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Not Even a Recession: The Great German Gas Debate in Retrospect

The German economy coped with the end of Russian gas and could have equally withstood an April 2022 cut-off

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8 May 2023

Executive summary: Recently released GDP numbers confirm that the German economy withstood the end of Russian gas imports and even avoided slipping into a recession last winter. This outcome would seem to finally settle last year's debate on the effects of an end to Russian energy supplies triggered by the "What If" paper (Bachmann et al., 2022a). The short-run economic costs of severing the energy ties with Russia turned out to be moderate and manageable. The doomsday predictions of companies, industry associations and unions, and associated think tanks turned out to be far off the mark. The German government likely formulated policy on the basis of a substantial overestimation of the potential economic consequences of an end to Russian gas supplies.

We show that, even with an earlier end to gas imports from Russia at the end of March 2022, Germany would have made it through the winter and would have exited the heating period with gas storage above critical levels. This analysis using data on gas imports and the gas storage situation at the end of the heating period settles the residual debate about the alleged importance of continuing gas imports after March 2022 until Russia stopped gas exports in August. Taking into account imports of Russian gas via third countries as well as re-exports, Germany imported about 100 TWh of gas from Russia between April and August 2022, and exited this winter's heating period with about 160 TWh of gas in storage. Assuming identical consumption and identical gas imports from third countries, German gas storage at the end of the winter would still have stood around 60 TWh or 25% even in a scenario in which Russian gas imports ended on 31 March 2022. Because a cut-off at the beginning of April would have coincided with the end of the previous heating period and a drop-off in household demand, gas supplies would have been sufficient at any point in time to satisfy both industrial and household gas demand. Shortages or rationing would have been avoided.

Moreover, the country did not simply get lucky with particularly mild winter temperatures, as often alleged. The average winter temperature in the 2022/23 winter of 2.9°C was actually slightly colder than the average

[1] Benjamin Moll: London School of Economics; Moritz Schularick: University of Bonn and ECONtribute and Sciences Po Paris; Georg Zachmann: Bruegel. Ben McWilliams from Bruegel conducted the calculations to compute net imports of Russian gas. We are also grateful to Marina Feliciano, Sven Eis and Seyed Hosseini-Maasoum for excellent research assistance.

temperature over the four previous winters. On the contrary, negative shocks to energy supply such as the French nuclear and U.S. LNG shutdowns were substantial and complicated the adjustment.

1. Introduction

On March 7, 2022, less than two weeks after the Russian invasion of Ukraine, we published, jointly with a group of coauthors, a paper that addressed a seemingly simple question: what if the German economy was cut off from Russian gas? The question was intentionally framed in a way that allowed the cut-off to be the result of a German embargo, or the result of an end to gas supplies initiated by Russia. The aim of the paper was to provide a compass for policy-makers facing momentous decisions. How would the German economy cope with a sudden stop of energy imports from Russia? Was the likely result a very severe recession like during the Global Financial Crisis or perhaps even a massive collapse in output and spiking unemployment comparable in its severity to the Great Depression of the 1930s? Or should we expect the economic costs to be more muted, i.e., a more ordinary recession of the kind that the German economy had dealt with in the past and was well-equipped to deal with in terms of the available policy space to cushion its impact?

Our answer at the time, based on some key statistics about the German economy and applied macroeconomic theory, was that an immediate emancipation from Russian energy was feasible and would entail "substantial but manageable" economic cost for the German economy. Our analysis foresaw an output cost in the range of 1-3% relative to a no-cut-off baseline scenario, in line with previous recessionary episodes that the country had successfully dealt with in the past. This prediction was highly co1ntroversial at the time and triggered an intense public debate that culminated in the German chancellor warning of the "irresponsible use of mathematical models" for policy-making on the main prime-time talk show.[2] Partly because of a (potentially overestimated) dependence on Russia's energy exports, the German government was widely perceived to have taken a softer stance in offering support to the Ukrainian government and sanctioning Russia.

2. German economic performance over the winter 2022/23

More than a year later, we can take stock of what happened. GDP numbers for the German economy for the winter 2022/23 have been published at the end of April 2023. Prima facie, the evidence seems to support the original argument of the "What if" paper. Germany was partially cut off from Russian gas in June 2022 and completely in August 2022, but did not go into a deep depression. Moreover, as shown in Figure 1, German GDP did not only not collapse, but actually expanded by close to 2% for the entire year 2022.[3]

[2] Anne Will Show with Chancellor Scholz on 27 March 2022. See https://benjaminmoll.com/Scholz/ for a transcript and English translation of Chancellor Scholz's comments as well as a linked video recording.

[3] Also other European countries withstood Russia's weaponization of natural gas remarkably well. According to the most recent Eurostat GDP flash estimates for 2023Q1 (Eurostat, 2023), both the European Union and the Euro area expanded in the first quarter of 2023, and only a very small number of individual member countries like Czechia and Latvia have experienced (very shallow) recessions (defined as two consecutive quarters of negative GDP growth) since the beginning of 2022.

