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Gas demand in times of crisis

The response of German households and industry to the 2021/22 energy crisis

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Abstract. Europe is in the midst of the most severe energy crisis in a generation, at the core of which is the continuously plummeting supply of Russian natural gas. With alternative supply options being limited, natural gas prices have surged. This paper empirically estimates the response of natural gas demand to the price increase, using data from Germany—the so far largest consumer of Russian natural gas. We identify the crisis response of small and large consumers separately, controlling for temperature, gas-fired power generation, and economic activity. For small consumers, including mostly households, we find a substantial demand reduction of 6% from March onwards—most likely due to political and ethical considerations after the start of Russia’s invasion of Ukraine. For industrial consumers, demand reductions started much earlier in August 2021, when wholesale prices for natural gas started to surge, with an average reduction of 11%. We conclude that voluntary industrial demand response has played a significant role in coping with the energy crisis so far.

1 Introduction

A historic crisis. Europe is amid the most severe energy crisis since the oil price shock of 1973. Since early 2021, natural gas prices have been on a steep rise, with average prices above 100 €/MWh between October 2021 and mid-2022. This is about seven times higher than the long-term pre-Covid price levels of around 15 €/MWh. While other commodities, including steam coal, crude oil and oil products, carbon allowances, and electricity also have witnessed strong price increases, the increase in gas prices is extraordinary. For Germany, at an annual consumption of close to 1,000 TWh of natural gas, the price increase corresponds to a total volume of about 2% of GDP. Residential retail prices have also increased, but with a time lag (Figure 1).

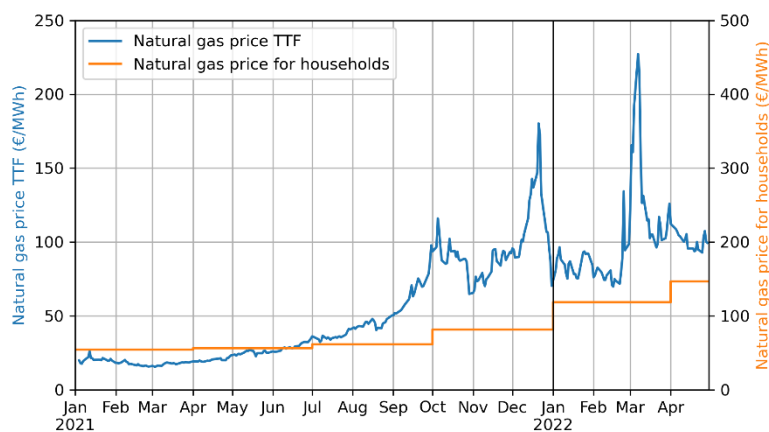


Figure 1: Prices of natural gas at the European wholesale market and at the German retail market. Wholesale prices from the Title Transfer Facility (TTF) spot market; retail prices are the average of existing and new single-family house contracts according to the German Association of Energy and Water Industries BDEW

Russia's role. While the post-pandemic recovery of global natural gas demand has driven up prices around the world, the most important driver of European gas prices was Russia's reduced supply. Russia's Gazprom avoided filling its European gas storages during 2021 and stopped supplying the spot market in the fall. Starting in the winter, also long-term contracts with individual countries and firms were no longer supplied, usually justified with dubious reasons.

Demand response is key. With domestic European gas supply being on a long-term downward trend, Europe turned to liquefied natural gas (LNG) as a substitute, but tight global LNG markets and limited European import terminal capacity lead to a surge in European natural gas prices. As Russia might reduce deliveries further or stop the flow entirely at any time, reducing gas consumption has become key to European security of energy supply. We are interested in understanding if and to what extent firms and households have responded to the energy crisis by reducing their consumption of natural gas so far. Such response could be driven by prices or by political or ethical considerations, in particular since the Russian invasion of Ukraine on 24 February 2022.

Household surveys. In several household surveys, a significant share of respondents has reported to save energy.¹ However, it is questionable how reliable such self-reported behavior is. Methodological shortcomings, such as a non-representative sample of respondents or the social desirability of certain

¹ <https://www.bitkom.org/Presse/Presseinformation/Ukraine-Krieg-Haelfte-spart-fossile-Energie>,
<https://www.tado.com/at-de/pressemitteilungen/energy-consumption-poll>,
<https://youngov.de/news/2022/05/24/deutsche-sorgen-sich-aufgrund-der-steigenden-energie/>

responses, could bias the results. Also, these surveys cannot be used to estimate the size of the response.

