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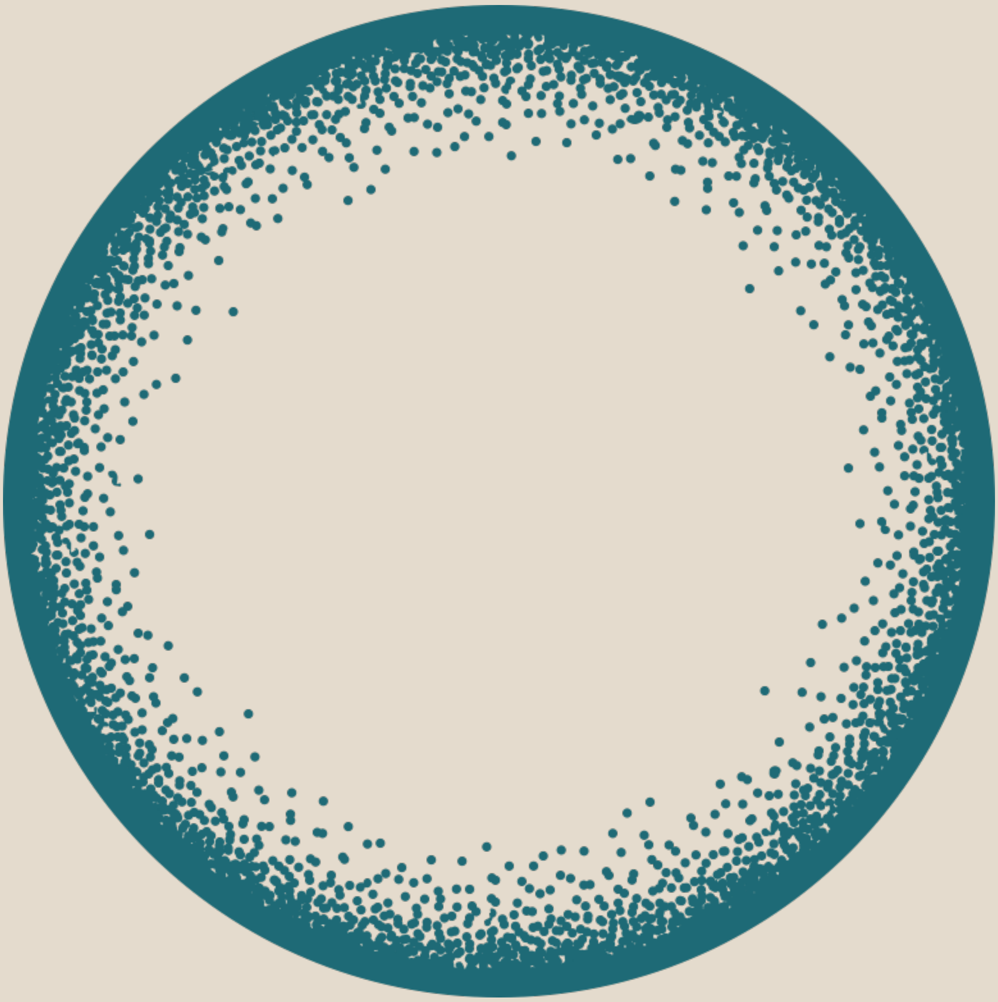

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THE ENERGY CRISIS IN GERMANY AND THE DESIGN OF A RESILIENT ENERGY SYSTEM

Tom Krebs*, University of Mannheim

Abstract

This study analyzes the short-run effects on the German economy of the fossil energy crisis in 2022 and discusses some implications for the design of a resilient, renewable energy system. The study shows that the energy crisis led to a short-run output loss comparable to the output losses associated with the Covid-19 crisis in 2020 and the financial crisis in 2008. In addition, real wage losses during the energy crisis far exceed the corresponding losses during the Covid-19 crisis and the financial crisis. Finally, the economic costs of the energy crisis would have been much larger in a worst-case scenario that could be avoided through a combination of government decisions and luck. Thus, large negative shocks to the supply of energy have high economic costs, and the design of a future energy system that is resilient to such shocks should have the highest priority. The study discusses two requirements for a resilient energy system based on renewable energy and two policy instruments that can help meet these requirements. First, there is the need to deal with the risk that the production of renewable energy from wind and solar power is extraordinarily low for several weeks or months due to adverse weather conditions. For Germany, this requires the build-up of sufficient reserve capacity using (hydrogen-ready) gas-based power plants. Second, there is the need to provide sufficient capacity to generate electricity "in normal times" using variable renewable energy sources. Public insurance against long-run price risk for the producers of renewable energy can spur the necessary investment in wind and solar power. To ensure efficient use of public finances, these insurance contracts should be fair in the sense that from an ex-ante perspective the government neither gains nor loses money.

JEL codes: E30, E32, E37, H12, Q40, Q43, Q48

Keywords: Energy crisis, cost of crisis, supply shocks, resilience, renewable energy, public insurance

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1. INTRODUCTION

There is a political consensus that Germany and Europe need to achieve climate neutrality by 2045, respectively 2050. In a future climate-neutral economy, renewable electricity in combination with renewable hydrogen will be the main energy input into the production process. Thus, the supply of renewable energy will strongly affect economic activity and living standards. The fossil energy crisis of 2022 has highlighted the economic and social costs of large energy supply disruptions. It is therefore of great importance to design an energy system that is resilient in the sense that it minimizes the possibility of future energy crises caused by large supply shocks.

This study proceeds in two steps to address the issue of a resilient energy system. In a first step, the study shows that in Germany the energy crisis in 2022 is already an economic crisis comparable to the Covid-19 crisis in 2020 and the financial crisis in 2008. In addition, the economic costs would have been much larger in a worst-case scenario that was avoided through a combination of government decisions and luck. In other words, large negative shocks to the supply of energy matter a lot, and therefore the design of an energy system that is resilient to such shocks should have the highest priority. In a second step, the study outlines the main components of a resilient energy system based on renewable electricity and derives some policy implications for Germany.

In the public debate, some economists have suggested that the energy crisis had only moderate economic effects in Germany since gross domestic product (GDP) barely declined.[1] Put differently, the large shock to the supply of natural gas that followed the Russian invasion of Ukraine in February 2022 did not matter much. There are at least two reasons to be skeptical of this claim.

First, to assess the impact of the energy crisis on GDP, a simple look at the time path of GDP during the energy crisis is not enough. We need to know the counterfactual, that is, we need to know the path of GDP in the hypothetical scenario without an energy crisis. Once we have this counterfactual, the aggregate output loss caused by the energy crisis can be computed as the difference between GDP in the scenario without a crisis (unobserved scenario) and GDP in the scenario with a crisis (observed scenario). Clearly, we can disagree on the nature of the counterfactual, but there should be no disagreement that any useful analysis of the cost of crisis requires spelling out a counterfactual.

Second, one should look beyond GDP to assess the economic impact of a crisis. The real wage is an alternative indicator that measures the inflation-adjusted income from (formal-sector) work. Of course, real wages and GDP often move together. However, these two measures diverged substantially during the energy crisis in Germany. While GDP declined only mildly, real wages took a nosedive, though there has been some recovery of real wages in the first quarter of 2023. Indeed, in

[1] See, for example, Moll, Schularick, and Zachmann (2023), Sandbu (2023), and Tabarrok (2023). On social media, some economists even declared that “it is time for a victory lap”.

2022 German workers experienced the largest drop in real wages since 1950 – the first year in German post-war history for which data are available.

This study computes the one-year output and wage losses in Germany during the energy crisis by comparing the values of these two economic indicators in a scenario without an energy crisis to the values in a scenario with the energy crisis. The values of GDP and real wages in the unobserved scenario without the energy crisis are taken from the before-crisis consensus forecasts of five economic research institutes (DIW, Ifo, IfW, IWH, RWI) that also conduct the business-cycle analysis for the German government (GD, 2022a).[2] These forecasts are in a sense the best available information we have regarding the development of GDP and real wages in a hypothetical German economy without an energy crisis, where the beginning of the energy crisis is dated to the Russian invasion of Ukraine in February 2022. Clearly, this approach captures all direct and indirect effects on the German economy of the Russian war in Ukraine (rise in energy prices, rising uncertainty, the reaction of monetary and fiscal policy) and this should be kept in mind when interpreting the results.

The results of our analysis are presented in Table 1. To put the numbers into perspective, Table 1 also shows the corresponding economic losses in the Covid-19 crisis of 2020 and the financial crisis of 2009 using an identical method across the three crises.

Table 1. One-year output and wage losses in Germany for three economic crises

	Output loss	**Real wage loss**
Energy crisis 2022/23	**4.3 %**	**3.4 %**
Covid-19 crisis 2020	**2.5 %**	**0.8 %**
Financial crisis 2008/09	**5.8 %**	**0.4 %**

Note: Output and wage losses are the difference between before-crisis forecasts and actual values of quarterly GDP and quarterly real wages one year after the beginning of crisis. Energy crisis Q2-2022 to Q1-2023, Covid-19 crisis Q1-2020 to Q4-2020 and financial crisis Q4-2008 to Q3-2009. Forecasts are taken from the consensus forecast of the five economic research institutes DIW, Ifo, IfW, IWH, and RWI (Gemeinschaftsdiagnose, GD).

Table 1 shows that the output loss during the energy crisis is already somewhat larger than the output loss during the Covid-19 crisis and somewhat less than the loss during the financial crisis of 2009.

[2] "GD" is short for "Gemeinschaftsdiagnose", which is the German term for the joint economic analysis, respectively joint economic forecast, of the five economic research institutes DIW, Ifo, IfW, IWH, and RWI. Since June 2022 the DIW stopped participating in the joint economic forecast, and the analysis is conducted in collaboration with the two Austrian economic research institutes IHS and Wifo.

The output loss during the energy crisis is mainly driven by the fact that economic growth was expected to be very strong before the energy price shock hit the German economy in 2022, whereas output growth before the Covid-19 crisis and the financial crisis was expected to be modest. Table 1 also shows that the loss in real wages during the energy crisis exceeds the corresponding losses during the Covid-19 crisis and the financial crisis. In short, the energy crisis in Germany was an economic crisis of a magnitude comparable to the Covid-19 and the financial crisis, but the negative effect on workers' wages has been stronger.[3]

The output losses depicted in Table 1 depend on the estimate of the GDP path in the hypothetical scenario without an energy crisis -- the so-called counterfactual. The consensus forecasts of the five economic research institutes constitute a good estimate of this output path if i) these institutes have produced relatively good forecasts in the past in "normal times" and ii) there has been no major macro shock unrelated to the energy crisis (the Russian war in Ukraine) hitting the German economy in 2022. This study provides some arguments that both conditions are met, though there is a large degree of uncertainty. Future work might lead to updates to the estimates in Table 1 and shed some light on the various economic channels causing the aggregate economic losses.

The energy crisis of 2022/2023 had large economic and social costs (Table 1), but it could have been worse. Specifically, gas prices rose quickly to unprecedented heights in the summer of 2022, but they also quickly declined after reaching their peak in August and Germany did not experience a gas shortage. In other words, a worst-case scenario could be avoided through a combination of government decisions and luck. We will never know for sure what would have happened in the hypothetical worst-case scenario, but the economic analyses conducted by the five economic research institutes (GD, 2022a, b, c) and the German central bank (Bundesbank, 2022a, b) in spring and early summer 2022 can give us a sense of the possible damage that could have occurred. Their model simulations suggest a short-run loss of (quarterly) GDP between 8 percent and more than 10 percent depending on the severity of the gas shortage. In addition, in the worst-case scenario, inflation rates and real wage losses would have been substantially higher than the already high levels that were observed in the "best-case" scenario.[4]

The second part of this study discusses the design of an energy system for a climate-neutral economy that is resilient in the sense that it minimizes the possibility of an energy crisis caused by large disruptions in the energy supply. As demonstrated by the energy crisis in 2022/23, resilience is

[3] The focus of the current study is on the short-run cost of the energy crisis. Clearly, there is also the danger that the current crisis causes long-lasting damage to the economy. The long-run impact of the crisis is a pressing policy issue, which cannot be discussed in the current study because of space limitations.