Even in the fourth quarter of 2022 and the first quarter of 2023, during the peak of the winter's heating season, Germany avoided a recession with GDP according to preliminary estimates, first contracting by 0.5% and then stagnating at 0.0%, i.e., not registering two consecutive quarters of negative growth.[4] The economic stagnation over the winter must be compared to estimates in studies financed by trade-unions and business associations that foresaw output losses between 6% and 12%, with the most apocalyptic estimates due to Krebs (2022) and Prognos (2022) that both predicted an output collapse of 12%, as well as Huether (2022) who warned of "2.5 or 3 million additional unemployed".[5] Overall, the economic costs of the end of Russian energy imports, as measured by the decline in economic activity over time, proved moderate and manageable, in line with the results of the original "What if" study.[6]

The economic outcomes confirm the core theoretical argument that macro elasticities are larger than micro elasticities and that "cascading effects" along the supply chain would be muted as opposed to destroying the economy's entire industrial sector.[7] As foreseen, producers partly switched to other fuels[8] or fuel suppliers[9], imported products with high energy content[10], while households adjusted their consumption patterns.[11] This qualification is important as the difference between a very low, but non-zero, and a literally zero elasticity translates into much smaller economic losses than in the case of zero substitutability (i.e., Leontief production functions). "Cascading effects" could not be observed: while production in energy-intensive sectors like chemicals and glass did see large drops, industrial production of other sectors was hardly affected (Destatis, 2023a, Figure 5). This observed "decoupling" between energy-intensive production and production of other sectors is the polar opposite of the much-feared "cascading effects" and

[4] The 0.0% number for GDP growth in the first quarter of 2023 is preliminary and subject to revision and may later be revised downward to, say, -0.1% thus resulting in a recession according to the usual definition. This paper's basic point that the economic consequences of the Russian gas cut-off proved moderate and manageable would remain even if Germany had, in fact, experienced a very mild recession. The same point applies to the economy's performance going forward throughout 2023.

[5] See IMK (2022), Krebs (2022) and Prognos (2022). See Bachmann et al. (2022b) and https://benjaminmoll.com/RussianGas_Literature/ for a summary of studies conducted by other entities. Of course, these model predictions and the observed evolution of German GDP are not directly comparable because the former are counterfactual predictions relative to a no-cut-off baseline scenario holding other factors constant rather than predictions about the unconditional evolution of economic activity over time. Nevertheless, it is clear that the dramatic counterfactual estimates between 6% and 12% have not come true. For example, given that GDP growth was close to zero over the 2022/23 period, in order to believe the calculations predicting a 12% GDP drop relative to a no-cut-off baseline scenario, one would have to believe that GDP would have grown at around 12% in the absence of a gas import stop which is clearly absurd.

[6] As discussed above, the German economy even avoided slipping into recession in the 2022/23 winter according to preliminary estimates. It is worth noting that presentations of the "What if" study mentioned this outcome as a distinct possibility, see e.g. the bullet point "perhaps not even a recession" on slides 1 and 2 of a presentation at "Markus Academy" (video recording here https://bcf.princeton.edu/events/david-baquee-and-ben-moll-on-what-if-germany-is-cut-off-from-russian-oil-and-gas/ and slides here https://benjaminmoll.com/What_If_slides/).

[7] e.g., household gas consumption dropped by about 12% in 2022 compared to average consumption in 2019 to 2021, according to https://www.bruegel.org/dataset/european-natural-gas-demand-tracker

[8] e.g., coal based power generation in Germany increased by about 10% in 2022 according to https://ember-climate.org/data-catalogue/yearly-electricity-data/

[9] e.g., additional European LNG imports replaced about half of the Russian gas according to https://www.bruegel.org/dataset/european-natural-gas-imports

[10] For the whole EU we estimate an avoided gas consumption of 29 TWh due to the higher net imports of urea.

[11] See Ruhnau et al (2023) and Moll (2023) for some empirical evidence on how Germany reduced gas demand and substituted at only moderate economic costs.

has resulted in overall industrial production remaining stable over the last year and even growing by 2% in February 2023 (Destatis, 2023b).

Market economies have a tremendous ability to adapt that was widely underestimated. In addition, the German economics ministry (BMWK) was very successful in quickly sourcing gas supplies from third countries and building LNG capacity. Finally, it probably helped that German policymakers refrained from imposing a price cap on natural gas (like in many other European countries) and instead opted for lump-sum transfers based on households' and firms' historical gas consumption.[12]