Industry press releases. With gas prices reaching all-time highs in the fall of 2021, news emerged that energy-intensive industries were reducing their production (see our summary in Stiewe et al., 2022). Ammonia and aluminum industries were the first to do so in September-November 2021, when natural gas prices reached 50 €/MWh. In March 2022, when natural gas prices temporarily spiked above 200 €/MWh, production cuts were reported by further industries, including paper, brick, and steel. However, this anecdotal, self-reported, and qualitative evidence cannot be translated into a quantification of how much natural gas has been saved in the industry as a whole.

The case of ammonia. To better understand the dynamics of industrial demand response, we previously analyzed the case of the ammonia industry as one of the largest gas consumers in Germany (Stiewe et al., 2022). We found that ammonia production was cut by as much as 40% in the third quarter of 2021, which alone saved about 0.03 TWh/d of natural gas or 3% of Germany's industrial demand. A spike in ammonia imports allowed downstream German fertilizer producers to maintain a stable level of production. Since November 2021, however, ammonia production recovered, which we explained by ammonia prices increasing more sharply than natural gas prices. It remains unclear, however, whether the case of the ammonia industry is representative of the overall industrial demand.

Year-on-year comparison. In blog posts, press articles, and on social media, numerous reports on reduced natural gas consumption have emerged in the past months.² These calculations are potentially problematic for three reasons: first, some of them are based on preliminary data, which we found to be quite unreliable. Second, the first half of 2021 saw an above-trend industrial gas demand during the post-Covid recovery, which inflates the year-on-year reduction found for 2022. More fundamentally, these year-on-year comparisons often do not control for temperature, business cycles, and electricity generation. In our view, it is misleading to interpret these numbers as a response to the crisis.

This study. To address these shortcomings of previous studies, we use an econometric model that allows us to control for confounders and to better identify to what extent households and firms have adjusted their natural gas consumption *as a response to the crisis*. Given the huge importance of space heating for gas demand, we carefully account for the non-linear relationship between temperature and gas consumption. We also control for seasonality at different time scales, economic activity in different sectors, and the development of gas-fired electricity generation. Using an econometric model does not only allow us to control for multiple variables simultaneously, but also to assess the statistical significance of demand reductions. We apply this model to daily measurements of the aggregate (national) demand of small and large consumers separately.

Findings and relevance. We find a significant gas demand reduction since the beginning of the crisis. The response of industry is much larger than of that households, and timing is different: households really reduced consumption only after Russia's invasion of Ukraine, while industry lowered consumption as early as August 2021, when wholesale prices started surging. In April 2022, which is the most recent data that we could use, residential demand declined by 6% and industrial demand by about 11%. These findings matter for public policy, because they show that prices are an effective means of incentivizing demand reductions. In turn, this implies that energy subsidies, many of which have been introduced as a way to mitigate the crisis, drive up natural gas consumption, which will then further inflate prices.

² <https://www.bruegel.org/2022/04/the-european-union-demand-response-to-high-natural-gas-prices/>, <https://www.bdew.de/presse/presseinformationen/zahl-der-woche-sinkender-gasverbrauch-ein-drittel-weniger-gas/>, <https://twitter.com/tmarzecmanser/status/1542235908103094276> (by ICIS)

2 Data and methods

Data. We use data on the aggregate German natural gas consumption at daily granularity from January 2017 to April 2022. The data were retrieved from Trading Hub Europe (THE), the German market area manager for natural gas. April 2022 was the last month with final data when this study was conducted, and we made the experience that preliminary data can be subject to substantial revisions. Two separate time series are used for small and large consumers. Small consumers include the residential and service sectors and account for 40% of the overall gas consumption, while the remaining 60% are attributed to large consumers in the industrial and power and district heating sectors.³

Method. We use an econometric model identify the response of small and large consumers to the current energy crisis, controlling for other factors driving natural gas consumption (see Appendix for model equations and data sources). In our main models, we capture the effect of the crisis with one dummy variable which is one since August 2021 and zero otherwise. To investigate the evolution of demand response throughout the crisis, we also run models with monthly dummies starting in May 2021, i.e., some months before the beginning of the crisis for comparison. In all model specifications, we exclude holidays, bridge days, and the period between Christmas and New Year, and we control for a linear time trend as well as for weekly and annual seasonality (with dummies for the weekday and for the month of the year). In more advanced specifications of the models for small and large consumers, we additionally control for the following time series.