[4] Krebs (2022) surveys the different model simulations available in spring 2022 and concludes that they imply an output-loss in the range of 5 – 12 percent in the worst-case scenario that (fortunately) did not occur. See section 2.6 for details.

a highly important property since the economic and social costs of non-resilience are high. The current paper does not provide a comprehensive analysis of a resilient energy system for a climate-neutral economy. Instead, it discusses two requirements for a resilient energy system based on renewable energy and two policy instruments that can help meet these requirements.

First, the future energy system in Germany and Europe needs to provide sufficient capacity to generate electricity in times when variable renewable energy sources generate relatively little electricity. Specifically, there is the macroeconomic risk that in one particular year, the production of renewable energy from wind and solar power is extraordinarily low for several weeks or months due to adverse weather conditions (*Dunkelflaute*). For Germany, this means a heavy reliance on (hydrogen-ready) gas-based power plants as reserve capacity when solar and wind power plants produce little electricity.[5] Regardless of the details of the future system of reserve capacity, one important insight holds quite generally: The social cost of not investing in sufficient reserve capacity is large. Specifically, this study shows that the economic costs of the fossil energy crisis 2022/2023 in Germany already amount to 100 billion Euro, and with 100 billion Euro one can build quite a few power plants whose main function is to provide reserve capacity in a climate-neutral energy system.

Second, the future energy system in Germany and Europe needs to provide sufficient capacity to generate electricity "in normal times" using variable renewable energy sources. For Germany, this requires doubling of electricity production from wind and solar energy until 2030, a goal that can only be achieved if current investment levels in wind and solar plants are substantially increased. One policy instrument to support the necessary increase in renewable energy investment is the public insurance of long-run electricity price risk for electricity producers through two-sided contracts-for-difference (Newbery, 2023, Neuhoff et al., 2023). To ensure efficient use of public finances, these insurance contracts should be offered to private companies in a transparent process and should be fair in the sense that they have symmetric pay-outs in expectations. From an ex-ante perspective, the government should neither gain nor lose money on these insurance contracts.

2. ENERGY CRISIS IN GERMANY

2.1. Energy Prices

The energy crisis in Germany and Europe was mainly a fossil energy crisis since its ultimate cause was a large, negative shock to the supply of natural (fossil) gas from Russia.[6] In Germany, about half of all households use natural gas for heating, energy companies use natural gas to generate electricity and a large part of industrial production uses it to generate process heat or as a basic input. This strong

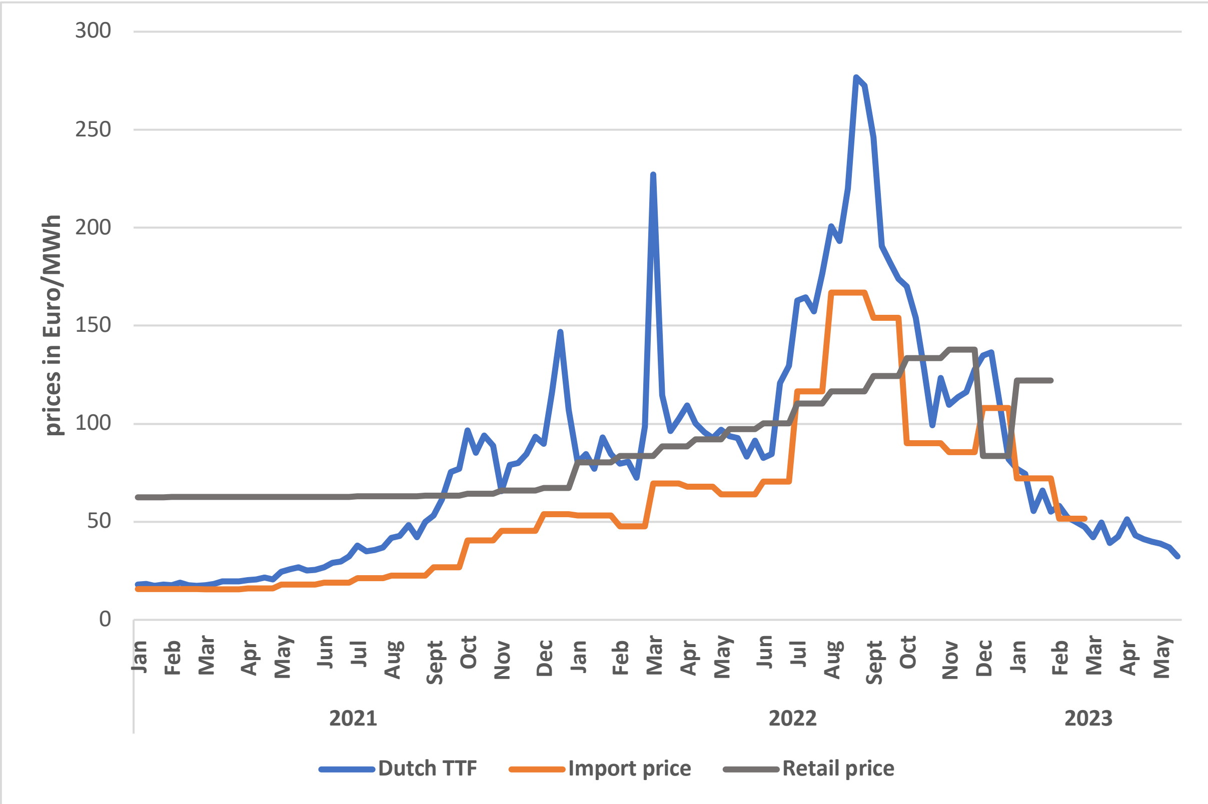
[5] Currently these gas-based power plants mainly use natural gas, but in the future natural gas will be replaced by renewable hydrogen.

[6] Of course, prices for the fossil fuels "coal" and "oil" also increased in Germany and Europe, but the increase in gas prices was more pronounced.

dependency means that movements in the supply and price of natural gas have substantial effects on economic activity and society.

The next figure shows the development of three types of prices for natural gas: The price determined through trading in European gas markets, the price paid by companies importing gas to Germany, and the price paid by German end users (households and small businesses).

Figure 1: Natural Gas Prices



Sources: Dutch TTF prices from Statista; import prices and retail prices from Federal Statistical Office (Statistisches Bundesamt or Destatis).

The figure shows that retail prices follow import prices with some time lag, and import prices follow in turn market prices with a lag. Further, market prices are the most volatile and user prices are the least volatile. In other words, user prices are a smoothed version of market prices. The figure also shows that fossil gas prices have increased dramatically since spring 2021 and have declined after market prices reached their plateau in August 2022. In this sense, the energy price shock was pronounced, but relatively short-lived. However, gas prices in spring 2023 are still substantially higher than in spring 2021.

Figure 1 shows that gas prices increased strongly after the Russian invasion of Ukraine on February 24, 2022. The beginning of the war in Ukraine is usually considered the decisive event that marks the beginning of the energy crisis in Europe, which finally led to the complete stop of German gas imports from Russia in August 2022. This study follows this convention. However, natural gas prices already started to rise in the summer of 2021, and in this sense, the beginning of the energy crisis in Europe predates February 2022.[7]

Figure 1 also shows two turning points of market prices in August 2022 and December 2022 that are associated with two specific events. First, towards the end of August, it became clear that gas tanks would be fully filled by October and the German government eased up on its strategy of buying natural gas via the Trading Hub Europe GmbH in world markets at any price (Business Insider, 2023). Second, in December 2022 EU member countries finally agreed to introduce a common gas price cap at 180 euros per megawatt-hour (Reuters, 2022). The market reactions to these events show that government announcements, if backed up by fundamental developments, can strongly move markets.

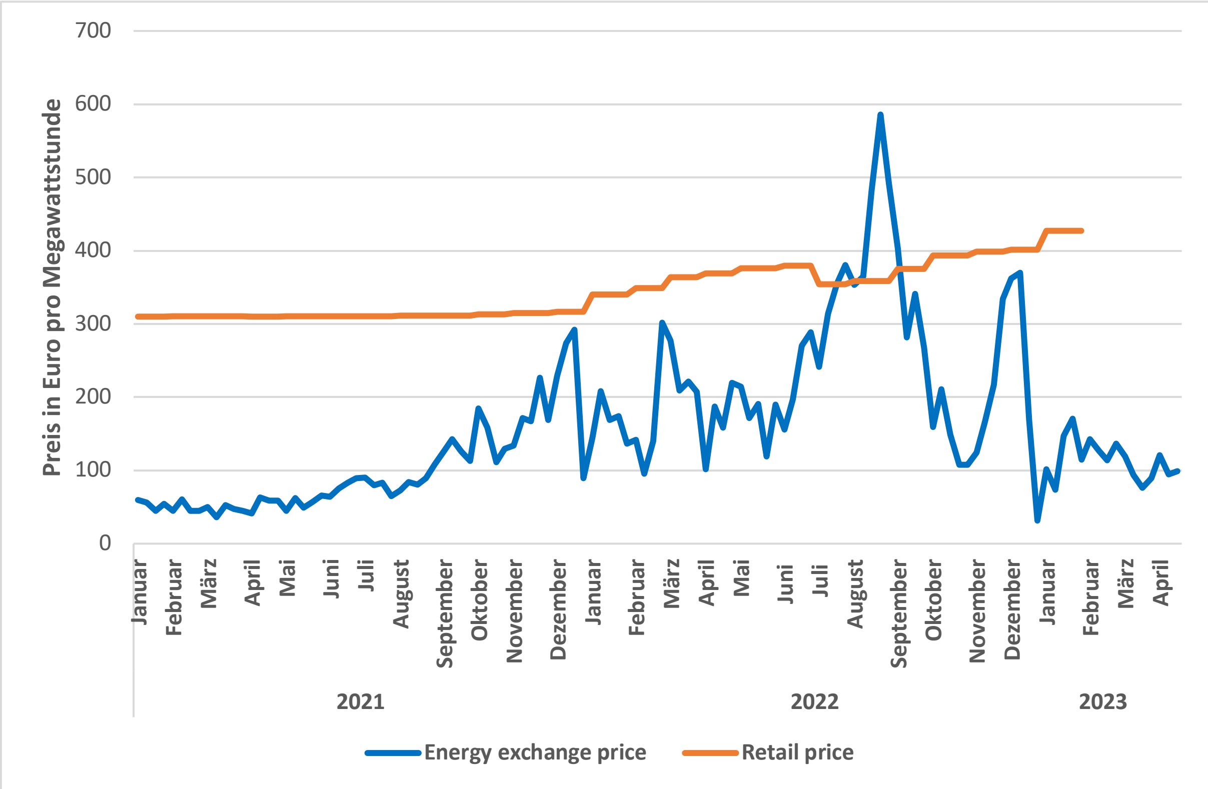
Finally, Figure 1 shows that, in the long run, market prices and import prices roughly coincide and that both are significantly lower than user prices. The difference between market prices and user prices is due to taxes, transportation costs, and profits made by energy companies. In the past (until spring 2021), this difference amounted to roughly 50 euro per megawatt-hour.

