief. We are also grateful to Stefan Kitzler, François Lafond, Marco Pangallo, Frank Neffke, Joern Huenteler, Karl Steininger and Kavita Surana for helpful feedback. We thank Philip Rodemeyer (AGCS) and Alexander Kirchner (Wien Energie) for providing us with their expertise and background information. Finally, a special thanks goes to Liuhuaying Yang and Verena Ahne for their help with visualizing and preparing this policy brief for publication.

About the CSH

The Complexity Science Hub Vienna was founded with the aim of using Big Data for the benefit of society. Among other things, the CSH systematically and strategically prepares large data sets so that they can be used in agent-based models. These simulations allow the effects of decisions in complex situations to be tested in advance and systematically assessed. Thus, the CSH provides fact-based foundations for evidence-based governance.

***CSH Policy Briefs** present socially relevant statements that can be derived from CSH research results.*

Results in detail

1 Gas consumption overview

1.1 Austria's dependence on Russian gas in the European context

EU-wide gas consumption amounted to 412 billion cubic meters (bcm) in 2021 (4% increase to 2020) of which Austria's gas consumption accounts for 2.3% (Figure 1, left panel), corresponding to 9.34 bcm in 2021 (5% increase to 2020).[1] While 155 bcm (38%) of EU's annual consumption comes from Russia, Austria's dependency is considerably higher – Austria imports 7.2 bcm from Russia, accounting for 80% of Austria's overall gas consumption[2] and 18.5% of Austrias primary energy consumption (Statistik Austria, 2022a). Without taking any further mitigation measures, Austria's high exposure towards Russian gas could dramatically compromise its short-term energy security in case of a sudden Russian gas supply stop. Its relatively small share of EU-wide gas consumption, however, indicates that European cooperation measures can considerably mitigate economic impacts.

1.2 Natural gas consumption in Austria

Austria's annual gas consumption has remained relatively stable between 8.7 and 9.5 bcm over the last six years (Figure 1, right panel). A large share of natural gas is used for heating and power generation, in particular in the winter months, leading to a strong seasonal component in the intra-annual gas consumption (Figure 1, right panel inset). This seasonality means that the timing of a possible gas supply shock is crucial in how strongly it will impact society.

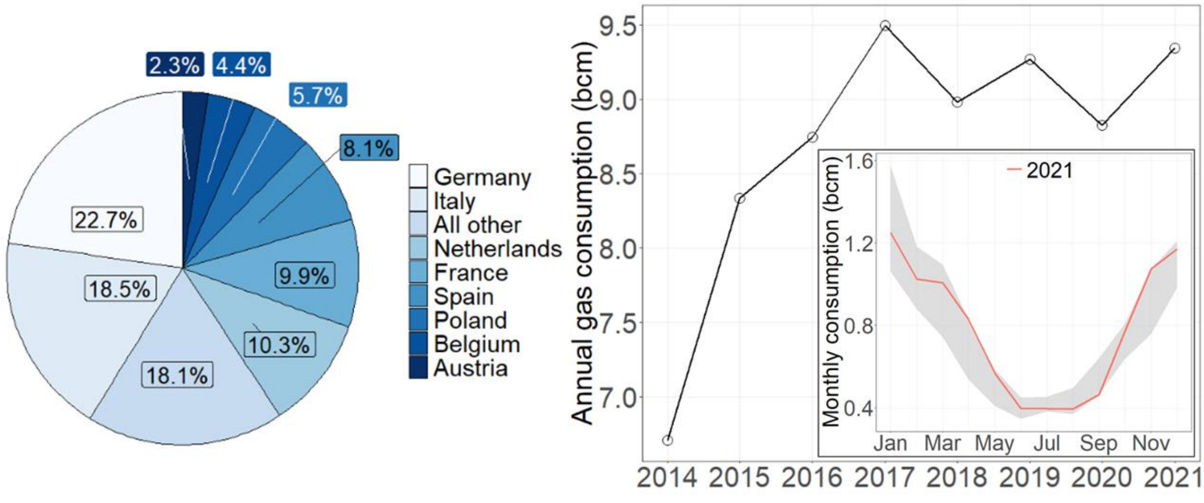

Figure 1. (Left) EU-27 gas consumption in 2021. Austria only accounts for slightly above 2% of EU's consumption but ranks among the countries with the highest Russian gas dependency. **(Right) Aggregate gas consumption over time.** Over the last six years Austria's annual consumption of natural gas fluctuated between 8.7 and 9.5 bcm. **(Inset):** There is a strong seasonality in gas consumption. The gray shade indicates the monthly min–max range between 2014–2021; the red line is the monthly consumption in 2021.

Figure 2 shows the gas consumption in Austria across consumer types. The right chart shows relative consumption shares of consumer types according to the energy balance (Statistik Austria 2022b). The

[1] Data from the Eurostat natural gas supply statistics (data code: nrg_cb_gasm, accessed 05 May 2022).

[2] Using data from the European Union Agency for the Cooperation of Energy Regulators (ACER), we estimate Austria's gas dependency on Russia (Russian imports as share of total inland consumption) to be 80.02% in 2019.

largest share of 44.1% is used by industry, followed by households (19.5%), combined heat and power (CHP, 17.5%), and electricity (8.8%). The remaining 10.1% are split between the service and public sector, transport in pipelines, and heating plants. The chart on the left shows the gas usage in the industry, according to official statistics (Statistik Austria 2022a). The largest share, 61.7%, is used for process heat, followed by 27.8% for room heat, and 10.4% for non-energetic uses (e.g., as a chemical reactant).