Small consumers. For small consumers, the most important driver is the ambient temperature because of space heating. We control for this with national heat demand time series of residential and commercial consumers, which we simulate based on spatial temperature data from across Germany. The simulation uses standard load profiles from the German gas industry to account for the non-linearity in the temperature-heating relationship (Ruhnau et al., 2019; Ruhnau and Muessel, 2022). We also include an interaction term between the linear time trend and the simulated national heat demand in the model to avoid seasonality in the residuals.⁴ In a sensitivity run, we also included solar radiation (as this may reduce heating demand), but this parameter was not significant. Finally, we control for economic activity in the retail and hospitality sectors.

Large consumers. For large consumers, we also control for the above-mentioned simulated national space heating demand time series. Its effect turned out to be significant, which may be explained by natural gas use in district heating, which is included in the group of large consumers. In addition, we control for electricity generation from natural gas. While changes in gas-fired electricity generation may be partly induced by the crisis, electricity generation is also affected by many crisis-unrelated factors, such as the availability of wind and solar energy.⁵ Finally, we also control for the economic activity in the producing and manufacturing sectors.

³ Large consumers (with > 1.5 GWh/a consumption) have daily metering, while small consumers are metered annually. The daily aggregate consumption of small consumer is inferred from daily measurements of the overall consumption minus the daily metered consumption of large consumers.

⁴ We interpret the seasonality in the residuals as a sign of different time trends for heat demand at warm or cold ambient temperatures.

⁵ Other relevant examples are the availability of (French) nuclear generation as well as the demand for district heating, affecting the generation patterns of combined heat and power plants.

3 Results

Overall crisis response. Figure 2 summarizes our model estimates for the average change in natural gas demand since August 2021 compared to the period January 2017 to July 2021. Controlling for seasonality, a time trend, temperature, economic activity, and gas-fired electricity generation, we estimate that, as a response to the crisis, the natural gas demand of small and large consumers was significantly reduced by 0.04 and 0.11 TWh/d, respectively. This corresponds a reduction of 3% in the demand of small consumers and a reduction of 6% in the demand of large consumers, compared to the average demand during the months August to April before the energy crisis.

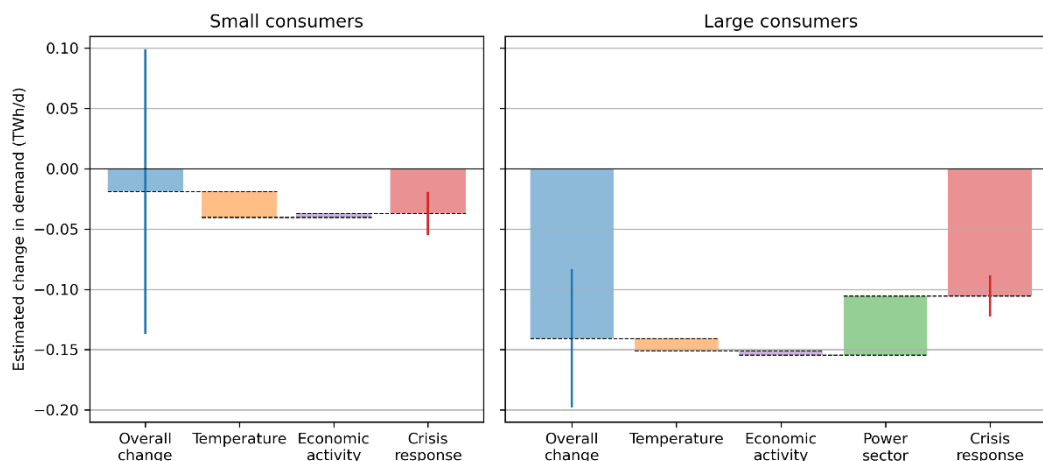


Figure 2: Estimated change in natural gas demand by small (left) and large (right) consumers during the energy crisis (Aug '21 to Mar '22) compared to before the crisis (Jan '17 to Jul '21).

We incrementally control for temperature, economic activity, and gas-fired power generation. The leftmost and rightmost bars indicate the point estimates with none and all these control variables, respectively; the vertical lines on these bars indicate the 5-95% confidence intervals of the estimates; the waterfall indicates the changes in the point estimates when adding control variables.

Temperature. For the overall crisis response, model estimates change little when controlling for temperature. However, the model can much better explain the daily variations in gas demand, which increases the accuracy of the estimates.⁶ Only through this increased accuracy can we identify a statistically significant crisis response for small consumers. Furthermore, the improved accuracy becomes even more important for the following analysis of the monthly evolution of demand response.