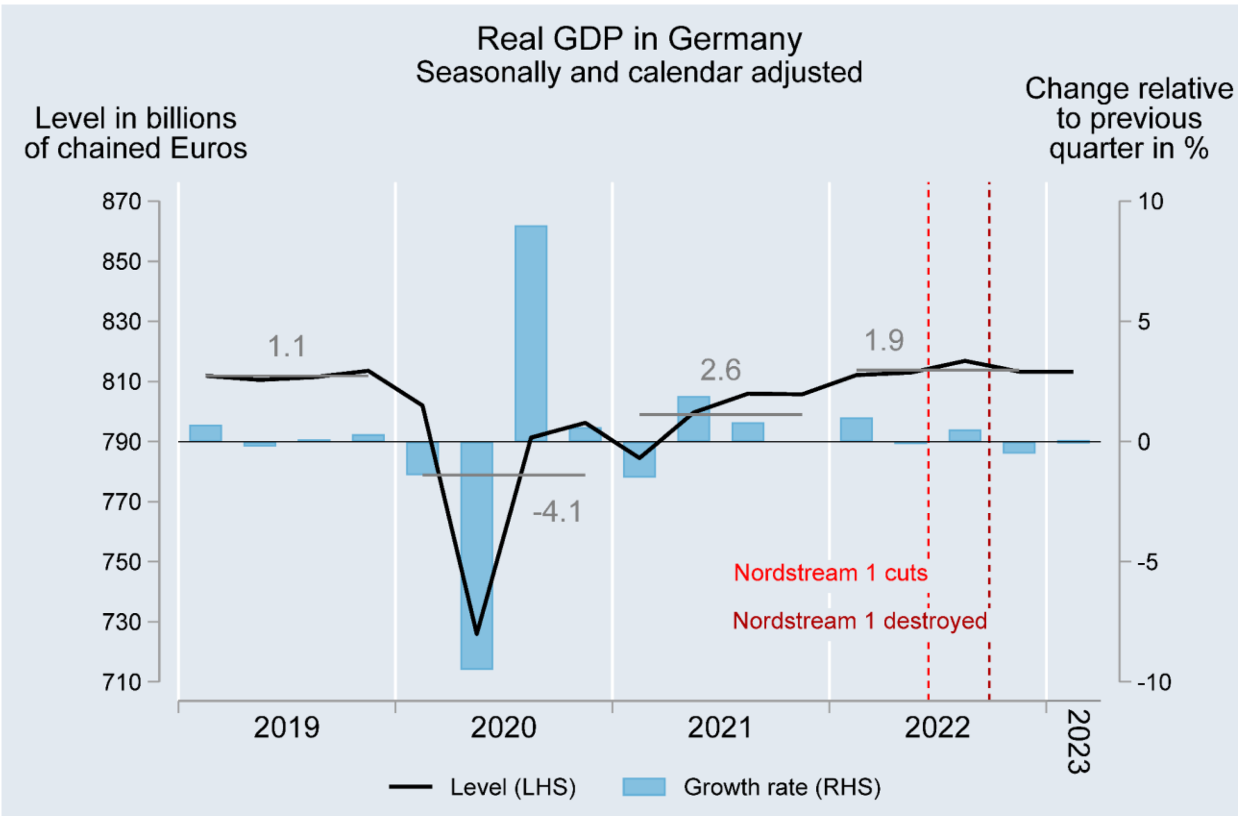

Figure 1: Real GDP in Germany

3. How important were gas imports from Russia from April to August?

To what extent did the timing of the cut-off matter for these benign economic outcomes? It is clear now that the cut-off from Russian gas that Germany experienced in the summer of 2022 had moderate and manageable economic consequences and that the country even exited the winter with substantial gas

[12] As has been widely discussed, the name of the German policy scheme, "gas price break", is a misnomer and "gas cost break" may instead have been a more accurate name. This is because the scheme caps household's or firm's total expenditure rather than the marginal price of an extra kWh of gas which remains equal to the pre-intervention market price. Precursors of this scheme were proposed by our co-author Christian Bayer in Bachmann et al. (2022a, 2002b).

reserves of around 65%. But it is an open question whether Germany would have made it through the winter with an earlier cut-off, possibly as early as April 2022 that would have left only a few weeks for preparations?

A prominent line of argument is that the additional months from April to August, during which Germany continued to import and stockpile Russian gas, were decisive to fill storage capacity sufficiently to get through the winter. Without those Russian imports, the argument goes, with an immediate severance from Russian energy starting in April 2022, shortages, rationing and high economic costs would have ensued.

We here provide some simple counterfactual calculations to answer this question, taking 1 April 2022 as the hypothetical cut-off date. We ask the following simple question: in retrospect, would Germany still have had gas left in its gas storage facilities at the end of the 2022/23 winter, if the country had stopped importing Russian gas on 1 April 2022 rather than continuing to import and stockpile Russian gas until the end of August 2022? Would Germany have run out of gas in the middle of the winter?

Figure 2 presents a simple counterfactual scenario that answers this question. The blue solid line plots the actual observed storage evolution including Russian gas imports after March 2022. The black dashed line plots the counterfactual storage evolution in the event of an April import stop calculated from combining data on Russian gas imports and the observed storage evolution (see the explanation below and in the appendix). The key takeaway is that, even with a 1 April gas cut-off, Germany would still have exited the winter with gas storages that are 25% full. In other words, Germany would have been able to cope with an earlier April embargo.