Gas prices also have an effect on electricity prices through the merit order system. Specifically, the price of (additional) electricity is determined by the operating power plant with the highest marginal cost, which has often been gas-fired power plants in 2022. In this sense, the hike in gas prices depicted in Figure 1 has been the main drive behind rising electricity prices in 2022. This constitutes another important channel through which natural gas prices affect households, companies, and the economy. Clearly, this channel will gain importance when the German economy moves closer to climate neutrality.

Figure 2 depicts the evolution of two types of electricity prices: The market price of electricity and the price paid by end users in Germany. A comparison of Figures 1 and 2 reveals that electricity prices followed the increase of gas prices, though there are also movements in electricity prices unrelated to gas price movements. In addition, the increase in gas prices has been more pronounced than the increase in electricity prices. Specifically, while gas prices for end users roughly doubled in the one-year period January 2022 to December 2022, electricity prices for end users "only" increased by 40 percent in the same period.

[7] The gas price increase in 2021 is to a certain extent also related to the Russian war in Ukraine. Specifically, the threat of a Russian invasion has been debated since the early summer of 2021, which could explain part of the increase in gas prices that began in May 2021 – market participants are forward-looking and are taking into account the possibility of future events. For example, when Russia started to amass troops at the Ukrainian border at a large scale in December 2021, prices in the gas market spiked.

Figure 2: Electricity Prices



Sources: Electricity exchange price from SMARD; retail prices from Federal Statistical Office (Statistisches Bundesamt).

As in the case of natural gas, the market price of electricity is substantially lower than the price paid by end users. In the past (until spring 2021), this long-run difference was more than 200 euro per megawatt-hour in Germany mainly due to heavy taxation of electricity in the past.[8]

Germany imports a large part of its fossil energy from abroad. For example, in the last few years, only 5 percent of the natural gas used in Germany was produced in Germany (AGEB, 2023). This implies that an increase in energy prices as depicted in Figure 1 leads to a loss of national income as long as the reduction in energy use is not sufficient to compensate for the increase in prices. In 2022, energy consumption declined by 5.4 percent, whereas the cost of net energy imports increased by 95 percent from 70 billion Euro to 137 billion Euro (AGEB, 2023). In other words, the direct effect of rising energy prices was a loss of about 2 percent of national income.

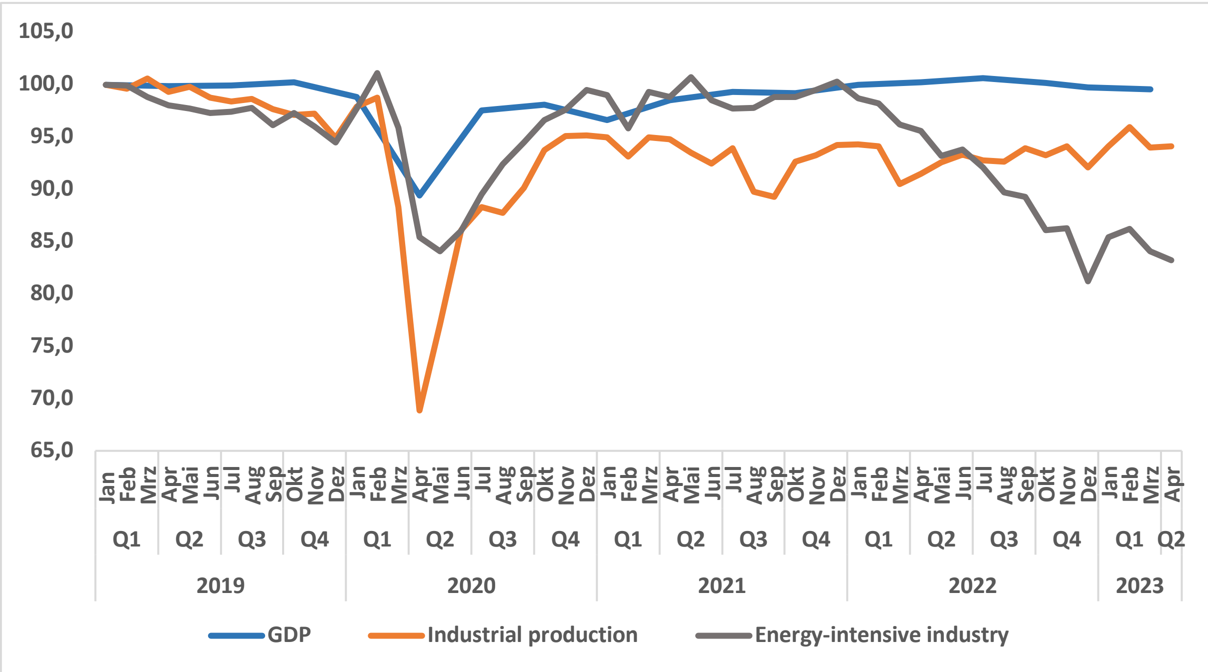
2.2 Production

A single economic measure often dominates the discussion in the media -- the gross domestic product (GDP). This economic yardstick measures the aggregate production of goods and services in an economy. Figure 3 depicts the time path of aggregate production (real GDP), industrial production, and

[8] In 2021, all taxes on electricity including value-added taxes amounted to 160 euro per megawatt-hour (BDEW, 2023). The German government has recently abolished several taxes on electricity suggesting that the long-run differential between market price and retail price should have declined.

production of the energy-intensive manufacturing sectors since January 2021. The figure shows that the production of energy-intensive manufacturing dropped by almost 20 percent in the period from March 2022 to December 2022. In other words, the energy-intensive industry fell into a deep recession in 2022. However, real GDP and total industrial production barely declined during the energy crisis in Germany, though aggregate production (GDP) declined for two consecutive quarters in Q4-2022 and Q1-2023. Thus, the German economy experienced what is commonly referred to as a recession in 2022/23.

Figure 3: GDP and Industrial Production



Source: Federal Statistical Office (Statistisches Bundesamt).

In the public debate, some economists have suggested that Figure 3 and similar figures show that the energy crisis had only a moderate economic effect since real GDP barely declined (Moll, Schularick, and Zachmann, 2023, Sandbu, 2023, and Tabarrok, 2023). Put differently, the large shock to the supply of natural gas following the Russian invasion of Ukraine in February 2022 (see Figure 1) only had small effects on the economy. This argument, however, is not convincing for two reasons.

First, to assess the impact of the energy crisis on real GDP, a simple look at the time path of GDP during the energy crisis is not enough. We need to know the counterfactual, that is, we need to know the path of GDP in the hypothetical scenario without an energy crisis. Once we have this counterfactual, the aggregate output loss caused by the energy crisis can then be computed as the difference between GDP in the scenario without a crisis (unobserved scenario) and GDP in the scenario with a crisis (observed scenario). The next section (section 2.3) analyzes the output cost of the energy crisis in 2022 using this method.[9]

Second, the real wage (inflation-adjusted labor income) is in many cases a better measure of the economic impact of a particular event on people's life. Of course, GDP and real wages often move together. However, the analysis in subsection 2.4 below shows that these two measures diverged substantially during the energy crisis in Germany. Broadly speaking, real GDP declined less than real wages because net payments for energy inputs to foreign countries (Norway) increased and capital income decreased less than labor income. In other words, rising energy prices lead to a loss of national income for given GDP in an energy-importing country, and high inflation leads to a drop in labor income relative to capital income if nominal wages are sticky and firms can pass increasing energy costs on to customers.[10]

2.3 Output Loss

The five economic research institutes that perform business cycle analyses for the German government provide estimates of the economic development in the hypothetical case that there would have been no energy crisis in Germany.[11] Specifically, the business cycle analysis of these institutes conducted in the spring of 2022 (the so-called spring-forecast, GD, 2022a) provides the "best" estimate of the path of German GDP without an energy crisis given the available information at that time (conditional forecast). These estimates can then be compared with the actual GDP development to compute the economic loss due to the energy crisis. Clearly, this approach captures all direct and indirect effects on the German economy of the Russian war in Ukraine (rise in energy prices, rising uncertainty, the reaction of the central bank and fiscal policy), and this should be kept in mind when interpreting the results.

Figure 4 shows the estimates of the GDP path in the hypothetical case (GD, 2022a) as well as the actual path of GDP.[12]

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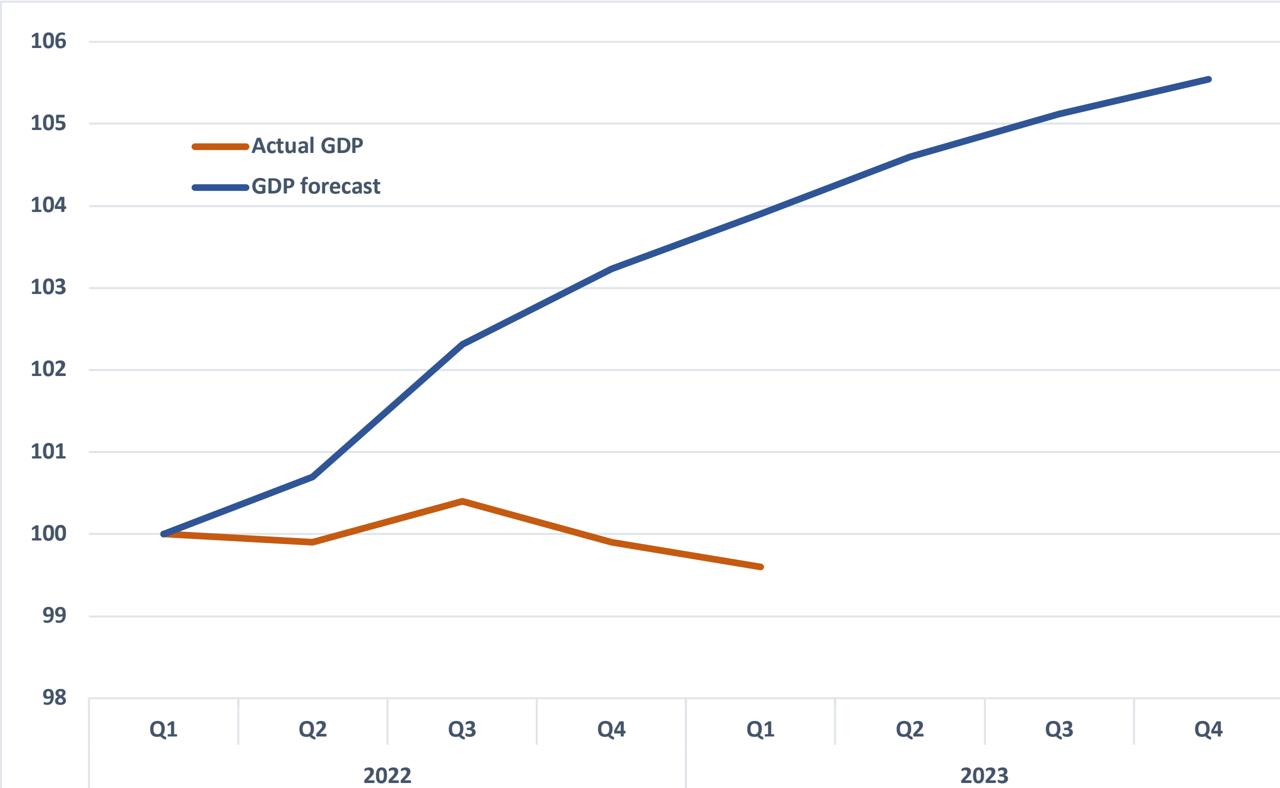
[9] Note that a similar analysis conducted for the manufacturing sector would yield similar results since industrial production was expected to expand even more than GDP before the crisis (GD, 2022a).