Economic activity. The finding that economic activity also has little effect on our estimate of the crisis response implies that, as a response to the crisis, gas demand was disproportionately reduced compared to economic activity. Put differently, the demand reduction was not caused by a general economic downturn in the manufacturing sector but rather by production adjustments in certain energy-intensive industries. One example is the ammonia industry, where ammonia imports substituted for domestic production, allowing for a stable output of the downstream fertilizer industry (Stiewe et al., 2022).

⁶ For both small and large consumers, the R^2 increases from 0.83 to 0.98 and larger, and the confidence intervals of the estimated demand responses become much smaller (indicated by the smaller vertical lines on the rightmost bars compared to that on the leftmost bars in Figure 2).

Power sector. When also controlling for electricity generation, the estimated demand reduction decreases from 0.15 to 0.11 TWh/d. We attribute the 0.04 TWh/d difference in the model results to reduced natural gas consumption in the power sector. This reduction in the power sector may only partly be interpreted as a crisis response, e.g., if coal substitutes for gas as a response to high natural gas prices or if electricity demand decreases because of high electricity prices (driven by high gas prices). However, our estimated reduction of natural gas use in the power sector is also affected by many factors unrelated to the crisis, such as the availability of wind and solar energy or the availability of (French) nuclear generation (Hirth and Schlecht, 2022).

Industry. We attribute the estimated 0.11 TWh/d reduction, which remains in the model with all control variables, to the extraordinary response of industrial consumers to the energy crisis. With an average generation of 1 TWh/d, this means a reduction of about 11% since the beginning of the crisis. The remainder of this paper will focus on the evolution of the isolated crisis response of residential and industrial consumers.

Evolution of the response. Figure 3 provides further insight into the evolution of the estimated demand response to the energy crisis, controlling for temperature, economic activity, and gas-fired electricity generation. While we find that the demand of industrial consumers was significantly reduced in every month since July 2021, the estimated demand reductions of small consumers tend to become significant only toward the end of 2021, with a substantial reduction becoming apparent only in March and April 2022.

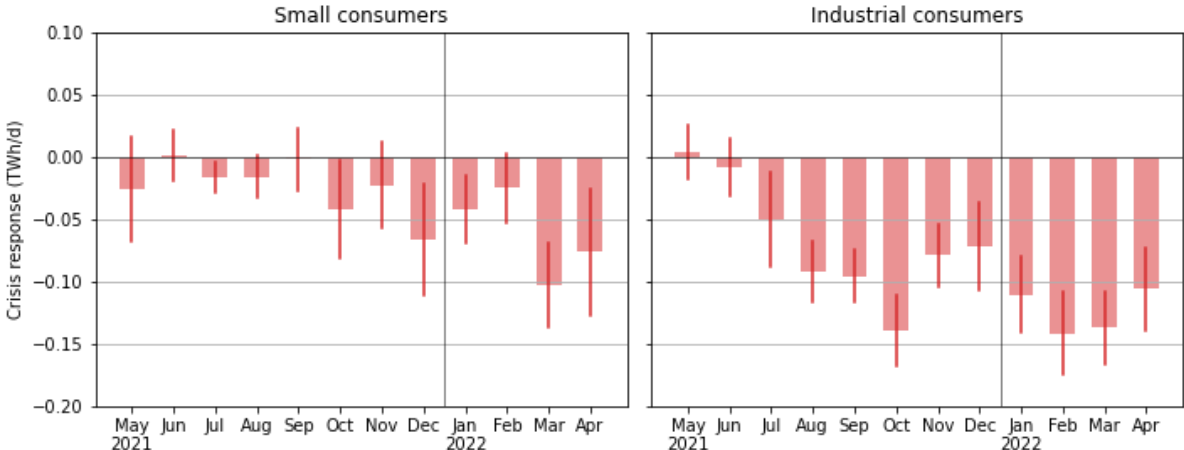


Figure 3: Estimated crisis response of natural gas demand by small (left) and industrial (right) consumers for each month since Apr '21 compared to previous demand (Jan '17 to Mar '21).

We control for temperature, economic activity, and gas-fired power generation. The bars indicate the monthly point estimates and the vertical lines the corresponding 5-95% confidence intervals.