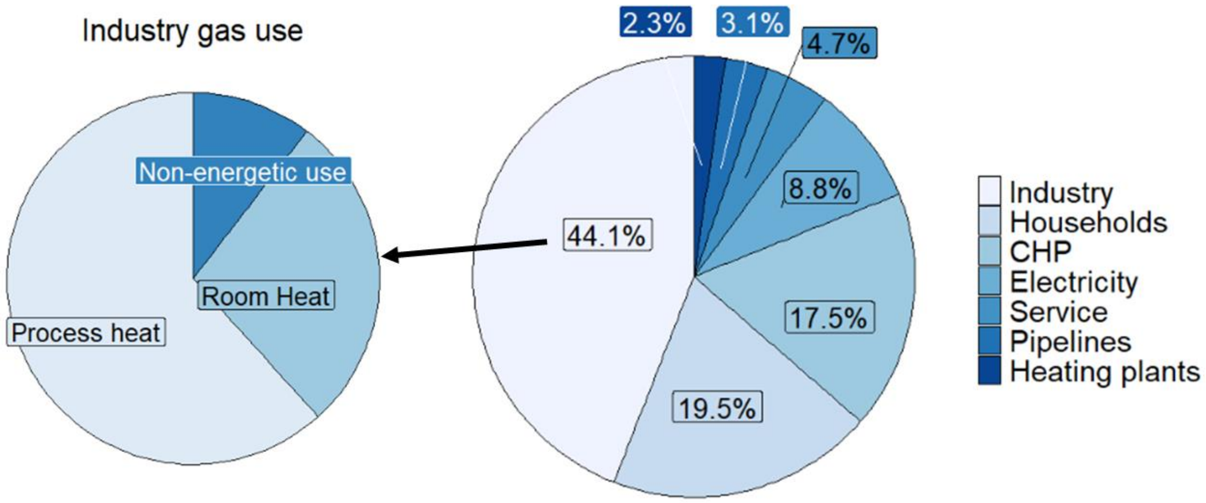

Figure 2. Relative gas consumption across consumer types. Data from Statistik Austria 2022b. “CHP” stands for *combined heat and power*, “Pipelines” refer to the distribution of gas, and “Service” includes the service sectors and the public sector. The left chart zooms into industry-specific consumption types, where we allocated “non-energetic use” to the industry sector ourselves. The numbers for room and process heat are from Statistik Austria 2022a.

2 Supply and demand measures for mitigating gas import reductions

Here we consider a complete halt of Russian gas imports, which translates into an 80% shock to Austria’s annual consumption. While this provides an upper bound to the gas supply shock, the realized supply shock will be lower due to mitigation measures that can and will be put in place, including additional imports of liquified natural gas (LNG) and gas from different trade partners, storage management, and fuel switching in the power and heat sector.

We focus on two main scenarios: In an *EU-cooperation* scenario (Scenario A), additional natural gas resources on the EU-level are distributed in a coordinated way to avoid excessively high import shocks for particularly exposed countries. In this scenario storage levels are also cooperatively managed. In this scenario every member state must bear reductions in its gas consumption, even if not highly exposed to Russian gas imports. We argue that this scenario is nevertheless plausible given that such a policy could avoid large economic downturns of several member states with likely negative repercussions to non-exposed countries via trade relationships and the common currency.

In an *uncoordinated* scenario (Scenario B), Austria mitigates the Russian import shock by buying gas from alternative sources *without* coordinating with other EU member states and manages its gas storage capacities individually. Below we present the main pillars of the two scenarios but present the details of our calculations in the online technical appendix (Pichler et al., 2022).

2.1 Alternative gas imports

To assess the potential of imports from alternative sources, we build upon the recently proposed EU

Commission strategy to reduce Russian gas imports by 2/3 until the end of the year (European Commission (2022). This goal involves importing an additional 50 bcm of LNG this year, as well as importing an additional 10 bcm via existing pipeline infrastructure from Norway, Azerbaijan, and Algeria. The proposed strategy on tapping alternative import sources has been considered as highly ambitious, but feasible in principle (Fulwood et al., 2022). The International Energy Agency (IEA) estimates a technical potential of an additional 60 bcm of LNG imports in the near-term (IEA, 2022).

We take a moderately conservative approach and assume that the EU falls 10% short of its goal of 50 bcm of additional imports of LNG by the end of 2022, while it realizes its additional 10 bcm pipeline import goal. Thus, additional EU-wide gas imports amount to 55 bcm, compensating for more than a third of Russian gas imports.

While we take the European gas imports as given, we distinguish two cases of how much of the additional EU-wide gas supply can be accessed by Austria.

- In the *EU-cooperation* Scenario A we assume that member states face a common shock and distribute existing and additional gas resources such that every country faces the same relative reduction in its gas supply. Given the overall reduction of 100 bcm and EU-wide gas consumption of 412 bcm, the gas supply reduction for every country amounts to 24.3% compared to usual levels. The gas supply shock to Austria is then reduced from 80% to 24.3%, resulting in 55.7% or 9.34 bcm * 55.7% = 5.20 bcm of additional imports.
- In the *uncoordinated* Scenario B each member state individually tries to substitute its current Russian imports from other countries. This means that Austria would demand 7.47 bcm of gas from the market. Since only 55 bcm of 155 bcm of Russian gas can be compensated on an EU-wide level, we assume Austria would only receive 7.47 bcm * 55/155 = 2.65 bcm (28.4% of annual demand). This corresponds to a scenario, where each member state places demand equaling its Russian import shortfall on international markets. Due to constrained supplies, however, every member state is rationed on a pro-rata basis. 2.65 bcm of additional imports might be optimistic in an uncooperative scenario, as Austria depends strongly on available capacities of pipeline and LNG port infrastructures of other countries, which might not be willing to pass through gas to foreign consumers.

The difference in additional gas imports between the *uncoordinated* and the *EU-cooperation* scenario is substantial, amounting to about 27.3% of Austria's annual gas consumption. This emphasizes high uncertainty associated with any estimate of economic impacts from a sudden Russian gas import stop. Both scenarios, and any outcome in between, could arguably materialize. Since the realized scenario depends largely on political factors that are impossible to predict, the extent to which Austrian gas availability will be reduced is not merely a question of market mechanisms and technical feasibility, but also a key policy variable.

2.2 Storage management

To mitigate gas shortages, the EU and Austria have passed laws that aim at filling storage levels to 80% of capacity before the coming winter[3]. Austria's gas storage accounts for almost 9% of EU total storage

[3] For the EU regulation see https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52022PC0135. See https://www.parlament.gv.at/PAKT/VHG/XXVII/BNR/BNR_00531/index.shtml for the Austrian Energielenkungsgesetz (both links accessed on May 20, 2022).

capacities[4], and given its 2.3% share of EU gas consumption, has a comparatively large capacity to smooth out varying gas in- and outflows. To understand the storage management potential for shock mitigation, we use a simple storage model, which we briefly discuss below, but present in full detail in the online appendix (Pichler et al., 2022). We again distinguish between the *EU-cooperation* Scenario A and the *uncoordinated* Scenario B. In the former we assume that the Austrian gas storage is only used for managing national consumption, while in the latter we assume that the usage of gas storage is coordinated on a European level.