[10] Note that the unadjusted data from the national income and product accounts (NIPA) do not provide a reliable guide for measuring these two effects. Indeed, according to the German NIPA for 2022, there is little difference between the change in GDP and the change in national income, and real labor income grew more than GDP. Clearly, the second observation is difficult to reconcile with the data on real wages.

[11] These are the five Leibniz-Institutes: the German Institute for Economic Research or "Deutsches Institut für Wirtschaftsforschung" (DIW) in Berlin, the "Institute for Economic Research at the University of Munich" (Ifo), the "Kiel Institute for the World Economy" (IfW), the "Halle-Institute for Economic Research" (IWH), and the "Ruhr-Institute for Economic Research" (RWI). Since June 2022 the DIW Berlin does not participate in the business cycle analysis anymore, and the analysis is conducted in collaboration with the two Austrian economic research institutes IHS and Wifo.

[12] Clearly, it has been pointed out before that in Germany the economic losses due to the energy crisis have been substantial because the actual path of GDP needs to be compared to the GDP path in the hypothetical scenario without a crisis. See, for example, Greive, Hildebrand and Olk (2023), Kooths (2023) and Kühnlenz (2023).

Figure 4. GDP With And Without Energy Crisis



Note: Quarterly GDP normalized to 100 in Q1-2022. "GDP forecast" is the consensus forecast of the five economic research institutes in spring 2022 (GD,2022a); "Actual GDP" is the GDP data taken from the Federal Statistical Office (Statistisches Bundesamt).

From Figure 4 we can see that the output loss in the one-year period following the Russian war in Ukraine, the period Q2-2022 until Q1-2023 amounted to 4.3 percent according to the five economic institutes. Here we computed this loss as the difference between the conditional GDP forecast taken from GD (2022a) and actual GDP as measured by the Federal Statistical Office (Statistisches Bundesamt).[13] This output difference is mainly driven by the fact that German growth was expected to rebound strongly in 2022 after the Covid-19 crisis, which in Germany basically lasted until the spring of 2022 when all Covid-19 restrictions were finally lifted. It should also be noted that the GDP forecast of GD (2022a) was published in spring 2022 and already takes into account some of the negative effects of rising energy prices. In this sense, it is an underestimate of GDP in a world without an energy crisis, and therefore an underestimate of the output cost of the energy crisis 2022/23. For example, in December 2021 the German central bank still expected an increase in quarterly GDP in the period from Q2-2022 until Q1-2023 of more than 5 percent (Bundesbank, 2021).

[13] As common in the business cycle literature, this paper uses GDP data at a quarterly frequency to analyze the short-run movements in aggregate economy activity. The use of the quarter-to-quarter change ensures that the measure of output loss constructed here is independent of the growth path before the crisis (before the "Russian energy shock" hit the economy). Using this approach, the one-year output cost of the energy recession is simply the area between the two GDP-time paths in Figure 4 (the sum of the differences for Q2-2022, Q3-2022, Q4-2022, and Q1-2023).

To put these results into perspective, this study also computes the corresponding economic losses in the Covid-19 crisis of 2020 and the financial crisis of 2008/09 using an identical method across the three crises. For the hypothetical output path in an economy without a financial crisis, respectively without a Covid-19 crisis, we use the forecasts of the five economic research institutes in the fall of 2008, respectively in the fall of 2019 (GD, 2008, 2019). The computations yield a one-year output loss of 2.5 percent in the Covid-19 crisis in 2020 and 5.8 percent in the financial crisis in 2009. Thus, the magnitude of the short-run economic loss during the energy crisis 2022 is somewhat larger than the output loss during the Covid-19 crisis and somewhat less than the loss during the financial crisis 2009.[14]

There is always a question of how to date the beginning of a crisis since crises usually do not happen out of the blue. This study chooses Q2-2022 for the energy crisis because it is the first quarter following the Russian invasion of Ukraine on February 24, 2022. For the Covid-19 crisis, the beginning is dated to Q1-2020 because it is the quarter in which the first lock-down measures were implemented. The choice of Q4-2008 as the beginning of the financial crisis is motivated by the observation that it is the first quarter following the bankruptcy of Lehman Brothers in September 2008. This timing of the three crises implies that for all three crises, the first crisis-quarter is also the quarter for which GDP declined for the first time.

The above calculation assumes that GD (2022a) provides relatively good estimates of output in the hypothetical scenario without an energy crisis. This is the case if i) past forecasts have been relatively good in normal times and ii) there has been no major additional macro shock hitting the German economy in 2022 unrelated to the energy crisis. If there had been another major shock, a significant part of the calculated loss would be due to the alternative shock. If there are forecasting models that have a proven track record clearly better than the GDP-forecasting performance of the consensus forecast of the five economic research institutes, then one should use these alternatives to construct the counterfactuals in the three crises.

There is extensive literature on the accuracy of GDP forecasts for the German economy that cannot be discussed here because of space limitations.[15] However, four general comments seem in order. First, in Germany, the consensus forecast of the five economic research institutes is widely used and provides an essential input into the policy process of the Federal government. Second, in normal times (absence of large macro shocks) these consensus forecasts do not deviate “too much” from the forecasts of other institutions like the German central bank (Bundesbank) and the German

[14] A further comparison to the oil crisis 1973-75 might also be useful. The oil price shock that hit the German economy in 1973 led to an absolute decline in annual output only in 1975 by 0.9 percent and there was no further year with negative output growth in the 1970s. Using the same method as in Table 1 (but with annual data) and the forecast of the economic research institutes taken from (IWH, 2023), we find an annual output loss of 3.4 percent in 1975.

[15] See, for example, Müller (2021) and Döpke, Fritsche, and Müller (2019).

Council of Economic Experts (Sachverständigenrat). Third, the output losses for the three economic crises are computed based on a common method using the forecasts from one source. Finally, by using the spring forecast 2022 for the energy crisis, the approach tends to underestimate the output loss associated with the energy crisis 2022/23 since it takes into account information that could be attributed to the energy crisis.

In the public debate, three shocks to the German economy have been mentioned that could have had a strong impact on GDP unrelated to the energy crisis: Global supply chain disruptions, a fall in Chinese demand or supply of intermediate goods due to lock-downs in 2022, and a labor supply shock due to an increase in sick days. A closer look at the data reveals that neither of the three shocks is a likely candidate for such an alternative explanation. Regarding global supply chains, all available indicators point towards an easing of supply chain problems over the year 2022. For example, the ifo-indicator of material shortage steadily improved during 2022 (Destatis, 2023). Thus, these developments improved conditions for economic growth in 2022 relative to 2021, and there were no significant surprises in 2022 regarding supply bottlenecks that could have invalidated the conditional forecasts. Regarding a possible "China shock" due to lockdowns in China, this type of economic China shock appears not to have had much of an effect on the German economy. Specifically, China remained the biggest trading partner for Germany in 2022, and exports to China, as well as imports from China, rose strongly compared to 2021, though the increase in imports was more pronounced (Matthes, 2023). Finally, the number of sick days increased in 2022 relative to 2021, and such a negative supply shock could presumably explain part of the weak growth performance in 2022. However, a look at the monthly data reveals that the increase in sick days already occurred in the first quarter of 2022 (BKK, 2023), which implies that it does not affect the output cost of the energy crisis as computed here since the method only captures changes that occurred after Q1-2022. Further, there was an increase in labor supply in 2022 due to the migration of almost a million people from Ukraine to Germany, which works in the opposite direction and leads to the conclusion that the output loss in Table 1 might be an underestimate of the true cost.

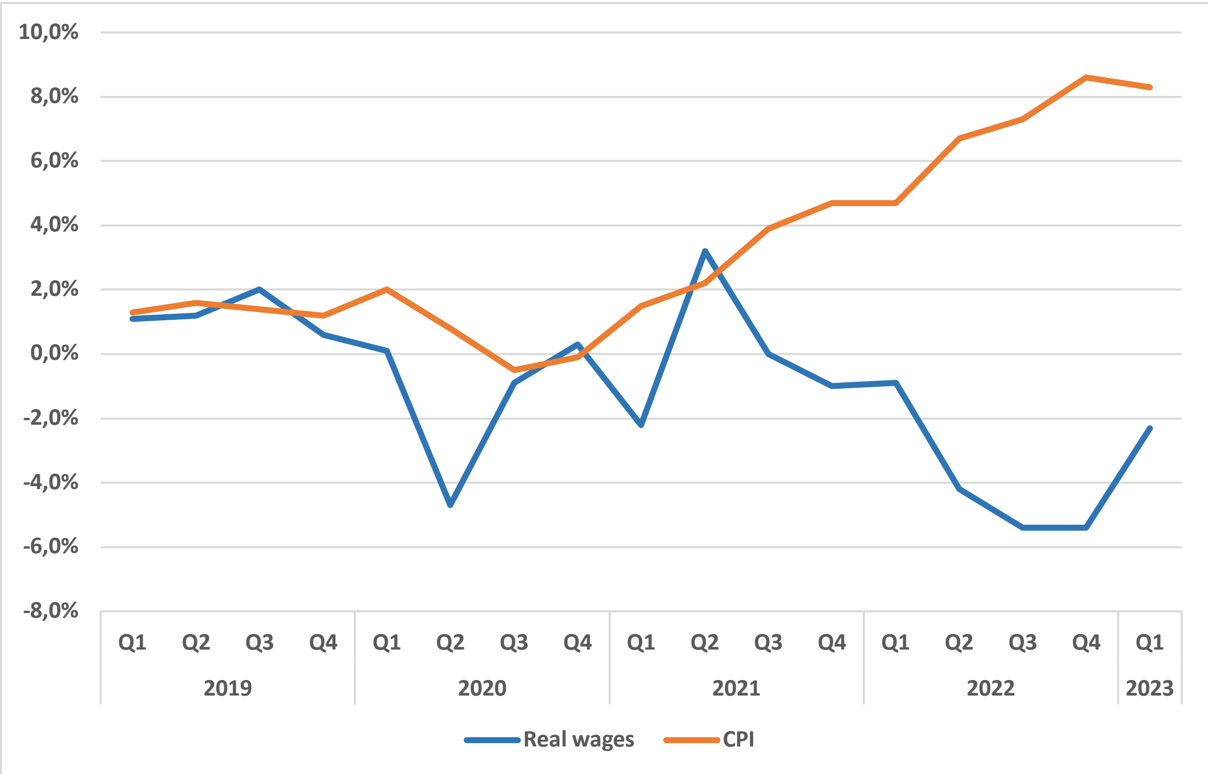
The tightening of monetary policy in 2022 is clearly a development that has an economic impact. However, changes in monetary policy only affect economic activity with a time lag, and it is therefore an open question how much of the monetary tightening of the European Central Bank that began in July 2022 has affected growth in 2022 substantially. Further, the tightening of monetary policy in 2022 should not be considered an independent shock unrelated to the energy crisis, but a policy reaction to rising inflation that was driven to a large extent by the dramatic increase in energy prices. In this sense, the energy crisis was the ultimate driver of these output losses. Note further that German fiscal policy in 2022 was quite expansionary, which tends to dampen the negative output effects of the energy price shock.