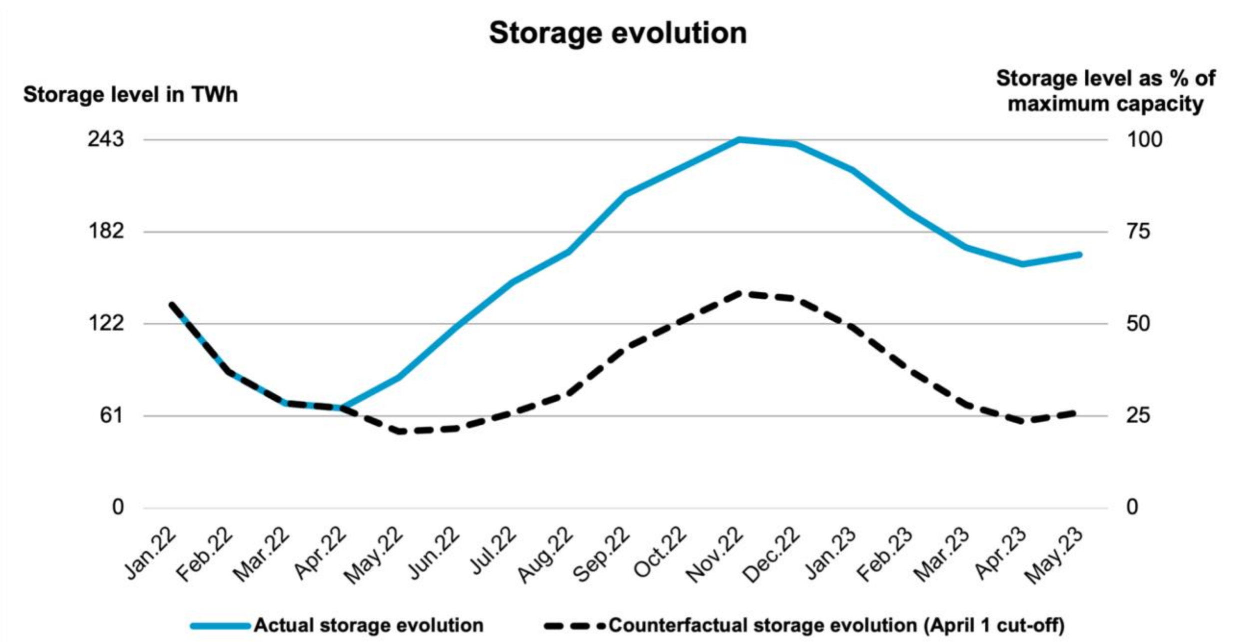

Figure 2: Counterfactual gas storage evolution in the event of an 1 April 2022 import stop of Russian gas

The following simple calculation explains this result. We compute the cumulative observed imports of Russian gas over the period April to August 2022 taking into account imports via third countries as well as re-exports (see appendix for details) and compare this number to the amount of gas left in German storages at the end of the 2022/23 heating period. The idea is simple: holding consumption and other gas supplies constant, if Germany exited the winter with more gas left in its storages than these cumulative imports, then Germany would not have run out of gas even with an April import stop from Russia. In contrast, if gas reserves at the end of the winter were less than these cumulative imports, Germany may have run out of gas without these imports.

Germany imported around 100 TWh (Terawatt hours) of Russian gas since April 2022 which is around 10% of the typical annual gas consumption in previous years or around 40% of maximum storage capacity.[13] On the other hand, Germany had around 160 TWh of gas left in its storage facilities which is around 16% of typical annual consumption or around 65% of storage capacity. Therefore even with a 1 April gas cut-off, Germany would still have emerged from the winter with gas storages that are 25% full (65% - 40% = 25%) which is exactly the number plotted in Figure 2 – see the data point for April 2023.

In fact, the 25% storage level implied by this simple counterfactual calculation should be viewed as a lower bound. First, our counterfactual calculation holds constant German gas consumption, i.e. it assumes that even with gas supplies falling much more substantially and storage levels being considerably lower before the start of the winter, consumption would have been unchanged relative to its actual time path. This assumption is unrealistic: it is reasonable to expect that with lower supplies and storage levels, further demand reduction would have occurred. Second, there was a time period in October and November 2022 during which German gas storages were virtually full and therefore gas imports were constrained by a lack of storage capacity to put this gas (readers may recall larger numbers of LNG tankers queuing off Europe's coasts unable to unload).[14]

In contrast, with an April 1 cut-off, storages would not have reached 100% (see Figure 2), gas imports from countries other than Russia would not have been constrained, and would have thus been higher. For both of these reasons (lower consumption and higher imports), the 25% storage level at the end of the winter that is the outcome of our counterfactual calculation is likely an underestimate, i.e. Germany would have arguably emerged from the winter with storage levels higher than 25%.[15] Despite this lower bound feature, we view our calculation as useful because of its simplicity.

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[13] For Germany-wide maximum storage capacity we use 246 TWh based on the fact that storages were completely filled by early November 2022 with 246 TWh (AGSI, 2023). Similarly, there is a question what the minimum storage level is at which storages can still operate efficiently. The lowest historical storage filling level was only 35 TWh of working gas in March 2018 (AGSI, 2023), significantly below the 60 TWh in our counterfactual scenario, and even at 35 TWh storages still contained significant volumes of cushion gas that could have been extracted in an emergency situation.