Our gas storage model assumes that natural gas imports and Austria's own gas exploration is constant throughout the year, i.e. the net inflow does not show a seasonality between summer and winter months. In the *uncoordinated* scenario we use the nine-year average from 2012–2021 consumption on a daily resolution[5] to model the annual outflow. The difference of daily in- and outflow corresponds to the storage injection or extraction, respectively, and allows us to predict daily storage levels. For the calculations below, we assume that the shortfall of Russian gas starts on June 1, 2022 with an estimated storage level of 3.56 bcm (32.7% full), predicted by extrapolating the average injection rate since May 1, 2022. We use the reduced in- and outflow as described in Table 1 and set the net extraction between June 1, 2022 and May 31, 2023 to 2.11 bcm. The net storage extraction is chosen such that the minimum storage level in our model is well above the historic minimum of 1.35 bcm in March 2022. According to the model we hit a minimum storage level of 1.40 bcm in April 2023.

Note that we assume that the Austrian storage is only used to provide natural gas for inland consumption which is currently not the case. For example, Germany has rented parts of Austrian storage – a fact that we neglect in the *uncoordinated* Scenario B. Thus, our estimate of the extent to which storage can be used for mitigating import shortfalls might be optimistic. Note that, in a truly uncoordinated scenario, if Austria would cut off Germany from its rented storage, Germany could retaliate by not allowing Austria to use its pipeline infrastructure to import LNG. This scenario highlights that cooperation among European countries is essential.

To simulate storage levels on the EU level we rely on monthly data provided by the Eurostat natural gas supply statistics. We average over the last two years for consumption and inflow levels. Extrapolating with the average injection rate since May 1, we estimate the EU gas storage to contain 58.02 bcm (46.2% of maximum capacity) on June 1, 2022. Again, using the reduced in- and outflows, as described in Table 1 and Section "Alternative gas imports", we predict monthly injection and extraction rates and the monthly storage level. We set the net extraction from June 1, 2022 to May 31, 2023 to 28 bcm. Our model predicts a minimal gas storage level of 22.04 bcm (17.4%) in March 2023, which is similar to the historic minimal gas storage of 22.10 bcm (17.5%) in March 2018. Assuming a proportional distribution in the *EU-cooperation* scenario, Austria is allocated 28/412 * 9.34 bcm = 0.64 bcm.

2.3. Fuel switching

Our analysis indicates that switching gas power plants to alternative fuels, such as oil, can substantially reduce gas demand in the short run by around 10.5% of total annual consumption (0.98 bcm). We emphasize, however, that fuel switching entails high environmental costs, as well as additional

[4] Computed based on the Aggregate Gas Storage Inventory (AGSI): https://agsi.gie.eu/ (accessed: May 14, 2022).
[5] Based on data by the Austrian clearing agency (EnergyMonitor.at, 2022).

economic costs.

Electricity generation and district heating plants are among the largest consumers of gas in Austria. Gas is currently the only non-renewable source in Austria's power mix (besides non-renewable electricity imports). Gas consumption in the electricity sector also exhibits a high seasonal component. Gas power plants burn natural gas mostly during the winter months to compensate for the higher electricity demand, lower production from renewable sources, and to stabilize the grid. Based on Austrian Power Grid dispatch data (APG, 2022), total electrical energy reserves for stabilizing the grid were 0.32 TWh in 2019. To obtain a conservative estimate of fuel switching potentials, we assume that all electrical energy dispatched for stabilizing the grid is produced only by gas turbines. Assuming an efficiency of 35% of gas turbines[6], this equals 0.32 TWh/0.35 = 0.9 TWh, corresponding to around 0.09 bcm of gas, needed per year for stabilizing the grid. This likely overestimates the gas needed for grid stabilization, since not all reserves are necessarily provided by gas power plants and we would expect much higher conversion efficiency (approx. 60%) if combined cycle plants are used. We assume that gas-based grid stabilization cannot be substituted from other sources in the short-term considered here. Thus, in our scenarios we require a minimum of 0.09 bcm gas as inputs to the electricity sector to always guarantee the functioning of the power grid.

Some Austrian gas power plants have the potential to run on both, gas and oil, and therefore are candidates for fuel switching in case of a serious shortage in gas supply. We estimate that Austria can reduce gas used for generating electricity by around 40% through these substitutions. To arrive at this estimate, we assume that a total gas power capacity of 800 MW can be switched to other oil-based fuels or coal. 800 MW amount to the capacity of the "Wärmekraftwerk Theiß" which, as of 2020, was still able to switch between oil and gas fuels (EVN 2020). We assume that in a scenario of limited gas availability, the power plants that can be switched to alternative fuels will be switched on preferably over gas power plants. Using historical data on electricity generation from fossil sources (in 15 min intervals) for the years 2016–2021, we integrate the power output exceeding the switchable 800 MW to estimate the amount of energy which must be provided by gas power plants. The procedure is illustrated in Figure 3 for 2017, where we highlight the electricity provided by gas power plants in red. The gas saving potential corresponds to the amount of energy produced by the plants running on alternative fuels, i.e., the blue area below the 800 MW intercept. Our method estimates potential annual gas savings between 40% and 50%. In the following we use the smallest saving of 40%, corresponding to 0.98 bcm per year, or equivalently, 10.5% of total consumption. A related study in Germany found a reduction potential of 43% (IEK, 2022).

We acknowledge the possibility of practical limitations that may make fuel switching difficult but emphasize its large potential for reducing gas demand. For example, by switching power plants, with a combined capacity of 350 MW, which would be equivalent to Simmering's Block 3 (Wien Energie 2021), Austria could save an additional 0.40 bcm per year. If such a switch is technically possible, these costs are likely small compared to the industrial production that could be saved with these measures (see Figure 6). Fuel switching requires the deployment of climate-damaging fuels, counteracting previously set emission targets. However, if the reduction of the economic shock can be reduced, parts of higher GDP can be committed to the installation of additional green capacity and thereby reducing emissions in the mid-term. Our findings show that fuel switching is, at best, a short-term solution that

[6] https://www.energy.gov/fecm/how-gas-turbine-power-plants-work

must be accompanied with increased investments in renewable energy and storage technologies.