2.4 Inflation and Real Wages

Driven to a large extent by rising energy prices (Figures 1 and 2), the inflation rate in Germany and the Euro area increased significantly. Specifically, in Germany, consumer price inflation increased from 3 percent in 2021 to 6.9 percent in 2022.[16] In addition, a large part of this rise in inflation is accounted for by an increase in energy and food prices. This underscores the social costs of inflation since energy and food make up a relatively large share of the consumption basket of low-income households.

Wages and salaries did not rise at the same rate at which goods prices increased in 2022, and real wages therefore declined. For most people, labor income is the main source of income, which means that the majority of people in Germany experienced a loss in real income before taxes and transfers. The next figure shows that this loss in labor income was substantial during the energy crisis.

Figure 5: Inflation and Real Wages



Note: Change in quarterly real wage and consumer price index compared to previous-year quarter. Data from Federal Statistical Office (Statistisches Bundesamt).

Figure 5 depicts the time path of real wage growth and consumer price inflation since 2019. The figure shows that real wages fell dramatically in 2022 and that the size of the drop is quite large.

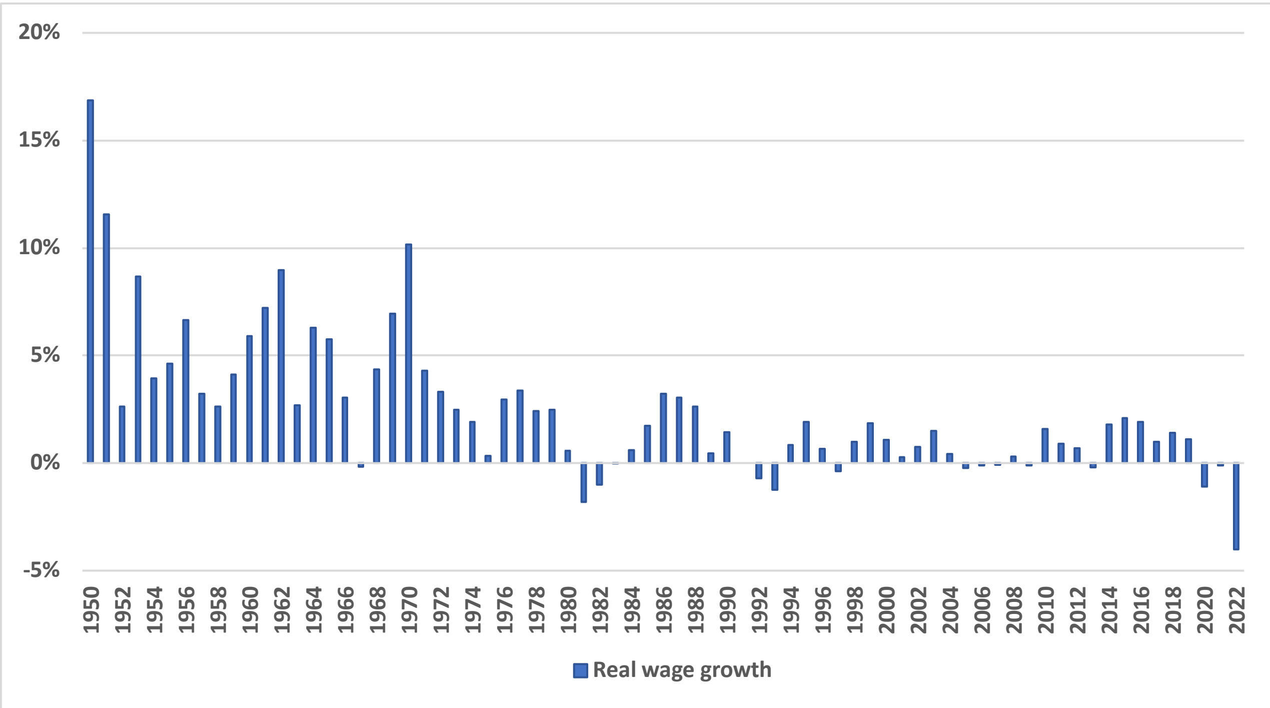
[16] For the year following the Russian war in Ukraine (Q2-2022 to Q1-2023), the consumer price inflation rate rose to 7.6 percent.

Specifically, in the three quarters Q2-2022 until Q4-2022 the real wage fell by 5 percent in comparison to the previous-year quarter. In comparison, real wages barely changed during the financial market crisis in 2008/2009, and in the Covid-19 crisis, real wages quickly recovered after the large drop in Q2-2022. In other words, the negative economic impact of the energy crisis on the lives of the majority of people in Germany has been more pronounced than the corresponding impact during the financial crisis and the Covid-19 crisis.[17]

Figure 5 also shows that real wages started to recover in the first quarter of 2023. This recovery is partially due to government-subsidized one-off payments made by employers to workers as an inflation compensation. At this stage, it is an open question of how much of this recovery is permanent, and if the real-wage recovery will continue so that the expected real wage growth in 2023 will be sufficient to make up for the losses experienced in 2022.

To put the real wage losses into a historical perspective, the next figure depicts the change in real wages since 1950, which is the first year in post-World War II history for which data are available.

Figure 6. Real Wages since 1950



Note: Annual percentage change of real wages; the real wage index is constructed using nominal wage data (the index of average gross monthly earnings) and the consumer price index from the Federal Statistical Office (Statistisches Bundesamt). Values from 1950 to 1990 refer to West Germany and values from 1992 to 2022 refer to (unified) Germany. The value of real wage change for 1991 is omitted because of the structural data break in the transition from 1990 to 1991.

[17] Of course, the fact that European workers' incomes have been hit hard in the energy crisis, and much more than suggested by GDP data, has been noticed before (Arnold and Romei, 2023).

Figure 6 shows that real wages declined by 4 percent in 2022 relative to 2021 and that this loss of income is the largest decline on record. There are only a few episodes in recent German history in which the annual real-wage decline was substantial: In 1981 real wages dropped by almost 2 percent and in 1993 and 2020 they declined by somewhat more than 1 percent. Thus, a careful look at the data can explain why most workers in Germany might not feel that it is time for a victory lap.

We compute one-year real wage losses in the three crises using the method of section 2.3. Specifically, we compute the change in quarterly real wages in the first year following the "beginning" of the crisis and compare this change with the forecast of the quarterly real wages of the five economic research institutes.[18] The results of the analysis on output losses and wages losses are summarized in the following table:

Table 1. One-year output and wage losses in Germany for three economic crises

	Output loss	**Real wage loss**
Energy crisis 2022/23	**4.3 %**	**3.4 %**
Covid-19 crisis 2020	**2.5 %**	**0.8 %**
Financial crisis 2008/09	**5.8 %**	**0.4 %**

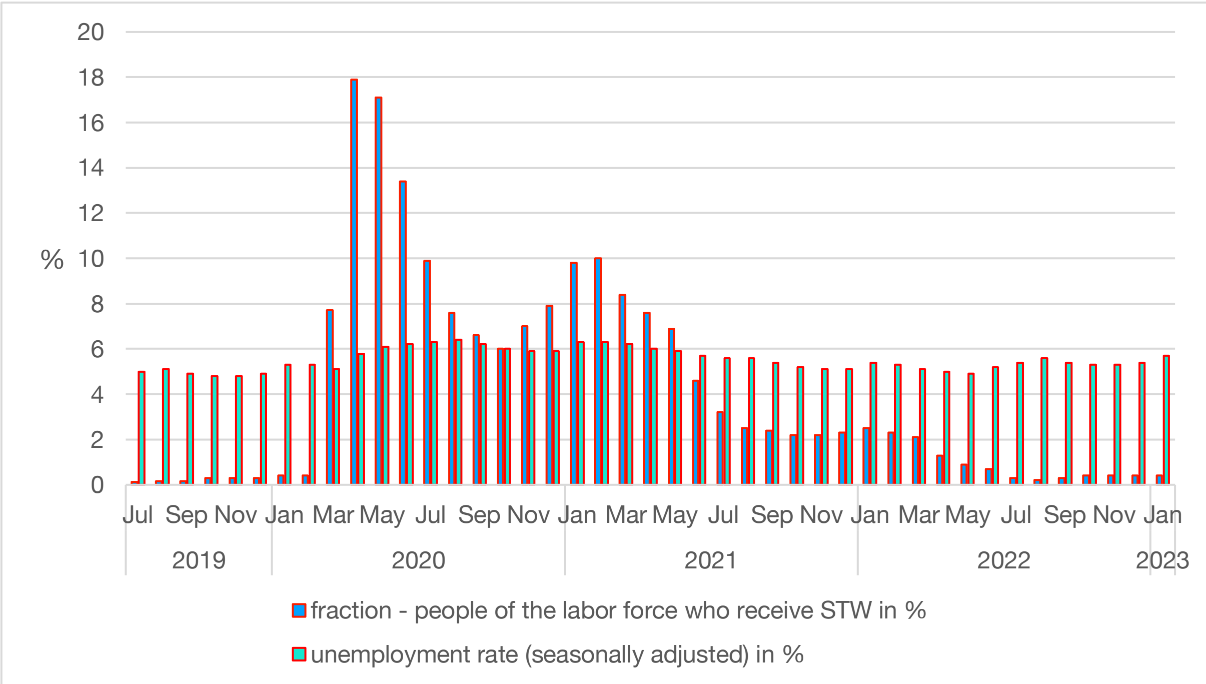
Note: Output and wage losses are the difference between before-crisis forecasts and actual values of quarterly GDP and quarterly real wages one year after the beginning of crisis. Energy crisis Q2-2022 to Q1-2023, Covid-19 crisis Q1-2020 to Q4-2020 and financial crisis Q4-2008 to Q3-2009. Forecasts are taken from the consensus forecast of the five economic research institutes DIW, Ifo, IfW, IWH, and RWI.

Table 1 shows that the output loss during the energy crisis 2022 was comparable to the output loss during the Covid-19 crisis and somewhat less than the loss during the financial crisis 2009. The output loss during the energy crisis is mainly driven by the fact that economic growth was expected to be very strong before the energy price shock hit the German economy in 2022, whereas expected output growth before the Covid-19 crisis and the financial crisis was modest. Table 1 also shows that the loss in real wages during the energy crisis by far exceeds the corresponding losses during the Covid-19 crisis and the financial crisis. In short, the energy crisis was an economic crisis of a magnitude comparable to the Covid-19 and the financial crisis, but the negative effect on workers' wages has been much stronger.

[18] The forecast of real wages is computed as the difference between the forecast of nominal wages and the forecast of consumer prices inflation in fall of the year preceding the crisis. I thank the IWH for providing me with the unpublished data for the respective forecasts of quarterly wages.

The unemployment rate and the extent of short-time work are two measures that are often used to assess the impact of various events on workers. Figure 7 below depicts the time path of the unemployment rate and the short-time work rate in Germany in the last two decades. The figure shows that both measures of labor market performance did not move a lot during the energy crisis in Germany. In contrast, the short-time work rate increased substantially during the financial crisis and the Covid-19 crisis.

Figure 7: Unemployment And Short-Time Work



Source: Federal Labor Agency (Bundesagentur fuer Arbeit).

Some observers have concluded from the data on unemployment and short-time work (Figure 7) as well as the data on gross domestic product (Figure 3) that the energy crisis in Germany had little economic impact on people's life. The results depicted in Table 1 and Figure 6 show that this argument is anything but convincing.