[14] See for example https://www.reuters.com/business/energy/dozens-lng-laden-ships-queue-off-europes-coasts-unable-unload-2022-10-17/ or https://www.cnbc.com/2022/10/24/wave-of-lng-tankers-overwhelms-europe-and-hits-natural-gas-prices.html

[15] The first of these mechanisms, additional demand reduction, would have likely been a particularly powerful force towards higher storage levels. This is because German gas storages are small relative to typical gas demand: maximum gas storage capacity is 246 TWh which is only about a quarter of annual gas consumption of around 1000 TWh (Bachmann et al, 2022b). Thus even an additional demand reduction of only 2% would have reduced demand

To construct the full counterfactual time path in Figure 2, we additionally break down imports of Russian gas by month. Figure 2 presents the results with the orange solid line plotting net imports (taking into account re-imports and -exports) in each month, and the red solid line plotting cumulative imports since April 1, i.e. the red line is a cumulative version of the orange line.

An important fact highlighted by the figure is that, while Germany continued to import Russian gas through the end of August 2022, these imports were small from June onwards. This is because Russia started weaponizing gas, substantially cutting deliveries in June in particular through the Nord Stream 1 pipeline which saw deliveries fall to 20% of capacity for much of the summer 2022. Thus, out of the cumulative 100 TWh of gas imported between April and August, 67 TWh were imported in the first two months April and May alone and only about 15 TWh were imported in the last two months before the complete cut-off, July and August. Thus, the skeptics' argument that the additional five months from April to August, during which Germany continued to import and stockpile Russian gas, were decisive for getting the country through the following winter is really an argument about two months alone, April and May.

Using the data on monthly Russian imports in Figure 3, the counterfactual storage evolution in Figure 2 is then computed by subtracting the Russian imports for each month from the observed storage net inflows. Apart from our main argument that Germany would have not exhausted its gas reserves at the end of the 2022/23 heating period, the Figure makes another important point, namely that gas storages are also not exhausted at any other point in time after April 2022. Put differently, the combination of gas imports from other countries and pre-existing storage would have been sufficient to satisfy both industrial and household gas demand at any point in time.

In particular, contrary to the arguments of some skeptics, there was never a danger of a gas shortage immediately following an April gas cut-off. One important reason for this result is the well-known seasonality of gas demand, i.e. that gas demand is much lower in the summer. An April cut-off would have coincided with the end of the 2021/22 heating period and thus the start of the low-demand summer period meaning that even relatively low levels of pre-existing storage would have been enough to prevent shortages and rationing. That the seasonality of gas demand means that there would be no immediate gas shortages even with a cold turkey import stop was an important argument in our March 2022 paper.

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by 20 TWh and would have increased the storage filling level at the end of the winter from 60 TWh or 25% to 80 TWh or 33%.