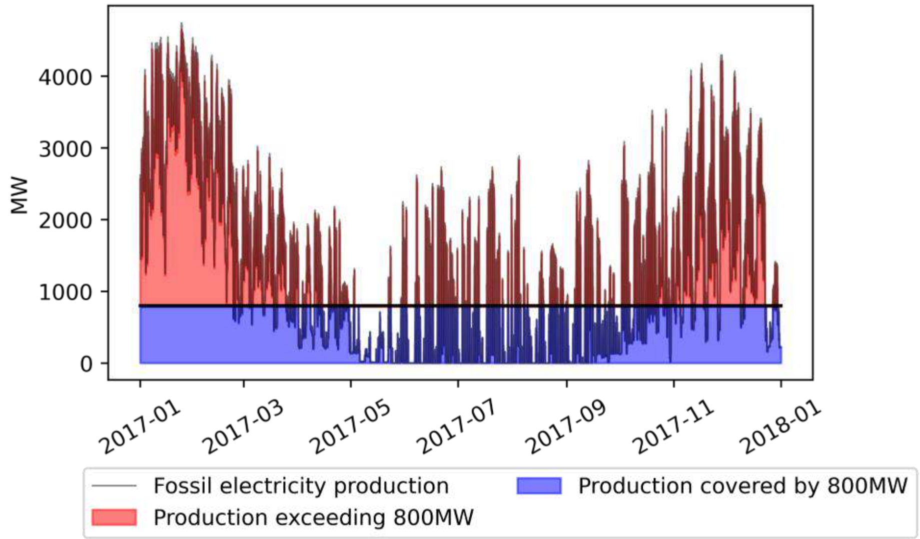

Figure 3: Seasonal electricity production from gas for the year 2017 (Fraunhofer 2022). The horizontal line is the assumed capacity of 800 MW which could be provided from other fossil sources (oil or coal). The red shaded part indicates electricity production from gas exceeding 800 MW, which we assume cannot be replaced by alternative fuels, it represents around 40% of the total fossil electricity produced.

2.4 Savings in heating

Given the drastic scenario of an immediate 80% gas supply shock, we assume that demand side measures will be implemented that target a reduction of gas usage for room heating. We assume that a price increase, on the one hand, and pleas to the solidarity of the public by policymakers, on the other hand, could motivate behavioral changes, like an average room heat reduction of approximately 1°C. On average, it can be assumed that these lead to a 5% reduction of gas requirements (DOE, 2022). We assume that the reduction in room heating applies to industry and services, households and the public sector. The savings in household heating amount to 0.11 bcm, and the savings in industry room heating before rationing amount to 0.06 bcm.

2.5 Pipelines

Natural gas is used as the main energy carrier to operate pipeline infrastructures. The distribution of gas through existing pipelines in Austria required 0.29 bcm in 2021, representing 3.1% of the total gas consumption. As consumption falls, also pumping needs and, consequently, gas usage for operating the infrastructure declines. We assume that gas usage for pipeline operation scales with total consumption by a fixed factor of 3.1%. This amounts to 0.05 bcm and 0.11 bcm of savings in scenario A and B, respectively.

2.6 Aggregate gas supply reductions

Combining the initial gas supply shock, resulting from a Russian gas import embargo, with the countermeasures discussed above in place (alternative imports, storage management, fuel switching, savings in heating and pipeline operation), we estimate the aggregate gas supply shock for both scenarios. We calculate that the aggregate gas supply shock amounts to 0.49 bcm (5.2%) in the *EU-cooperation* Scenario A and to 2.21 bcm (23.7%) in the *uncoordinated* Scenario B.

Given the high Austrian dependency on Russian gas imports, engaging individually in the international markets for alternative gas sources is suboptimal compared to an EU cooperative scenario. This holds true even if more storage can be used for own consumption in the uncoordinated scenario.

2.7 Industry-specific gas supply reductions

The Austrian industry currently uses 44.1% of the total gas, i.e., 4.12 bcm per year[7]. Other consumers, like households, services and the public sector, power plants, and pipelines, are considered as protected in this scenario, in accordance with the recent communications of the infrastructure ministry (BMK, 2020; BMK, 2022). This means, while we consider some savings in these sectors, like reducing room heating by 1°C, industry has to bear the bulk of the gas shortfall.

To calculate the gas available for industry consumption, first we compute the consumption by protected consumers after all consumption reducing measures have been applied. This comprises household consumption (after lowering room temperature), electricity generation (reduced by fuel switching), and consumption in pipelines (with reduced throughput). Second, we subtract this number from the gas supply to Austria in the respective scenario (A or B), resulting in the amount of gas that is available for industry. As mentioned before, 29.6% of industry consumption is attributed to room heating. We assume that industry also reduces the average room temperature by 1°C, resulting in a reduction of overall industry gas demand of 0.06 bcm (–0.61%). Moreover, due to lack of better information, we assume a scenario, where the gas supply is distributed proportionally to all industries.

Figure 4 shows how the aggregate gas supply shock translates into industry gas supply shocks when taking these assumptions into account. Our results show that there is a 10.4% shock to industry gas supply in the *EU-cooperation* Scenario A, whereas there is a 53.3% shock to industry gas supply in the *uncoordinated* Scenario B. These results underline the large value of coordination in the distribution of limited gas to mitigate the gas supply shock to the industrial sector.

In the extreme case of very large shocks above 58%, the gas supply is less than the demand by protected consumers and no gas is available for industry consumers. The slope of the curve for shocks between around 12% and 58%is 2.2. In this region an additional percent aggregate gas supply shock translates into an additional 2.2% industry gas supply shock, indicating the sensitivity of industry gas supply reduction with respect to overall reductions in the country's gas supply.

[7] Note that we use Eurostat gas volume data which can be different from national statistics.

