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BACKGROUND PAPER

Fossil Fuel to the Fire

Energy and Inflation in Europe

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Executive Summary

Energy made an outsized contribution to the recent inflationary wave in Europe: On average, 50 percent of year-on-year inflation in 2022 was directly due to energy, the vast majority of which was due to fossil fuel price rises. Additional inflationary effects followed from indirect impacts on other prices, especially food.

Renewable energy can help fight inflation both in the short and in the long run. In the short run, faster renewable energy deployment saved European consumers around 95 billion euro between 2021 and 2023 and reduced electricity prices by up to 15 percent (IEA 2023c). In the long run, the secular downwards trend in renewable energy costs suggests further cost saving potential and, once the transition is complete, price stability.

The situation is more complicated in the mid-transition. Three challenges appear salient: As long as electricity prices remain linked to fossil fuel prices, especially gas, any increase in fossil fuel price volatility spills over into the pricing of electricity. Supply chain risks may materialize as renewable energy deployment accelerates. And if investment in grids, energy storage, and supply- and demand-side flexibility fails to keep up with accelerating renewable deployment, further bottlenecks and price spikes may emerge.

However, these risks are not set in stone. The extent to which they will materialize will depend on today's policy choices. While further research and policy action is needed on the mid-transition, the overall picture that emerges from our analysis is therefore clear: fossil fuels added to the economic and political instability of recent years. Replacing them with renewables can become a pillar of future stability.

#Inflation[1]
#FossilFuels
#RenewableEnergy
#Europe

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[1] This paper is in large parts inspired by, and a replication of, Melodia and Karlsson (2022). We are very grateful for the support and advice that Lauren Melodia and Kristina Karlsson very kindly provided. Needless to say, any remaining errors are ours.

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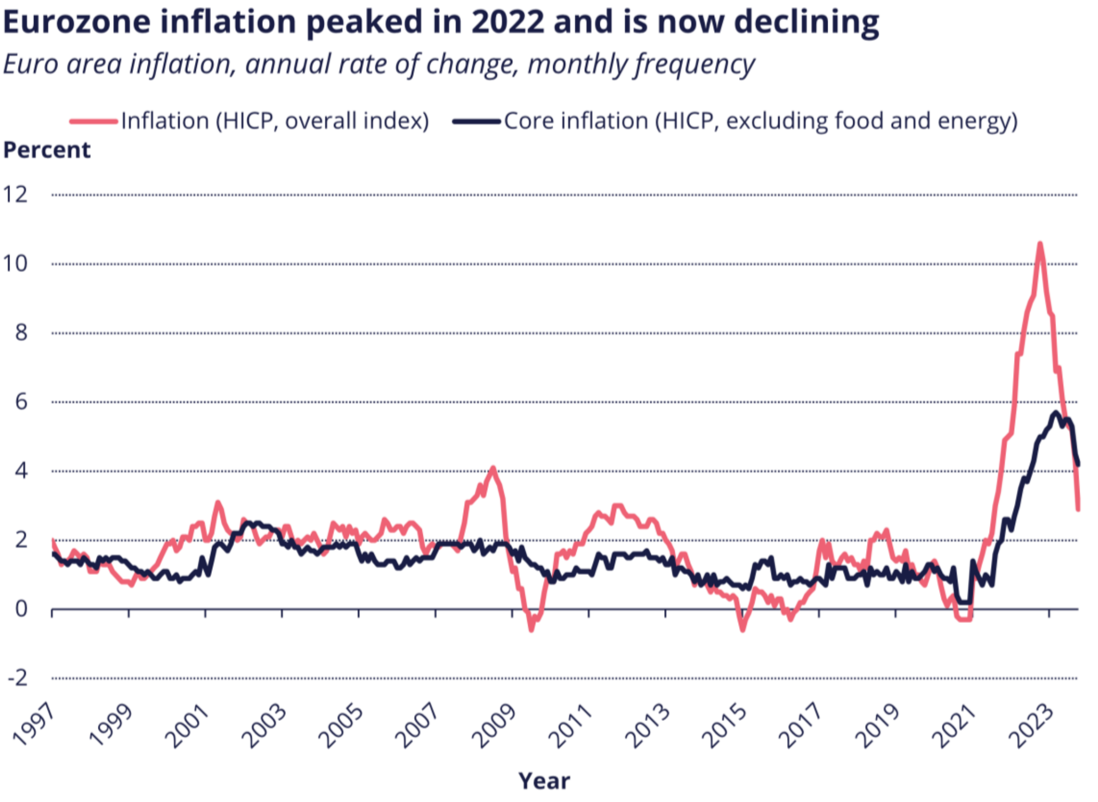
Introduction

The inflationary wave that hit Europe and much of the world in 2021, 2022, and 2023 is beginning to recede (Figure 1). As this shock gradually fades, it is important to take stock and draw lessons: further shocks will come, and learning from the past may help to prepare for the future.