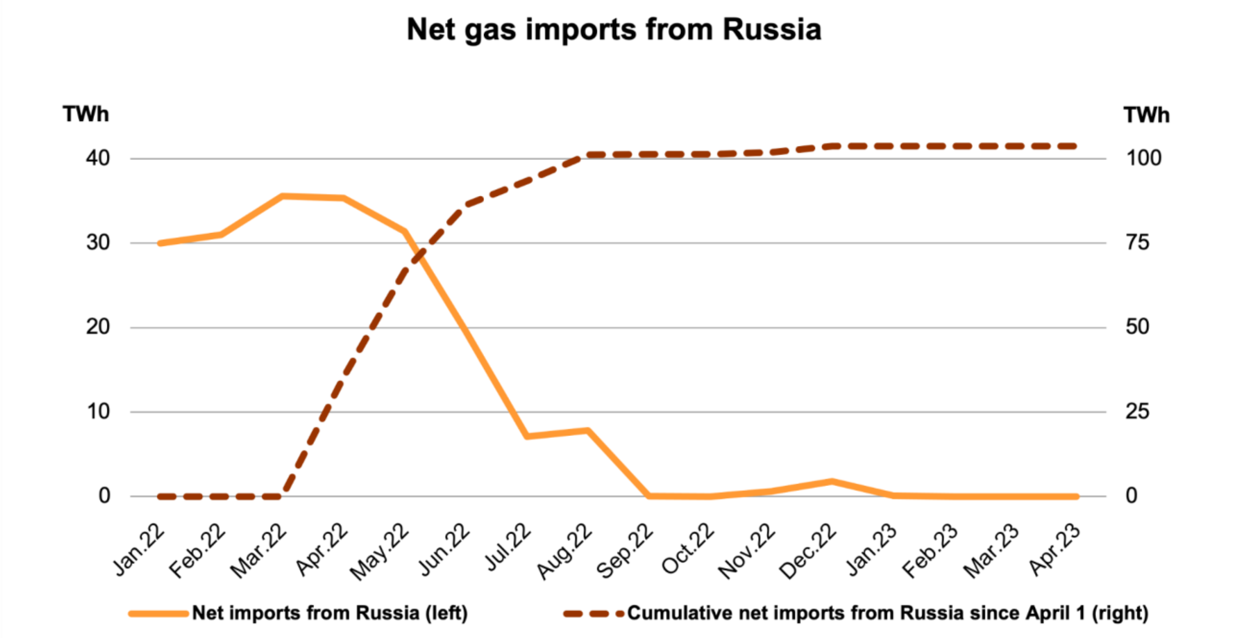

Figure 3: Net imports of Russian gas since April 2022

One more observation helps put things into perspective. This observation is that the observed cumulative Russian imports since April 2022 of around 100 TWh were small relative to typical annual gas demand and supplies, totaling only around 10% of typical annual consumption. This is important because there is another quantity that is small relative to typical consumption, namely total storage capacity which has a maximum capacity of "only" about a quarter of typical annual consumption (or about the consumption of two winter months). The observation of storage being small raises the question: how would these limited storage facilities have been sufficient to get Germany through the winter following an earlier 1 April import stop? The answer is "demand reduction". Because demand is large relative to storage, the sizable demand reduction observed in the data resulted in Germany emerging from the winter with substantial storage levels of 65%.[16] In turn, because the imports from Russia were small relative to demand, our counterfactual calculation concludes that the loss of these imports would not have led to storages running out and shortages.

Although we focus on outcomes in Germany, our counterfactual scenario considers a cut-off from Russian gas for the European Union as a whole rather than just Germany. Because the European gas market is complex and heavily interconnected, we therefore take into account not only direct imports to Germany from Russia (via the Nord Stream 1 pipeline) but also indirect imports via third countries (e.g. flows via Ukraine Transit and Czechia or Austria to Germany) as well as re-exports. See the appendix for a detailed explanation of the methodology. Thus the red dashed line plots the cumulative amount of Russian gas that actually entered and was consumed or stored in Germany and is therefore "missing" in the event of an earlier import stop. Our counterfactual scenario then subtracts these missing imports from total net inflows into German storages. Note that the subtracted missing imports do not include Russian gas that was then

[16] See also Moll (2022) who showed that German gas storages are small to typical inflows and outflows and therefore gas demand reduction would be much more important than entering the winter with full gas storages.

re-exported to third countries because doing so would overstate the gas shortfall by effectively assuming that, after 1 April, Germany would have just re-exported the same amount of gas as if nothing had happened despite being cut off from Russian gas. The appendix contains a more detailed discussion.

While our analysis considers the isolated case of Germany, a remaining question is how the whole European market would have managed with an earlier cut-off from Russian gas. Zooming out, we have therefore also computed a counterfactual scenario analogous to the one in Figure 2 but for the European Union as a whole. This exercise shows that also the EU as a whole exited the winter with more gas remaining in its storages than it imported from Russia after March 2022 and, therefore, would have similarly made it through the winter without this additional Russian gas. While this exercise shows that an earlier cut-off would have been feasible at the aggregate level, it does not speak to the feasibility for individual member countries. Most countries to the west of Germany had lower shares of Russian gas and did have a comparatively easier time adjusting. On the other hand, certain member states such as Hungary (which is supplied via the Turkstream pipeline) and Slovakia (supplied via Ukraine Gas Transit) might have faced more significant difficulties without Russian gas.

4. The role of other factors

Were there other specific factors that helped Germany over the line and meant that the country got lucky and under normal circumstances the doomsday scenarios of non-academic think tanks and others would have been correct?

The most prominent factor mentioned frequently is the presumably mild winter weather. But was the winter actually milder than usual? At a very basic level, the average winter temperature for Germany in the 2022/23 winter of 2.9°C was actually slightly colder than the average temperature over the four previous winters of 3.0°C (Deutscher Wetterdienst Climate Data Center, 2023).[17]

A more sophisticated analysis examines so-called "heating degree days", a measure of the severity of the cold and hence the need for heating over a specific time period.[18] The year 2022 had an average of 2736

[17] Comparisons over shorter or longer time horizons yield similar results, i.e. the 2022/23 winter was either slightly warmer or colder than previous winters depending on the precise comparison group. For example, the average temperature over the previous three winters was 3.1°C whereas it was 2.5°C over the previous six winters (though see the point about the time trend in temperatures due to climate change in the next paragraph). Deutscher Wetterdienst defines "winter" as the time period from 1 December to 28/29 February https://www.dwd.de/DE/service/lexikon/Functions/glossar.html?lv2=102936&lv3=103204. Analyses for alternative "winter" definitions using more fine-grained monthly data available through Deutscher Wetterdienst Climate Data Center (2023) are also possible and yield similar results.

[18] Heating degree days (HDD) is an index of the severity of the cold in a specific time period taking into consideration outdoor temperature and average room temperature (in other words the need for heating). The calculation of HDD relies on the base temperature, defined as the lowest daily mean air temperature not leading to indoor heating. The value of the base temperature depends in principle on several factors associated with the building and the surrounding environment. By using a general climatological approach, the base temperature is set to a constant value of 15°C in the HDD calculation.

If $T_m \leq 15°C$ Then $[HDD = \sum_i(18°C - T^i_m)]$ Else $[HDD = 0]$ where T^i_m is the mean air temperature of day i.

heating degree days in Germany - this is less than the ten-year average of 2939 in the years 2012-2021. However, looking at the trend 2022 does not stand out. The linear heating-degree days trend since 1979 is clearly downward sloping due to climate change. This trend would in 2022 have implied around 2850 heating degree days. Hence, a significant share of the warm temperatures in 2022 are explained by the trend, and not "good luck".