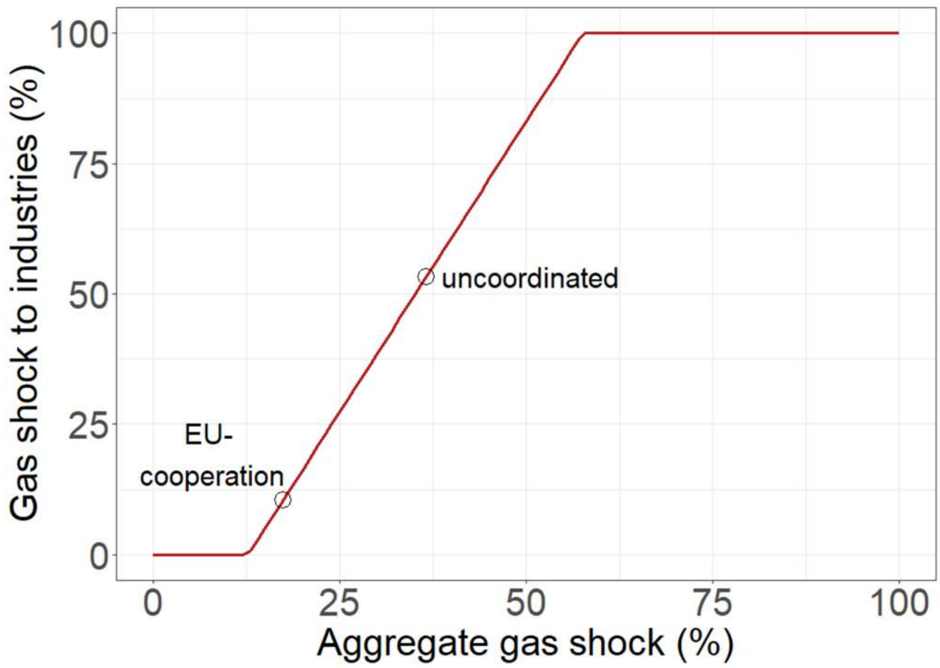

Figure 4. Mapping aggregate gas shocks to gas supply shocks for the industry. The x-axis shows the possible range of aggregate gas shocks. The y-axis is the gas supply shock in % of pre-shock industry gas usage. We find ranges where no aggregate shock is transmitted to the industry due to measures like savings or alternative imports. On the other hand, industries experience a 100% shock already for aggregate shocks of 58% and higher, due to prioritization of other customers.

3 Economic analysis

3.1 Sector-specific output shocks resulting from gas shortages

We use the gas supply reductions for industrial sectors as the main input into an economic model to quantify overall economic impacts. Since different industries exhibit different dependencies on gas inputs, we first estimate the gas exposure of each industrial sector. Note that there exists intra-industry heterogeneity: while some firms rely on the use of gas in their production processes, others do not. In the case of a gas supply shock, companies depending on gas in their production need to reduce their output accordingly, while firms independent of gas can continue production. Thus, to quantify the direct economic shocks resulting from a gas supply reduction to industrial sectors, we first estimate the share of companies in a given sector that uses gas in their production process (we assume gas to be non-substitutable in the short run).

We achieve this step by matching the input statistics ("Gütereinsatzstatistik") (Statistik Austria 2022c) and the structural business statistics ("Leistungs- und Strukturstatistik") (Statistik Austria, 2022d).[8] The Gütereinsatzstatistik reports the annual natural gas consumption for one to four digit levels of the following OENACE sectors: B (Mining), C (Manufacturing), D (Energy), E (Utilities) and F (Construction). The total gas consumption in each sector refers to the gas consumed by firms whose annual revenues exceed 10 million EUR and employ at least 20 workers, resulting in 1,388 reports. The number of gas-using firms allows us to compute the average gas consumption of a given sector, conditional on the size threshold. The structural business statistics contains industry-specific information on the total

[8] We have the Gütereinsatzstatistik of 2020, while the most recent year of the Leistungs -und Strukturstatistik is 2019. This will introduce errors to the presented procedure, although we expect them to be small due to expected high time correlations of industry statistics.

number of firms, as well as a rough employment-based firm size distribution. The gas consumption reported in the input statistic only accounts for 81.3% of the total industry gas consumption reported in the energy balance (Statistik Austria 2022b). The remaining 18.7% can be attributed to firms that fall below the reporting threshold of 10 million EUR turnover and 20 employees. We estimate the share of firms depending on gas in each sector by dividing the number of firms per sector that report the use of gas by the number of firms in the same sector that are in principle subject to the reporting obligation[9]. We assume that the same ratio of gas-using to non-gas-using firms also holds for smaller firms and distribute the remaining 18.7% accordingly.

The left panel of Figure 5 shows the estimated gas dependency, i.e., the share of firms in an industry that uses gas, against the relative output share. The figure makes it clear that sectoral gas dependency is highly heterogeneous. Based on our estimates, "Manufacturing basic metals" with more than 70% of its firms using gas exhibits the largest gas exposure amongst all industrial sectors. The exposure is also high for the "Manufacturing paper and furniture" industries. Every industrial sector uses natural gas to some extent, with the smallest gas dependency being in the "Manufacturing wood" and, interestingly, the largest sector, "Construction".