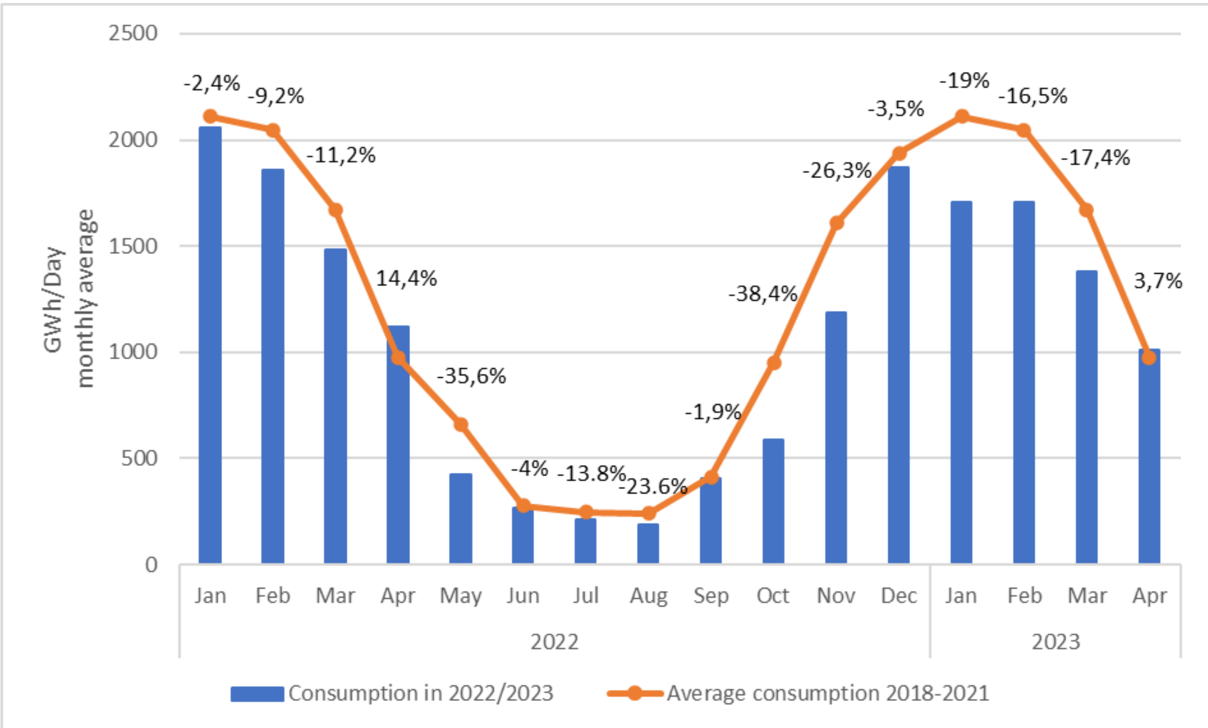
Economic crises generate economic and social costs because economic growth and employment decline in the short run. The short-run output effect of the energy crisis is the focus of the previous analysis summarized in Table 1. However, the current crisis in Germany and Europe can also cause long-lasting damage to the economy and society. These permanent damages represent additional costs of a crisis that persist even after the economic recovery has taken place, and they are of major concern for policy makers. This study does not analyze the possible long-run consequences of the energy crisis because of space limitations.

2.5 Energy Use and Substitution

The hike in gas prices depicted in Figure 1 also led to a reduction in gas consumption. The decline in gas use was spread evenly across all sectors, though large industrial users were most affected. Specifically, large industrial users (including energy companies) reduced their gas consumption by 17% in 2022 relative to 2021, and households reduced their gas consumption by 14% (AGEB, 2023). In total, gas consumption in 2022 declined by almost 16 percent relative to 2021. Of course, other factors beyond gas prices (temperature) affect gas consumption and without further analysis, one should not attribute the whole decline in gas consumption to rising prices.

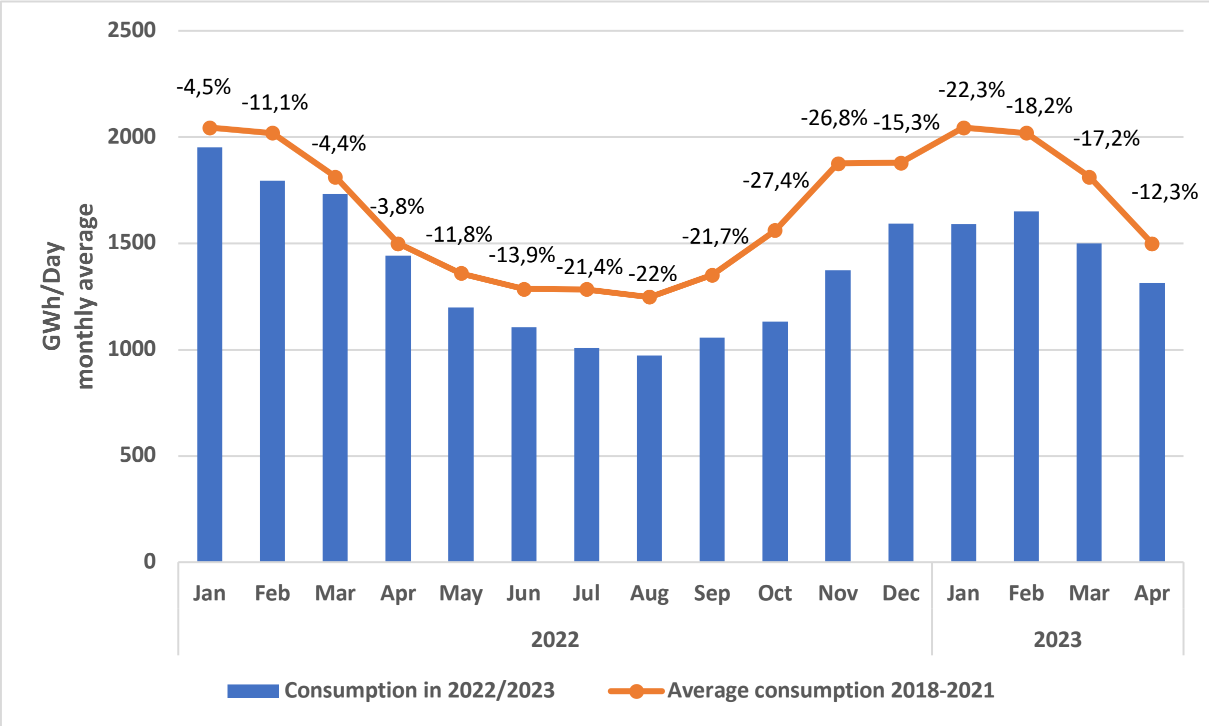
The next two figures provide a more detailed account of the changes in natural gas consumption over time. The data are taken from the Federal Network/Grid Agency (Bundesnetzagentur) that is responsible for regulating the German energy market and companies operating the energy infrastructure. The data are split into two categories: Users with annual gas consumption below 1.5 gigawatt-hour (households and small businesses) and users with annual consumption above 1.5 gigawatt-hour (industrial users including companies in the energy sector). The category of large gas users (industrial users) accounts for roughly 60 percent of annual gas consumption.

Figure 8: Gas consumption households and small businesses (small users)



Source: Bundesnetzagentur.

Figure 9. Gas consumption industrial companies (large users)



Source: Bundesnetzagentur.

Figure 8 shows that the gas consumption of households and small businesses is highly seasonal dropping to very low levels in the summer months. The reason is that the main use of gas in the household sector is for heating purposes, which is not necessary in the summer months. In addition, there are almost no houses and buildings with air conditioning in Germany.

Figures 8 and 9 together suggest that the rise in gas prices depicted in Figure 1 led to a significant reduction in gas consumption. In the one-year period April 2022 until March 2023 (Q2-2022 until Q1-2023), the gas consumption of households dropped by 16% relative to the average of 2018-2021 and the gas consumption of industrial users by 17%. Of course, the winter of 2022/23 was milder than the average of 2018-2021, which might explain some part of the reduction in consumption independently of price movements. In general, the reduction in gas consumption by industrial users depicted in Figure 9 can be achieved in three ways. First, companies can replace natural gas by an alternative energy input like coal or oil. Second, companies can try to improve the efficiency of energy use. Third, firms can use less energy by reducing production. In the short run, the potential for the first and second adjustment mechanism is often limited, whereas in the long run there is much more scope for substitution and the negative production impact of rising energy prices is smaller.

It is sometimes asserted that the time evolution of industrial production (Figure 3) and industrial gas use (Figure 9) suggest that there has been a lot of energy substitution or efficiency gains -- the first two adjustment mechanisms -- and little production reduction -- the third adjustment channel

(Moll, Schularick, and Zachmann,2023, Sandbu, 2023, and Tabarrok, 2023).[19] There are at least two reasons to be skeptical of such claims. First, as in the case of output, for industrial production we need to construct the counterfactual of industrial production in the hypothetical economy without an energy crisis. As mentioned above, production in the manufacturing sector was expected to grow by even more than output (GD, 2022a). Second, from Figure 3 we can see that the energy-intensive industry took a big hit and reduced production by almost 20 percent within a time span of nine months. This does not suggest that there has been much substitution, though one needs to study this issue in more detail to draw any conclusions. Indeed, GD (2023) conducts an analysis using production and gas consumption data for the various German industrial sectors and finds that only one-third of the reduction in gas consumption was due to energy substitution or efficiency gains (the first two channels) and two thirds was driven by a reduction in production (the third channel).[20] Clearly, more analysis is needed to draw any firm conclusions regarding the ability of the Germany economy for energy substitution, but any claim that "substitution worked in the German energy crisis" clearly lacks any foundation at the current stage.

Electricity consumption in Germany also decreased in response to increasing prices, but the decline was much less pronounced compared to the decline in gas consumption (Agora, 2023). Specifically, electricity consumption decreased by only 2.7% from 566 terawatt-hours in 2021 to 550 terawatt-hours in 2022. On the production side, there was a significant increase in electricity production based on renewable energy by 22%, and a decline in electricity generation with gas power plants by 14%. Further, coal-based electricity production increased by 17% and nuclear-based electricity generation declined by 33% in Germany.

2.6 What if: Output Losses in a Worst-Case Scenario

The energy crisis of 2022/2023 had large economic and social costs (Table 1), but it could have been worse. Specifically, gas prices rose quickly to unprecedented heights in the summer of 2022, but they also quickly declined after reaching their peak in August and Germany did not experience a gas shortage. In other words, a worst-case scenario could be avoided through a combination of government decisions and luck. For example, if in March 2022 the German government had decided to implement an immediate and complete embargo on energy imports from Russia, then gas prices would most

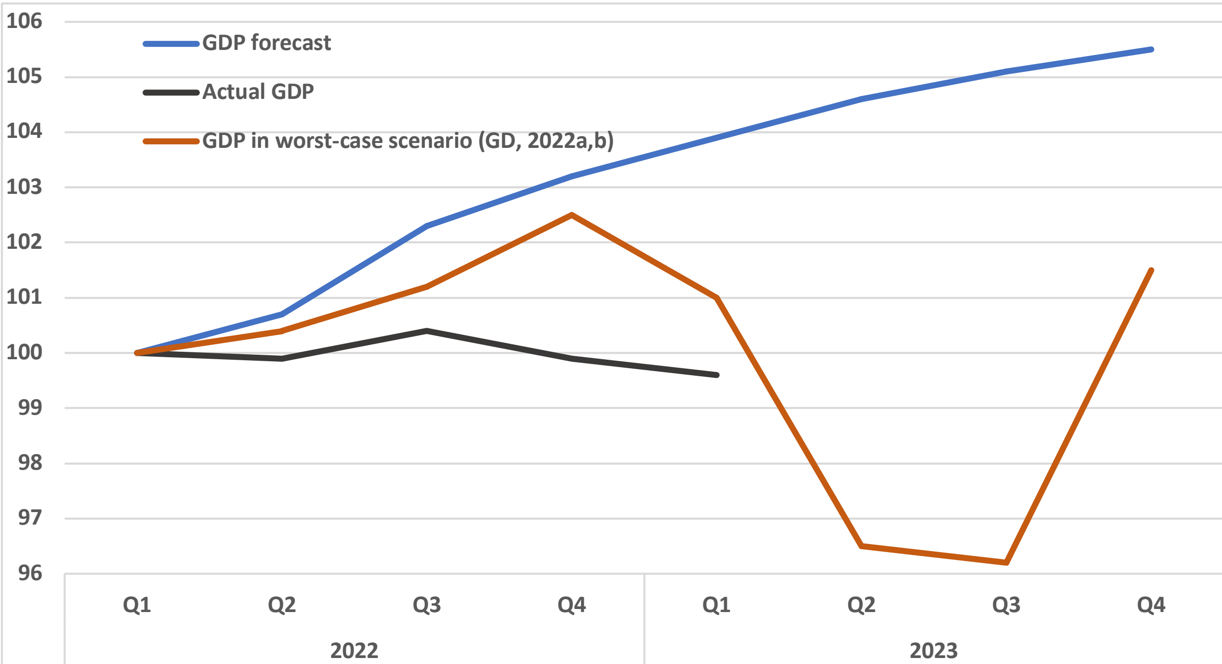
[19] See, for example, Moll, Schularick, and Zachmann (2023), Sandbu (2023), and Tabarrok (2023).