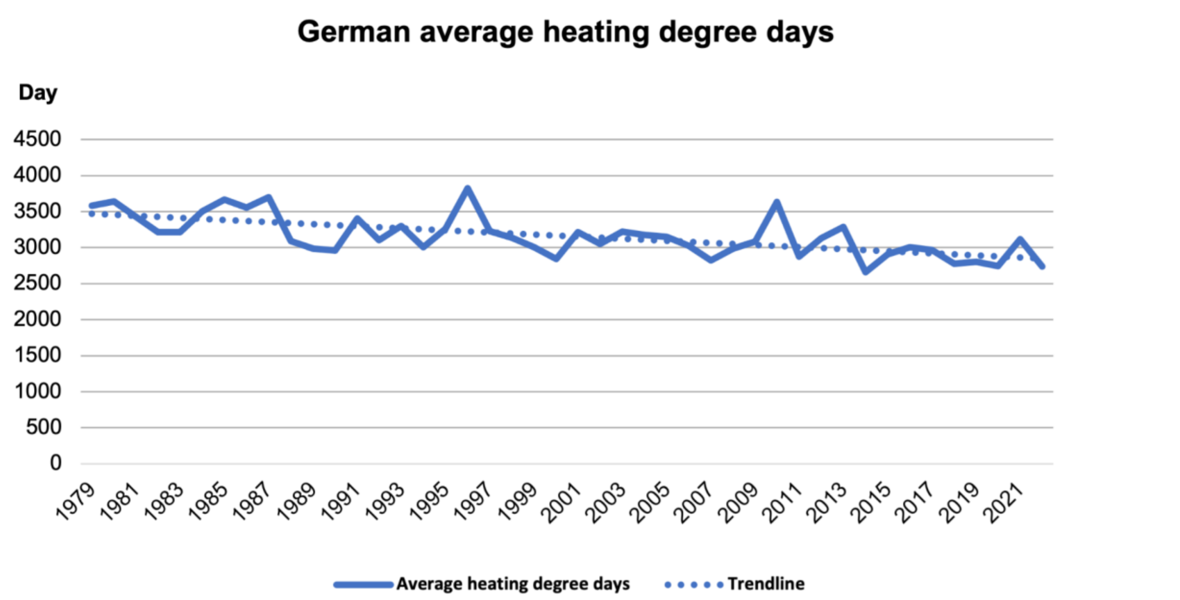

Figure 4: German average heating degree days 1979 to 2022[19]

While heating demand was indeed a bit lower than in past winters, energy supply saw more than one negative supply shock. In particular, maintenance issues at French reactors meant that French nuclear generation in 2022 was 82 TWh below the already low 2021 values. Generating this power with the gas -- that is often the marginal fuel in the northwest European power market – would have meant burning about 160 TWh of gas (equivalent to the German storage capacity).

Moreover, in June 2022, the Freeport LNG plant in the U.S., the fourth-largest LNG liquefaction plant in the world, was put out of action by a fire and only re-started loading cargoes in mid-February 2023. It would have been able to liquify more than 100 TWh of US natural gas, had it not been dysfunctional.[20]

In conclusion, the "bad luck" elements actually exceeded the "good luck" ones over the last year. The role of "good luck" in getting Germany through the winter has been considerably overstated in the popular debate. Instead, it was primarily the economy's ability to adapt in combination with good economic policy

Examples: If the daily mean air temperature is 12°C, for that day the value of the HDD index is 6 (18°C-12°C). If the daily mean air temperature is 16°C, for that day the HDD index is 0.
These calculations are executed on a daily basis, added up to a calendar months and subsequently to calendar years.

[19] Source: https://ec.europa.eu/eurostat/web/products-datasets/-/nrg_chdd_a

[20] Freeport has a liquefaction capacity of about 20 bcm per year - hence more than 100 TWh in the 8 month of its dysfunctionality.

(quick sourcing of alternative gas supplies and well-designed policies to support households and firms) that blunted Putin's energy weapon.

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Appendix: Details on construction of German imports of Russian gas (Figure 3) and counterfactual storage evolution (Figure 2)

We consider monthly natural gas imports and exports to Germany by aggregating data from the ENTSO-G transparency platform API. This allows us to calculate net imports. We use the *Bruegel Dataset on Gas Attribution by EU Country* to attribute a share of this gas to Russia. This allows us to take into account that the European gas market is complex and heavily interconnected, in particular that a country like Germany both imports gas via third countries (e.g. flows of Russian gas through Ukraine Transit which pass through Austria or Czechia) and re-exports part of its direct imports, and to compute the amount of Russian gas that effectively ends up in Germany (either ending up in German storages or being consumed by German households and firms). This is the series plotted in Figure 3. We then use this series on effective imports of Russian gas to calculate the counterfactual storage evolution scenarios in Figure 2. This appendix provides details on the construction of each series. Replication materials including an excel spreadsheet for constructing Figures 2 and 3 can be found here https://benjaminmoll.com/MSZ_replication/.