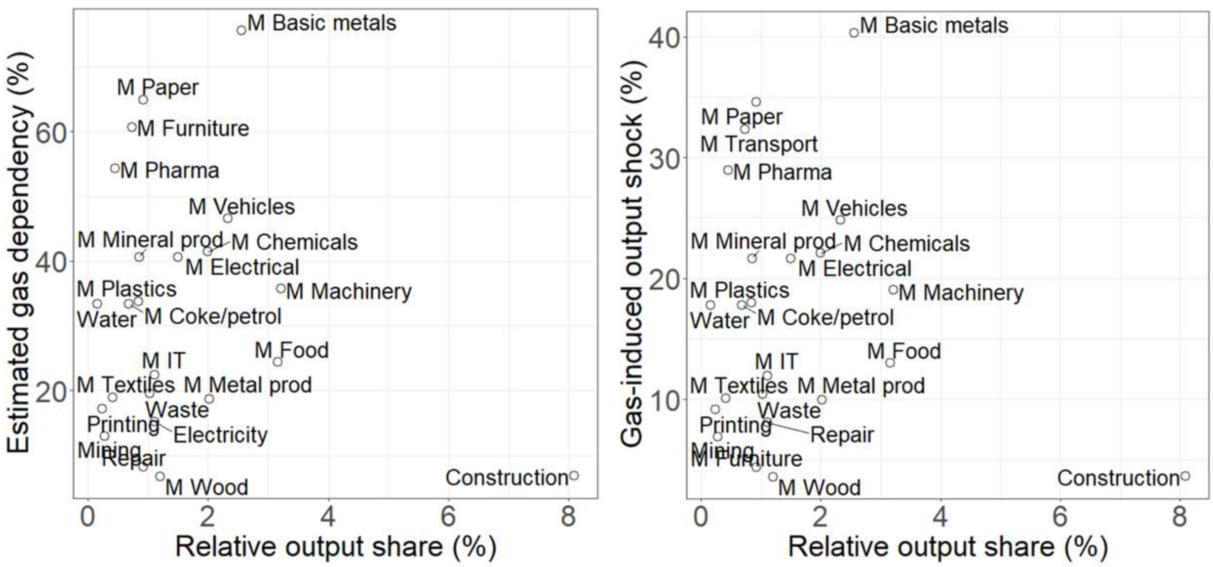

Figure 5. (Left) Gas dependency. Share of firms using gas in a sector plotted against the relative sector size. (**Right) Direct sectoral supply shocks in the *uncoordinated* scenario B.** We assume that output scales linearly with gas inputs for gas-using firms. The letter "M" in the labels refers to manufacturing.

We use the overall gas shock to industry, and the industries' gas dependency, to estimate *direct* shocks to the relevant sectors. We assume that the reduced supply of gas for industries is distributed proportionally among them, according to their gas intensity, i.e., the gas supply to each gas-using firm is reduced by the same relative amount. We further assume a linear relation between the production capacity of a gas-using firm and its gas inputs, where an X-% reduction in gas inputs leads to an immediate X-% drop in output. Firms that are not using any gas in their production, however, do not experience any direct decline in their production capacity (they could be affected by indirect impacts).

[9] Since we can match the two datasets only on employment numbers, even though the gas reports also include a revenue threshold, we only consider the reporting criterion of employing more than 20 workers. This might cause a downward bias in our estimates of the share of gas-using firms in a given industry. We have experimented with manually correcting for this bias and found that our results are robust against slightly higher share estimates.

Note that in the *EU-cooperation* Scenario A, where there are strong countermeasures put in place, the shock to the industrial sector amounts to 1.1%. In the *uncoordinated* Scenario B, however, industries face a direct shock to output, amounting to 5.6%. The right panel of Figure 5 shows the resulting direct output reductions for the different sectors. In line with intuition, industries that face the highest gas dependency experience the largest adverse hits to economic production. Note that the "Electricity" sector does depend on gas, as shown in the left panel in Figure 5, but it doesn't experience a direct shock, shown in the right panel. As discussed in Section 2.3, the Electricity sector is a protected consumer and, therefore, not exposed to a gas shock.

3.2 Economic impact analysis

To quantify total economic impacts, i.e., direct shocks plus indirect impacts, we use a dynamic out-of-equilibrium input-output model which has recently been used to successfully forecast the economic impacts of the Covid-19 pandemic in the United Kingdom ahead-in-time (Pichler et al., 2021). We adapt this model for gas shortages by explicitly considering industrial gas usage in production and calibrating gas usage according to the Austrian economy. In this model the economy initially rests in a steady state until it experiences exogenous shocks, in this case due to shortages in gas inputs.

This model was designed to understand the upstream and downstream propagation of the industry-specific demand and supply shocks and was inspired in part by previous work on the response to natural disasters (Hallegatte, 2008; Henriet et al., 2012; Hallegatte, 2014; Inoue & Todo, 2019). The model includes a new functional form for industry-specific production functions based on a survey of industry analysts, and incorporates inventory dynamics, consumption, and labor market effects. For the details of the model, we refer to the technical online appendix (Pichler et al., 2022).

In contrast to standard general equilibrium models as used, for example, in Bachmann et al. (2022), our model is dynamic and simulates the economy on a 63 industry level on a daily resolution. We apply the gas shocks to industries on June 1, and let the model evolve over two months. We report the relative reductions in gross output after two months, compared to pre-shock levels as our main results.

We simulate the model with different production functions and show results of estimated gross output reductions in the blue ribbon in Figure 6 where the area indicates lower and upper bounds of economic impacts[10]. Our model yields an upper bound of aggregate output reduction slightly above 16% compared to pre-shock levels once the maximum shock to industry gas supply has been reached; see Figure 4. The direct shocks hit an upper limit of slightly above 10% aggregate output reduction.

The figure illustrates the potential adverse economic consequences resulting from aggregate gas shocks and indicates which impacts can be expected under different scenarios. We indicate the two scenarios discussed in this policy brief with the two dashed vertical lines. The left line, indicating the *EU-cooperation* Scenario A, represents a –17.4% aggregate gas shock. These aggregate gas shocks translate into a –1.1% direct shock to output and a –1.9% total aggregate impact after indirect effects have been taken into account For the *uncoordinated* Scenario B, we observe a –5.6% direct shock to gross output and a –9.1% overall negative impact on gross output.

[10] The lower bound represents a linear production function, the upper bound a Leontief production function. The relatively small distance between lower and upper bounds indicates that our model predicts limited downstream shock propagation in the input-output network.