[20] Specifically, in the data use by GD (2023) total gas consumption in 2022 fell by 17 percent relative to 2021, and this reduction was split as follows among the different sectors and adjustment channels: 4 percent due to production reduction in the industrial sector (without energy sector), 2 percent due to energy substitution or efficiency gain in the industrial sector (without energy sector), 2 percent in the energy sector, 3 percent in the household sector, and 6 percent due to milder temperature in 2022 than 2021.

likely have risen in April or May 2022 to levels above 300 euro per megawatt, and would have remained at such elevated levels until the Winter 2022/23.[21] Clearly, such a sudden and dramatic energy price shock would have led to output losses exceeding the outputs losses shown in Table 1.

We will never know for sure what would have happened in the hypothetical worst-case scenario, but the economic analyses conducted by the five economic research institutes (GD, 2022a, b) and the German central bank (Bundesbank, 2022a, b) can give us a sense of the possible damage that could have occurred. The model simulation of a worst-case scenario in GD (2002a, b), which is called the "alternative scenario" in the paper, is depicted in Figure 10.

Figure 10. GDP with and without energy crisis including worst-case scenario



Note: Quarterly GDP normalized to 100 in Q1-2022. GDP data (actual GDP) taken from Federal Statistical Office (Statistisches Bundesamt). GDP forecast is the consensus forecast of the five economic research institutes in spring 2022 (GD,2022a); GDP in worst-case scenario is the alternative scenario simulated by the five economic research institutes in spring 2022 (GD,2022a, b).

Figure 10 shows that according to the analysis of GD (2022a, b), the output loss in the worst-case scenario would increase to around 8 percent in Q2-2023. Further, the economy would recover relatively quickly from this deep drop in aggregate economic activity. In contrast, Bundesbank (2022a,

[21] The reason to expect such market turbulence is that without gas imports from Russia in the period April 2022 to August 2022, gas tanks in Germany would not been fully filled up before the winter. Note that the decision not to impose an immediate embargo on Russian gas imports in March 2022 was only one of several government decisions that made a difference. For example, the implementation of a large fiscal package clearly played a role dampening the economic effect of rising energy prices. Further, the purchase of fossil gas at a large scale in world markets, though this also drove up gas prices. The two most important "luck" events were the mild winter and the weak Asian gas demand in 2022. A thorough analysis of the contribution of the various factors is an important topic for future work.

b) finds a drop in output of similar size, but the drop occurs earlier and is somewhat more persistent. Krebs (2022) discusses the different modelling assumptions that explain these differences. In addition, inflation rates and real wage losses are substantially higher than in the baseline scenario shown in table 1.

Bundesbank (2022a, b) and GD (2022a, b) consider the demand-side and supply-side effects of high energy prices and a possible gas shortage on aggregate production.[22] The analysis in GD (2022a, b) assume that even in the worst-case scenario, the supply-side effect is relatively small because the manufacturing sector has to reduce gas consumption by a little more than in the baseline scenario. GD (2022c) provides additional simulation results for a worst-case scenario leading to a gas shortage that forces manufacturing companies to reduce gas consumption by roughly two-thirds in one quarter and finds that only the supply-side effect of such an energy-shock would lead to a short-run output loss of 10 percent. Clearly, the combined demand-side and supply-side effect of such an energy shock would cause output to drop by even more than 10 percent.[23]

Krebs (2022) surveys the literature and provides simple back-of-the-envelope calculations to illustrate how different assumptions about economic channels and gas availability in a worst-case scenario affect the implied output losses. The analysis suggests that in a worst-case scenario with some gas shortage, the short-run output losses would lie in a range of 5 – 12 percent if both demand-side and supply-side effects are taken into account. Of course, these results are subject to a high degree of model uncertainty since they pertain to an extreme event – the sudden and unexpected large-scale reduction in energy supply in an economy with a large manufacturing base – that has no exact counterpart in recent history. The next table summarizes the results of the analyses in Bundesbank (2022a, b), GD (2022a, b, c) and Krebs (2022).

Table 2. Short-run output loss in a worst-case scenario

	Bundesbank (2022a, b)	**GD (2022a, b)**	**GD (2022c)**	**Krebs (2022)**
Output loss	**9 %**	**8 %**	**10 %**	**5 % - 12 %**

Note: Bundesbank (2022a, b) and GD (2022a, b) are the differences between the before-crisis forecasts and the simulated worst-case scenario of quarterly GDP five quarters after the beginning of the energy crisis (Q2-2022 until Q2-2023). GD (2022c) includes only supply-side effects; all others include demand-side and supply-side effects.

[22] In addition, there are a number of studies that confine attention to demand-side effects and therefore disregard an economic channel that would most likely play an important role in a worst-case scenario. See Krebs (2022) for a survey. Moll, Schularick, and Zachmann (2023) also discuss parts of the literature (but - oddly enough - do not mention the work by Bundesbank (2022a, b) and GD (2022a,b,)).

[23] The full-blown analysis taking into account both demand-side and supply-side effects was not conducted in GD (2022c) because of time constraints.

The size of the supply-side channel depends on the degree to which companies can substitute one energy input (oil) for another input (gas) or save energy without a loss in production. Based on the available evidence for the German manufacturing sector, the simulations of Bundesbank (2022a, b) and GD (2022a, b, c) assume that, in the short run, manufacturing companies can reduce their gas consumption by 10 percent without any loss in production simply by energy substitution or improvements in energy efficiency. Krebs (2022) assumes that manufacturing companies can reduce their gas consumption by 20 percent without any loss in production. Thus, the analyses conducted by Bundesbank (2022a, b), GD (2022a, b, c), and Krebs (2022) suggest that the supply-side channel played a minor role in the observed best-case scenario (Table 1), but would have played a major role in the unobserved worst-case scenario with a gas shortage (Table 2).

Bachmann et al. (2022) is another paper that analyzes the economic consequences on the German economy of a sudden reduction in energy supply. The paper finds that even in a worst-case scenario, the output loss would not have exceeded 2.3 percent. Indeed, the computations based on what the authors call a "state-of-the-art multi-sector macro model with network effects" yields output costs in a worst-case scenario between 0.2 percent and 1.5 percent.[24] Clearly, these results stand in stark contrast to the results shown in Table 1.

The work by Bachmann et al. (2022) is derived based on a static model of the German economy that disregards aggregate-demand effects, adjustment costs (unemployment, retraining, time-to-build), uncertainty (uninsurable risk) as well as market power in goods or labor markets (the marginal productivity theory of real wages holds). In addition, the authors assume that energy is, like capital and labor, an input into a CES production function.[25] In the model, the market outcome is Pareto efficient (at least in the initial equilibrium), and the output loss is determined by the share of energy in output (first-order approximation) and its change (second-order approximation). Given the strong assumptions made in the analysis, it is perhaps not too surprising that the authors find that large shocks to the energy supply have little short-run effect on GDP. Clearly, it seems doubtful whether this type of model is a useful tool for the analysis of the short-run macroeconomic effects of an energy crisis – see Geerolf (2022) for a detailed criticism of the approach. Indeed, Larry Summers made a similar point in a speech he gave about ten years ago (Summers, 2013):[26]

[24] See Table 2 of Bachmann et al. (2022) for the upper bound of 2.3 percent. However, this upper bound is not derived from the state-of-the-art macro model. The output loss of 1.5 percent is computed in the appendix of Bachmann et al. (2022) using the so-called sufficient-statistics approach. The 3 percent output loss mentioned in the executive summary of Bachmann et al. (2022) and often quoted in the media is not based on any precise calculation. Geerolf (2022) provides an excellent discussion of the different approaches taken in Bachmann et al. (2022).

[25] In some sense, Bachmann et al (2022) use a (static) real business cycle model to analyze short-run output movements, but in contrast to the original contribution by Kydland and Prescott (1982) the work by Bachmann et al. (2022) does not allow for time-to-build (adjustment frictions) and lacks any empirical validation using business cycle data.

[26] To be fair, Summers (2013) describes the result of the first-order order approximation of the model, whereas Bachmann et al. (2022) also compute the second-order approximation. However, in this particular application the difference between

"*Now, think about the period after the financial crisis. I always like to think of these crises as analogous to a power failure or analogous to what would happen if all the telephones were shut off for some time. Consider such an event. The network would collapse. The connections would go away. And output would, of course, drop very rapidly. There would be a set of economists who would sit around explaining that electricity was only 4% of the economy, and so if you lost 80% of electricity, you couldn't possibly have lost more than 3% of the economy. Perhaps in Minnesota or Chicago there would be people writing such a paper, but most others would recognize this as a case where the evidence of the eyes trumped the logic of straightforward microeconomic theory. And we would understand that somehow, even if we didn't exactly understand it in the model, that when there wasn't any electricity, there wasn't really going to be much economy.*"

3. RESILIENT ENERGY SYSTEM

3.1 Renewable energy and resilience

In a climate-neutral economy, the production of goods and services will mainly use renewable electricity in conjunction with renewable hydrogen as energy input. In addition, there is almost no possibility to replace renewable electricity by alternative energy inputs. Thus, we would expect large shocks to the supply of electricity to have output effects that exceed the already large output losses shown in Table 1. This underscores the urgency to minimize the possibility of future energy crises caused by major supply disruptions.

Energy production and consumption in a climate-neutral economy will differ significantly from the current situation in the sense that almost all of the renewable electricity used in Europe will be produced in Europe. Further, even for large countries like Germany, it seems wise to plan for a future in which net electricity imports are not too large on average. Put differently, the future European energy system will be one that is relatively immune to large external supply shocks caused by political events, such as the war-related stop of gas imports from Russia in 2022.[27] Indeed, one could imagine a future in which the production of goods and services is climate-neutral and no wars are fought over scarce fossil energy resources – renewable energy becomes peace energy.

Although the future energy system in Germany and Europe will most likely be resilient to external supply disruptions, there is an increased danger of large internal supply shocks.[28] Specifically, the

the two is not large. Note also that it seems a bit of an overreach by Summers to classify this particular class of models as "microeconomic theory" – it is one particular application of microeconomic theory with strong and highly questionable assumptions imposed on the analysis.