Eurozone inflation peaked in 2022 and is now declining

Euro area inflation, annual rate of change, monthly frequency

Note: HICP stands for Harmonised Index of Consumer Prices.

Reading example: Overall inflation peaked in October 2022 at an annual rate of 10.6%. Core inflation peaked slightly later, at 5.7% in March 2023.

Source: Eurostat (prc_hicp_manr)

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Figure 1 Headline and core inflation in the Eurozone over the last 26 years

Zooming in on inflation in the Euro area, this paper finds three main results. First: fossil energy drove inflation. On average, 50 percent of year-on-year inflation in 2022, when the inflationary wave peaked, was directly due to energy, the vast majority of which was from fossil fuel price rises (Figure 4). In the case of Europe, given the pivotal role of gas power plants in electricity price formation, these fossil price spikes also drove up electricity prices (Figure 8 and Figure 9). Additional inflationary impacts followed from indirect effects, especially on food prices.

Second: renewable energy can help fight inflation both in the short and in the long run. In the short run, faster renewable energy deployment between 2021 and 2023 already saved European consumers around 95 billion euro and reduced electricity prices by up to 15 percent (International Energy Agency 2023c). In the long run, the downwards trend in renewable energy costs (Figure 12) suggests further cost saving potential and, once the energy transition is complete, price stability.

Third: the mid-transition presents a more complex picture. As long as electricity prices remain linked to fossil fuel prices, increasing instability in fossils spills over onto electricity pricing (see Box 2 below). Supply chain risks may materialize as renewable energy deployment accelerates. And if investment in grids, energy storage, and supply- and demand-side flexibility fails to keep up with accelerating renewable deployment, bottlenecks and price spikes may emerge. However, these risks are not set in stone. The extent to which they will materialize will depend on today's policy choices.

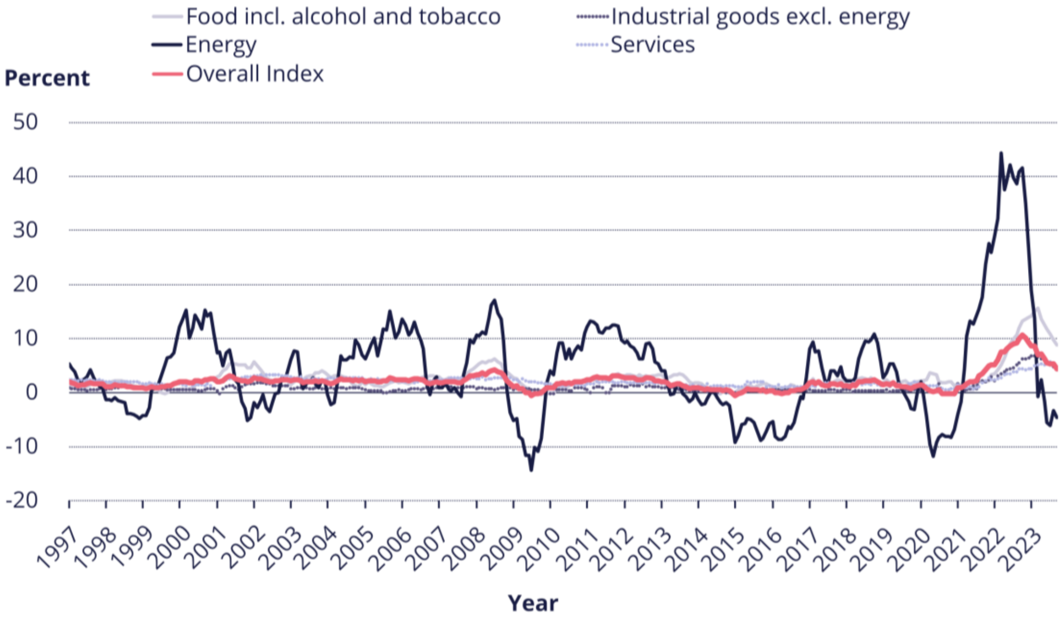
Overall, the overarching lesson is: **an ambitious renewable energy policy can be a pillar of future stability for Europe**. Besides their obvious role in reaching climate neutrality, renewables provide protection against inflation and geoeconomic dependency. In virtue of this, they also shore up political stability: History shows that moderate inflation, even in low double digits, does not harm democracy. An inability to understand and to manage it, however, does.