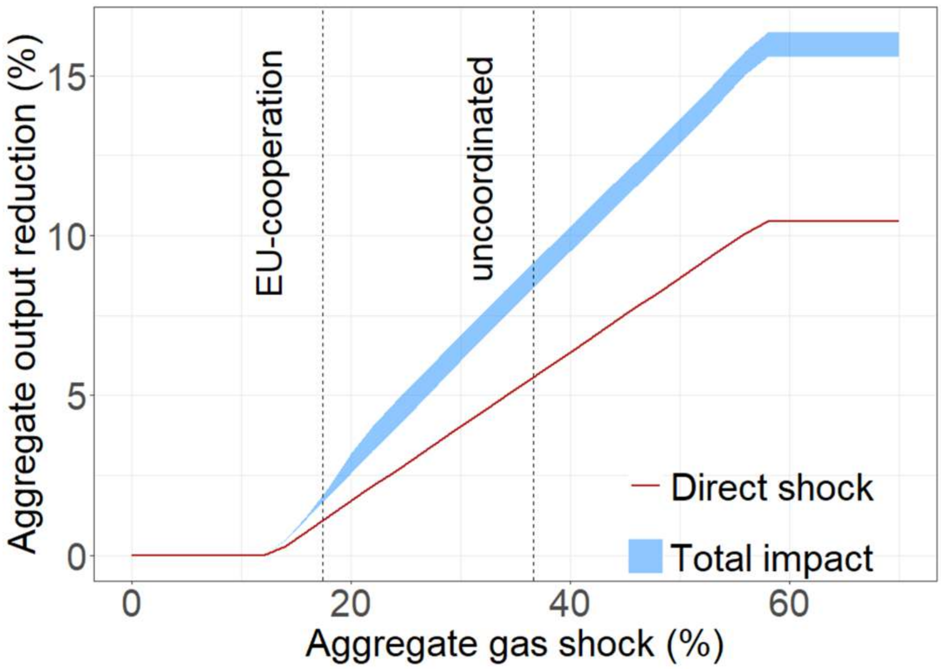

Figure 6. Aggregate economic impacts resulting from an aggregate gas shock. The x-axis denotes the overall reduction in gas supply, the y-axis the reduction in total gross output. The red line is the aggregate direct shock to gross output, the blue ribbon indicates the range of total economic impacts predicted by the economic model. The lower bound of the ribbon is obtained from simulating the model with a linear production function, the upper bound from a Leontief production function. The dashed vertical lines indicate the two scenarios considered in this policy brief. The left line is the *EU-cooperation* Scenario A, with an estimated 17.4% aggregate gas supply shock that leads to a 1.9% reduction in gross output. The right line is the *uncoordinated* Scenario B, where a 36.6% gas supply shock translates into a decline in economic production of 9.1%. The model runs on a daily resolution and values presented here are obtained from simulating the economy for two months when a new steady state has been reached.

4 Limitations and uncertainties of our analysis

We emphasize that the present analysis is subject to several limitations. We divide them into limitations concerning the supply and demand shock mitigation scenarios, and limitations in the economic analysis.

4.1. Supply and demand shock mitigation scenario limitations.

Note the large uncertainty between the cooperative and uncooperative scenarios. Policy makers on the EU level have publicly stated plans to cooperate (European Commission, 2022) and cooperation in previous crises, such as EU-wide coordinated Covid-19 vaccine procurement, suggest that the cooperative scenario is plausible. Further uncertainties arise around the EU plans to acquire additional 50 bcm LNG and additional 10 bcm gas through existing infrastructure in the next year. The assessment of global liquifying and shipping potentials, as well as European re-gasification and transport capabilities is beyond the scope of this policy brief. However, based on a detailed analysis of Fulwood et al. (2022), the EU import goals seem possible. Here we assume – very conservatively – that the EU only receives an additional 45 bcm of LNG within the next year, falling 10% short of their stated plans.

It is important to note that the scenarios presented here assume that one gas power plant in Austria, the thermal power plant in Theiß, or equivalently, several plants with total generation capacities of similar size, can be switched to oil in the short-term. In principle, several Austrian gas power plants could be retrofitted to use different fuels. Thus, we assume some flexibility in switching fuels, but acknowledge that there might be practical limitations to fuel switching that are not factored into the analysis. Conversely, there might be additional fuel switching possibilities that we have not considered. For example, due to a lack of more information, we did not consider fuel switching for district heating which accounts for another 2.3% of gas consumption. To estimate gas savings through fuel switching we employ a very simplified view of the Austrian power grid. For example, we do not take into account the possibility of importing electricity.

Given the short-term focus of the present study, technological adaptations or the possibility of a massive ramp-up of renewable energy technologies are not considered. However, continuing high prices of natural gas will encourage substantial technological adaptations. Similarly, high gas prices incentivize investments in renewable energy capacities which could substantially contribute to reducing Austria's dependency on natural gas in the mid- to long-term.

4.2. Economic model limitations.

Imperfect production functions. The second large source of uncertainty in the outcomes are limitations in the economic analysis. Due to limited availability of data, we had to estimate the gas dependency for each sector based on firm counts, which is obviously imperfect. Similarly, without further details on underlying production functions, we assumed a linear relation between production capacity and gas inputs for gas-using firms, even though in reality we expect substantial heterogeneity across firms. While these estimates are imperfect, we stress that they can be improved as additional information on gas usage in firms becomes available, for example through surveys.

Imperfectly observed supply networks. Since we use an economic model on the industry-level, we assume that each industry produces a homogenous good. As a consequence, goods produced by non-gas-using and gas-using firms are indistinguishable, which substantially reduces the potential of downstream shock propagation in the production network. If a gas-using firm produces very specific goods, which are critical inputs to other firms, we are likely to underestimate the amplification of gas supply shocks. We note, however, that this limitation is not specific to our study, but applies to essentially every macroeconomic model. Detailed data on firm-level supply network relationships are usually not available and are very hard to include in general equilibrium models. We emphasize that our model could incorporate more fine-grained production network data and firm-level details if the data were available.

Prioritizing some sectors. Due to the lack of detailed statistics on gas usage, we did not consider direct shocks to the "Agricultural", "Service", and "Public sector". For simplicity, these sectors are prioritized over industrial sectors and thus are always served first. In case of gas shortages they could also be considered for rationing which would free up additional gas for the industrial sectors.

Static prices. We point out that our analysis assumes time-invariant prices, no shifts in consumer preferences, and no changes in international trade. An EU embargo of Russian gas would likely drive prices for natural gas up, incentivizing firms to reduce demand and invest in alternative energy sources. Similarly, households have an incentive to switch to alternative heating systems, such as heat pumps. These effects would reduce the gas supply shock, although their magnitude and time-dependence are difficult to quantify. We note that we have incorporated these effects to some extent exogenously by assuming reductions in gas demand in industry and households, e.g., for heating.