[27] Of course, if we count cyber-attacks to the energy system as external shocks, then the danger of external shocks remains real.

[28] There is a large literature on the resilience of energy systems, and the use of the term varies quite a bit across areas and publications. See, for example, Jasiunas, Lund, and Mikkola (2021) for a survey. Indeed, one could argue that the type of resilience analyzed in the current study is better describe by the term "reliability" or "robustness".

heavy reliance on solar and wind energy in a climate-neutral economy implies that there is a significant danger of weather-related fluctuations in the availability of electricity at a macroeconomic scale. Specifically, there is the risk that in one particular year, the production of renewable energy from wind and solar is extraordinarily low for several weeks or months in the winter (*Dunkelflaute*), and that this leads to a substantial reduction in total energy supply given the large share of wind and solar energy. To make the energy system resilient against these types of "internal" shocks, there is a need to build enough storage/reserve capacity that provides electricity in times when renewable energy production using wind and solar power is low.

Resilience against large supply shocks is not the only desirable feature of the future energy system. There is also the need to provide sufficient renewable energy in the absence of shocks. If this condition is not satisfied, then energy prices will be high on average and sensitive to supply shocks.[29] This would severely impair the ability of the economy to produce goods and endanger long-run prosperity. In sum, a resilient energy system requires the following two conditions to be met:[30]

i) Sufficient capacity to generate electricity "in normal times" mainly based on wind and solar power;

ii) Sufficient capacity to generate electricity in times when wind and solar power generate relatively little electricity.

The next two sections analyze what it takes for the German energy system to satisfy these two requirements, and what policy measures can help build such an energy system.

3.2 Renewable investment and public insurance

The future energy system in Germany and Europe needs to provide sufficient capacity to generate electricity "in normal times" using wind and solar power. In Germany, the energy transition to climate neutrality in 2045 requires the phasing out of coal-based energy production by 2038 (target year being 2030) and the replacement of natural gas by renewable hydrogen in the gas-based power plants. Given that nuclear energy has been phased out in 2023, the German energy transition can only be successful if renewable energy production is massively expanded in the coming years. Specifically, Germany needs to substantially increase its capacity to generate electricity from wind and solar power. According to Agora (2022), electricity production from wind and solar power has to increase from around 190 terawatt-hours in 2022 to 380 terawatt-hours in 2030 and 580 terawatt-hours in 2040. In other words, electricity production from wind and solar power has to double until 2030 and has to increase fourfold by 2040. Other studies reach similar conclusions, though imply even more ambitious goals

[29] Note that the first is a statement about the location of the energy supply function (for given demand function), whereas the second is rather a statement about the slope (elasticity) of the supply function. Even though it seems theoretically useful to separate these two features, in reality they are linked.

[30] Of course, this is not an exhaustive list of requirements. For example, a resilient energy system also requires a good energy transport infrastructure (electrical grid) and a market design that avoids excessive, endogenous price volatility.

for the expansion of wind and solar power in Germany (Ariadne, 2021). Indeed, the German government has currently even more ambitious plans. Specifically, recent work by Energy Consulting (2023) in collaboration with the Federal Ministry of Economic Affairs and Climate Protection (BMWK) suggests that wind and solar energy production should increase to 540 terawatt-hours by 2030, which would amount to a share of 77 percent of electricity production.

Clearly, the German government needs to implement a broad policy package in order to enable the additional investment in renewable energy that is necessary to achieve a doubling of wind and solar energy production until 2030. The current study does not provide a comprehensive analysis of an entire policy package but focuses instead on one particular policy instrument and the economic logic behind its use. This policy instrument is the public insurance against long-run macroeconomic price risk that producers of renewable electricity face.

Private investments in large wind power plants (onshore and offshore) are associated with large sunk costs and highly uncertain payoffs that only accrue many years after the investment has been made. One important source of payoff risk is the risk due to long-run movements in electricity prices (sales prices for renewable energy). Public insurance against this type of long-run price risk will lead to an increase in energy investments for given prices, respectively lower prices for a given volume of energy investment – the long-run energy supply function shifts to the right. The economic logic is simple: The public insurance of long-run price risk induces the producers of renewable electricity to discount future profits associated with investment at a lower rate (the risk premium decreases) therefore reducing the average electricity price required to make a given investment project profitable.[31] Of course, this price-dampening effect is only passed on to electricity consumers if the transport infrastructure (electricity grid) does not hit capacity constraints and electricity markets are well-functioning. A detailed analysis of this issue is beyond the scope of the current study.

The public insurance of long-run, macroeconomic price risk can be implemented most straightforwardly via a two-sided contract-for-difference (CfD) that the government offers to producers of renewable electricity.[32] In Germany, wind power plants are mainly operated by (regulated) private companies that compete for the right to build new power plants in government auctions. Currently, most government auctions include a contract that provides one-sided price insurance for electricity producers for a fixed time period (15 years) that puts a lower floor on the price electricity producers receive.[33] The use of two-sided CfDs would transform the one-sided insurance contract

[31] Note that this argument presupposes that energy producers display a certain type of risk aversion when making large-scale investment decisions. Though not always explicitly stated, this is a common, implicit assumption in any investment theory that uses as discount factor of future payoffs a risk-adjusted interest rate (risk-free rate plus risk premium).

[32] See Newbery (2023) and Neuhoff et al. (2023) for more details on the use of CfD to insure producers of renewable energy.

[33] This lowest price (floor) is part of the bidding mechanism and can be zero, as it has been in the most recent auction for offshore wind energy (Bundesnetzagentur, 2023). In this case, there is no insurance against future price risk.

into a two-sided insurance contract that can either fully insure against price risk or partially insure by using a price band.

As with any type of insurance, there is the question of moral hazard, that is, the question of whether the provision of insurance gives individual agents an incentive to act in a way that could lead to an increase in the risk to be insured. However, it is unlikely that individual wind plant operators can substantially affect electricity prices over longer periods of time thereby changing the long-run price risk. Further, if a group of electricity producers tried to manipulate electricity prices strategically to their advantage, this constitutes an illegal action that can be punished accordingly. The one actor that could substantially affect the price risk is the government through its policy decisions. However, the CfDs increase the government's incentive to expand renewable investment and lower electricity prices. Thus, in this case, there is a positive incentive effect of insurance.

One possible danger of public insurance against long-run electricity price risk is that the insurance contracts are not fairly priced, and the government loses money on average. In other words, the contract ought to be a fair insurance contract that avoids the misuse of public funds.[34] This risk of the misuse of public funds can be minimized if CfDs are offered to energy producers in a transparent manner as part of the public auction in which rights to build power plants (wind or solar) are assigned. In contrast, it is much harder to avoid the misuse of public funds when the government is a third party to a deal between two private companies.[35] From this point of view, CfDs (public insurance offered as part of a public auction) are fiscally more efficient than Power Purchase Agreements (public insurance offered as part of an agreement between two private companies), and should therefore be the preferred method of offering public insurance against long-run energy price risks.

3.3 Reserve Capacity

The future energy system needs to provide sufficient capacity to generate electricity in times when wind and solar power generate relatively little electricity. Specifically, there is the macroeconomic risk that in one particular year the production of renewable energy from wind and solar power is extraordinarily low for several weeks or months due to adverse weather conditions (*Dunkelflaute*). Germany has limited capacities to store energy using hydroelectric power, which means that it has to rely heavily on gas-based power plants that are used as reserves in "abnormal time" when solar and wind power plants produce little electricity.[36]

[34] The condition of "zero expected pay-outs" is clearly not satisfied for the so-called climate contracts the German Ministry for Economic Affairs and Climate Protection (BMWK) offers to industrial users of renewable energy (BMWK, 2023). These climate contracts are therefore not CfDs in the strict sense; they are a combination of a CfD and direct subsidies that are unrelated to risk. For reasons of transparency, it would be useful to separate these two components.

[35] For example, Deutsche Energie-Agentur (Dena, 2020) calls for the government to provide an "attractive institutional setting" (attraktive Rahmenbedingungen) for Power Purchase Agreements, but then lists special tax breaks and electricity price reductions – i.e., standard forms of subsidies – as the main components of an attractive institutional setting.

[36] Currently, these gas-based power plants mainly use natural gas, but in the future natural gas will be replaced by renewable hydrogen.

Most studies of the energy transition in Germany assume that gas-based power plants play a significant role (Ariadne, 2021). For example, Agora (2022) assumes that in 2030 about 150 terawatt-hours of electricity will be produced using gas-based power plants, in 2040 about 100 terawatt-hours of electricity will be produced using gas-based power plants, and in 2045 this drops to 60 terawatt-hours (plus 30 terawatt-hour storage capacity). While in 2030 most of the gas used is natural gas, by 2045 all natural gas is replaced by renewable hydrogen. In their study for the BMWK, Energy Consulting (2023) assumes that gas-based power plants will produce close to 100 terawatt-hours in 2030 (respectively about 35-gigawatt power). They also conduct an energy security analysis based on simulations and the weather conditions of the last 6 years and conclude that the likelihood of having a supply shortage is basically nil. This suggests that if the future, climate-neutral energy system relies on 60 terawatt-hours from hydrogen power plants and 30 terawatt-hours of storage capacity, as suggested in Agora (2022), it will most likely be highly resilient to weather-related, internal supply shocks.

Summing up, the currently discussed plans for the energy transition in Germany are likely to lead to a resilient energy system. Of course, weather conditions in the future could differ substantially from current conditions, and more analysis on the reliability of future energy supply is needed to draw firm conclusions. In addition, there is the issue of how to design the electricity market and how to implement the remuneration of reserve capacities (Bublitz et al. 2019, European Commission, 2023). Finally, plans are not yet actions, and there could be economic pressure on the government to build fewer dispatchable power plants than planned. In the end, it is still an open question how many back-up power plants (reserve capacity) Germany will need to secure energy resilience in the climate-neutral future, and how many will be built. Regardless of the exact path the German energy transition will take, one important insight holds quite generally: The social cost of not investing in sufficient reserve capacity is large. Specifically, the analysis in section 2 shows that the economic cost of the energy crisis in Germany already amounts to 100 billion Euro, and with 100 billion Euro one can build quite a few power plants whose main function is to provide reserve capacity.

Finally, a comment on related work by Sinn (2017) seems in order. Sinn (2017) considers the "upside risk" that in a renewable energy system with a large share of wind and solar energy, there are times when more electricity is produced than needed, which leads to efficiency losses if the storage capacity is limited. The study was criticized by Zerrahn, Schill, and Kemfert (2018) for overstating the efficiency losses due to this upside risk. Clearly, upside risk and downside risk should be considered when designing the energy system of the future, but it is the downside risk that generates the larger economic costs and therefore should be the center of attention. Specifically, even if the calculations in Sinn (2017) do not overstate the efficiency losses of variable renewable energy sources, then the economic cost of the implied "waste" of energy is small relative to the economic cost of the downside risk of having a non-resilient energy system as the one German energy supply was based on in the past.[37]

[37] Sinn (2017) estimates that roughly 10 terawatt-hour energy is "wasted" in an energy system based to 80 percent on solar and wind energy. If we assume that the average cost (capital plus operating cost) of generating renewable energy is about 5 euro per megawatt-hour, then the efficiency loss calculated in Sinn (2017) amounts to 0.5 billion euro per year. Of course, Zerrahn, Schill, and Kemfert (2018) argue that the true costs are at least one order of magnitude smaller.

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