Small consumers. The pattern of the response can be well explained by price exposure. Most small-scale consumers have fixed-price tariffs for one year, so the wholesale price trickled down only after some time. The lagged response matches well with the lagged increase in retail prices to which these consumers are exposed (recall Figure 1). In addition, the substantial response from March 2022 onwards is in line with surveys identifying political and ethical considerations in face of Russia’s invasion of Ukraine, which started on 24 February 2022, as a major driver of demand reductions. In relative terms, the estimated -0.1 and -0.08 TWh/d change in demand in March and April 2022 translates to a reduction of about 6% each, compared the expected demand without crisis response as estimated with our model based on March and April 2022 temperatures.

Large consumers. For large consumers, the demand was significantly reduced by 0.7 to 1.4 TWh/d since wholesale prices started to surge in August 2021 (recall Figure 1). These estimates translate to relative reductions of 7 to 14% of the average industrial demand of 1 TWh/d. The large demand reduction from the beginning of the crisis onwards matches well with industrial press releases about demand reductions starting at that time (Stiewe et al., 2022). After an exceptionally large reduction in October 2021, demand partly re-increased in the end of 2021, before stabilizing at lower levels in the beginning of 2022. The somewhat smaller reduction in April 2022 compared to March 2022 may be explained by the somewhat lower wholesale prices for natural gas (Figure 1).

The role of ammonia. This pattern in industrial demand response can be compared to our earlier study of the ammonia industry (Stiewe et al., 2022). The largest reduction in ammonia production appeared in September and October 2021, which coincides with the stark reduction in aggregate demand in October 2022. Production cuts in ammonia alone explain about 0.02 of the 0.09–0.14 TWh/d aggregate reduction.⁷ Since November 2021, ammonia production re-increased, because ammonia prices increased faster than natural gas prices, which also matches well with the somewhat smaller estimates of the aggregated demand reduction in the end of 2021. The further reduction in the aggregate demand in the first quarter of 2022 cannot be explained by ammonia production, which remained relatively stable. This reduction must hence be due to a further reduction in other industries.

4 Conclusion

Policy implications. We conclude that industrial demand response plays an important role in the current energy crisis. Our findings suggest that industrial consumers have adjusted gas consumption to rising gas prices and also that households have responded, albeit somewhat weaker. As wholesale gas prices have doubled again during June 2022 following a further steep cut in Russian deliveries, we expect further significant reductions in industrial gas consumption in the summer. This has important implications for policy. Market prices are an effective means of coordinating and incentivizing demand reductions. This implies that energy subsidies, many of which have been hastily introduced as a way to mitigate the crisis, drive up natural gas consumption, which in turn will further inflate prices. Our findings suggest that exposing consumers to prices and avoid diluting prices through subsidies is important to reduce gas consumption.

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⁷ In Stiewe et al. (2022), we find ammonia production cuts of about 70 kt/month during September and October 2021. Given a consumption of 9 MWh natural gas per 1 t of ammonia produced, this translates into a reduction in natural gas demand of about 0.6 TWh per Month or 0.02 TWh/d.

Appendix

Model equations. The econometric models are based on the following equations:

$$gas_d^s = a_0 + a_1 crisis_d + \mathbf{a_2 time}_d + \mathbf{a_3 heat}_d + \mathbf{a_4 econ}_d^s + e_d \quad (1)$$

$$gas_d^l = a_0 + a_1 crisis_d + \mathbf{a_2 time}_d + \mathbf{a_3 heat}_d + \mathbf{a_4 econ}_d^l + a_5 power_d + e_d \quad (2)$$

where

gas_d^s, gas_d^l	gas consumption of small and large consumers
$crisis_d$	crisis dummy (alternatively: vector of monthly crisis dummies)
$time_d$	vector of monthly and weekday time dummies as well as a linear time trend
$heat_d$	vector of simulated residential and commercial heating profiles, solar radiation, as well as an interaction term of residential heating and time
$econ_d^s$	vector of economic activity of retail and hospitality sectors
$econ_d^l$	vector of economic activity of producing and manufacturing sectors
$power_d$	gas-fired electricity generation
$a_0 \dots a_5$	model parameters (bold font: vectors of parameters)
e_d	error term

The subscript d indicates the daily resolution of the model. Model parameters are estimated with an ordinary least squares (OLS) estimator. In the main text, we report the results for a_1 , which estimates the demand response to the crisis.

Data sources. The following table summarizes our data sources.

Table A1: Data sources

Parameter	Source
Measured gas consumption	Trading Hub Europe
Simulated residential and commercial heating profiles	When2Heat dataset
Economic activity	German Statistical Office (DESTATIS)
Gas-fired electricity generation	European Network of Transmission System Operators of Electricity (ENTSO-E)