No short-term substitution of gas inputs. Given the lack of additional data, we assume no possibility of fuel switching in the industry, except for the energy sector where we assumed fuel switching for some plants to help mitigate the initial gas supply shock. Other reductions in industrial gas dependency most likely require retrofitting of gas-burning machines or substantial shifts in production mechanisms in case of non-energetic gas use. We argue that our assumption is reasonable for the short time horizon considered here but obviously wrong in the long run. In fact, substantial reductions in the gas dependency is key for achieving the Paris climate goals and feasible over the next few years (AEA, 2022).

5 Conclusion

5.1. Summary

In this policy brief we analyzed the possible economic impacts resulting from a sudden stop of Russian gas imports to Austria. We first estimate the additional availability of natural gas for Austria in two scenarios, an *EU-cooperation* Scenario A and an *uncoordinated* Scenario B, where Austria tries to secure additional gas individually. We then quantify the likely reduction of natural gas available for industrial production and simulate the overall economic impact on the Austrian economy with a dynamic out-of-equilibrium input-output model.

Results show that through coordinated policy measures on the supply and demand side, a gas shock can be substantially reduced. The economic damages to the economy are –1.9 in the *EU-cooperation* scenario, but amount to a substantial reduction in gross output of roughly 9.1% in the *uncoordinated* scenario. A similar economic shock size for the non-cooperation scenario is within the range of previously reported studies, e.g., for Germany (Bachmann et al., 2022; Krebs, 2022; Bundesbank, 2022). The estimated impact is comparable but somewhat lower than the effects from the Covid-19 pandemic where we have observed a 14% loss in GDP in the second quarter of 2020 (Eurostat, 2021).[11] Therefore, a mix of previously used economic policy interventions like furlough schemes (“Kurzarbeit”) can be repurposed to cushion the effects of the gas shock.

The model results imply a high sensitivity of gross output reduction depending on the aggregate gas availability. For a reasonable range of aggregate gas shocks, an additional 1% decrease in aggregate gas supply translates into a 0.3% decrease in gross output. Note that Austrian gross output amounted to roughly 700 bn EUR in 2020[12], indicating that even policies leading to small improvements of gas availability can have substantial positive effects on the economy, even when these measures are costly.

Note that even EU countries that are not dependent on Russian gas can benefit from cooperation with more exposed countries. By accepting manageable reductions of their gas supply, countries independent of Russian gas can avoid likely large economic downturns of highly exposed countries, and, consequently, avoid potential EU-wide supply chain disruptions and adverse impacts on trade.

5.2. Policy implications

To cushion potential gas supply shortages, we identify several policies to mitigate possibly large adverse economic impacts.

[11] Note, however, that our analysis is based on gross output, not GDP.

[12] Obtained from Eurostat (code: naida_10_gdp) by summing gross value added and intermediate consumption (current prices).

1. **Need of European coordination in gas supply policies.** In case of successful coordination on the EU-level, Austria might experience only small adverse economic impacts. Ensuring alternative sources of gas supply, as well as intelligent storage management, will prove key for counteracting a sudden embargo of Russian gas.
2. **Prepare power plants for fuel switching over the summer.** Fuel substitutions in gas-powered plants represent large potentials for mitigating gas shortfalls. The summer months, when gas usage in electricity and heating is low, should be used to prepare for gas shortages in the winter months by ensuring flexibility in fuel switching for at least some of the largest power plants.
3. **Incentivize changing production processes.** Austria and the EU should incentivize the change from gas-based production to gas-independent technologies, ideally to renewable energy technologies to avoid counteracting long-term decarbonisation plans. Possible examples could be investment subsidies or provision of cheap financing.
4. **Incentivize changing heating systems.** Austria and the EU should encourage the replacement of gas-based heating with renewable heating systems, including heat pumps and biomass. Measures should be targeted at households, industries, and district heating plants. Possible examples could be investment subsidies, provision of cheap financing and banning gas heaters in new homes.
5. **Investments in green energy technologies.** The electricity sector is currently the largest single user of natural gas which could be decarbonised fairly quickly by renewable energy technologies and storage. Noting that renewable energy technologies by now represent the cheapest form of electricity (IEA, 2020), a massive ramp-up of these technologies would entail large positive economic effects beyond reducing gas dependency (IRENA, 2014).
6. **Encourage gas savings.** Reducing room temperature, saving electricity, and reducing the consumption of gas-intensive services and materials can mitigate the gas supply reduction to industry. Compliance might be improved by clearly communicating that saving gas and electricity can support the economy, and consequently saves jobs. A successful example is Japan after the Fukushima disaster where large public campaigns contributed to significant (interestingly persistent) savings in electricity consumption (Kimura, & Nishio, 2016).

5.3. Wider perspective

We complete our discussion by putting the potential consequences of a gas embargo in context with the consequences of the ongoing war in Ukraine. In 2021 Austria imported Russian gas worth of 3.6 bn EUR[13] and the EU imports of Russian gas since the outbreak of the war have been estimated to almost 24 bn EUR at the time of writing (May 22, 2022) (CREA 2022). Europe's imports of Russian gas therefore are a major source of funds for the Russian attack in Ukraine.

As a consequence of the war, the IMF GDP forecasts for the EURO area have been revised downward from January to April by 1.1%, resulting in more than 130 bn EUR (annualized) lost (IMF, 2022). Since the beginning of the Russian invasion in February, the EU supported Ukraine financially and militarily with more than 4 bn EUR, and rebuilding costs in Ukraine are in the range of trillions (Reuters, 2022). These financial burdens do not compare to the human suffering that Ukrainians have endured and continue to endure as long as the war goes on. On top of this, the war exacerbates already record-high

[13] Official trade balances only show imports from regions, not countries. In 2021 Austria imported 3.6 bn EUR from CIS of which Russia is a subset. Using data from the Agency for the Cooperation of Energy Regulators (ACER), Austria's gas dependency is fully explained by imports from Russia, Germany and its own production (in 2019). Thus, most likely all of the 3.6 bn EUR has gone to Russia.

levels of acute food insecurity with the potential of triggering further humanitarian crises across the globe (FAO, 2022).

Our results suggest that adverse economic impacts could possibly be large if no sufficient countermeasures are taken. However, in case of strong policy commitment, adverse consequences could be substantially mitigated and, given the high costs of the ongoing war, also be a viable economic strategy for the EU and its member states.

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Appendix

Technical details on the economic model and methodological approach used to derive these results are presented in the online supplementary information.