Bruegel Dataset on Gas Attribution by EU Country

The European gas market is complex and heavily interconnected. Foreign gas enters the market through pipelines or LNG terminals. This gas then continues its journey through European pipelines, often crossing multiple international borders, before being dispersed into city centres and industrial clusters. With gas crossing multiple borders, tracking the true origin is complicated. We consider all gas flows into and across Europe. By doing so, we can apply Wassily Leontief's Nobel prize winning input-output matrix, using the average share of gas in each country to attribute proportions to origin countries.[21] In this way we split gas imports by Russia (Nord Stream, Yamal, Ukraine Transit, Turkstream, Other), Norway, Azerbaijan, North Africa, Domestic production in the United Kingdom, the Netherlands, or elsewhere, and LNG according to source country.

The main dataset used is the ENTSO-G transparency platform. We queried all points both within and entering the EU's gas market. Manual validation was necessary to remove redundant points due to duplication of direction (i.e., when both imports and exports of the same gas are reported), duplicates by operator (i.e., where the same gas is reported by multiple operators and aggregators), duplicates by point (i.e., when points are duplicated, such as through VIPs). We compared the resulting dataset to a range of sources including the IEA, Eurostat, ACER, and in the German case, BNetzA. Our data are broadly consistent across these sources – although discrepancies among the range of sources are noted.

We take LNG data from the Bloomberg terminal. Bloomberg's ship tracking shows the origin of ships which arrive in LNG ports. We combine this monthly proportionally with the LNG send-out recorded from each terminal on the ENTSO-G platform.

[21] While assuming Leontief input-output structures with elasticities of substitution equal to zero is generally inappropriate when analyzing production networks (and may have played an important role for analysts overestimating the economic costs of a gas import stop), this strategy is likely more appropriate for analyzing a fixed physical pipeline network, at least in the short run.

Net imports from Russia taking into account indirect flows (Figure 3)

Using the *Bruegel Dataset on Gas Attribution by EU Country* we attribute a share of imported gas to Russia to arrive at our series for effective imports from Russia taking into account indirect flows plotted in Figure 3. One noteworthy feature of this series is that effective net imports from Russia differ substantially from direct imports via the Nord Stream pipeline. On the one hand, there are substantial onward exports from Germany, i.e., not all of the gas imported via Nord Stream served the German market but some was also re-exported. On the other hand, flows through Ukraine Transit which pass through Austria or Czechia and end in Germany add to the amount of Russian gas ending up in Germany. In practice, re-exports were larger than indirect imports resulting in effective net imports that were smaller than direct imports via the Nord Stream pipeline. For example, in April 2022 effective imports were around 35 TWh whereas direct imports were approximately 50 TWh. This is important because it means that the cumulative amount of Russian gas imported after March 2022 and actually ending up in German storages or being consumed in Germany was lower than measured direct imports.

Counterfactual storage evolution with 1 April 2022 cut-off (Figure 2)

Our scenarios begin with actual gas storage of 66 TWh on 1st April 2022 in Germany. We then plot a hypothetical evolution of German gas storage in a world where no Russian gas imports were received after 1st April 2022. Although we focus on outcomes in Germany, our counterfactual scenario considers a cut-off from Russian gas of the European Union as a whole rather than just Germany. Because the European gas market is complex and heavily interconnected, we therefore take into account indirect flows via third countries. Starting from the actual storage level on 1 April 2022, we calculate the counterfactual evolution by subtracting the effective net imports from Russia (calculated as explained above) from total net imports to Germany. Our analysis identifies from an accounting perspective the Russian gas which entered and was consumed or stored in Germany and which is therefore "missing" in the event of an earlier import stop. Our study thus evaluates the German position assuming relative gas flows and consumption remained unchanged.

Note that, in this counterfactual scenario, we do not subtract re-exports, i.e. gas which enters Germany but is then passed on to neighbouring countries (e.g., France, Austria, Czechia). Subtracting re-exported gas would effectively assume that, in the counterfactual scenario in which Russian gas is cut off on 1 April, Germany would have just kept re-exporting the same total amount of gas as if nothing had happened and would thus overstate the amount of missing Russian gas.

To be precise, consider the April 2022 import numbers from the previous section. As noted there, direct imports from Russia were around 50 TWh but Germany re-exported around 15 TWh of this gas so that 35 TWh of Russian gas were actually consumed or stored in Germany. In our counterfactual scenario, when the Russian gas stops flowing on 1 April 2022 and direct imports from Russia drop by 50 TWh, Germany cuts its consumption and storage inflows by 35 TWh and its re-exports by 15 TWh. If we had instead assumed that German net imports would fall by 50 TWh, we would have effectively assumed that Germany would have just kept re-exporting the same 15 TWh as if nothing had happened and would thus overstate the drop in gas available for consumption and storage. We then calculate the counterfactual storage level on 1 May 2022 as follows: starting from the initial storage level on 1 April 2022 of 66 TWh, we add total net imports from all countries minus these 35 TWh of missing Russian gas and then subtract total German domestic consumption.

We isolate the impact on Germany while not considering the impact on neighbouring countries. As discussed in the main text, our estimate is likely a lower bound, as Germany would have been able to increase imports without running out of storage capacity and demand would have likely been lower.