1. Energy was the main driver of Europe's recent inflationary wave

Energy prices exhibit an outsized and unique volatility relative to the other components of inflation[2] (Figure 2).

Energy prices are the most volatile component of overall inflation

Euro area inflation, annual rate of change, monthly frequency



Reading Example: Overall inflation can be decomposed into inflation in the prices of energy, food, goods and services. Overall inflation is less volatile than inflation in the energy component, with overall inflation peaking at 10.6% in October 2022 while energy inflation at its highest point reached 44.3% in March 2022. The final contribution of individual components to overall inflation depends on the share of household expenditure on the respective items.

Source: Eurostat (prc_hicp_manr)

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Figure 2 Euro area inflation by major components

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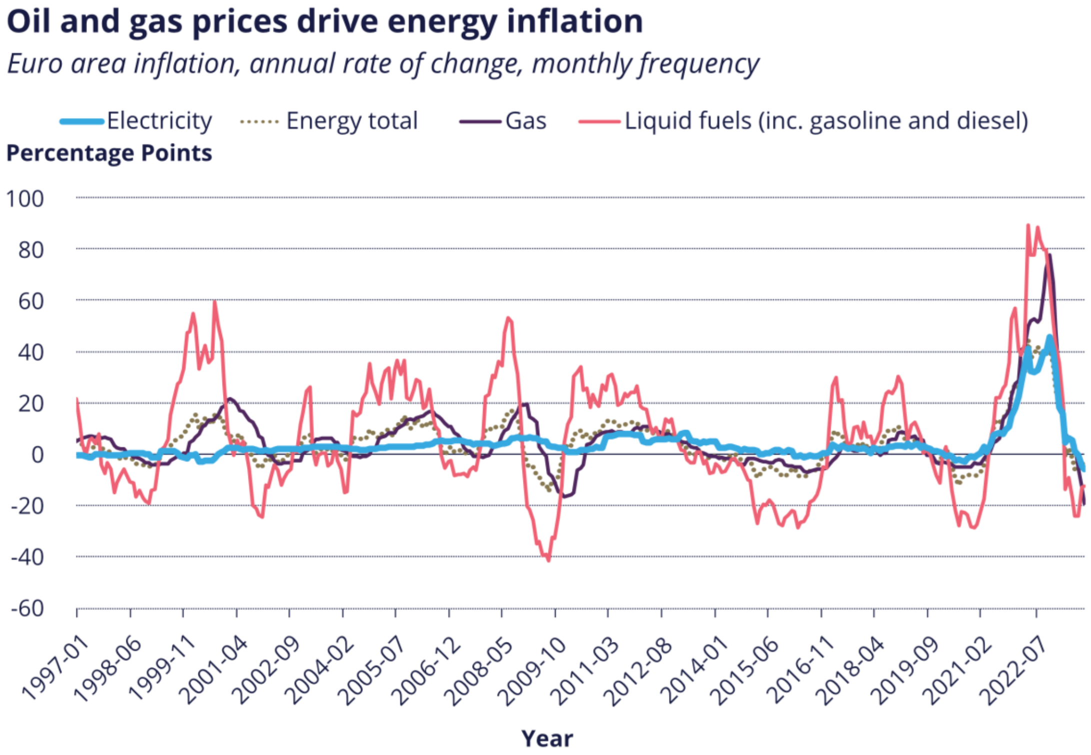
[2] In this study, we define inflation as the change, usually over 12 months, in the Harmonised Index of Consumer Prices.

Because of this volatility, energy, like food, has traditionally been excluded from core inflation indices. This can be a useful strategy for accurately assessing the underlying state of the (macro)economy, and hence for the conduct of monetary and fiscal policy. However, this approach risks overlooking the systemic impact of energy price volatility, especially that of fossil fuels — an issue whose importance became obvious once more in recent years, particularly following Russia's invasion of Ukraine.

The volatility of energy prices is predominantly the result of volatile fossil fuel prices, especially oil and gas. Figure 3, which shows the evolution of consumer energy prices in the euro area since 1997, illustrates this: Liquid fuel prices – mainly oil and its derivatives, i.e. gasoline and diesel – are by far the most volatile, followed by gas. Gas prices rose to unprecedented levels following Russia's invasion of Ukraine and the associated curtailment of Russian pipeline gas supplies to Europe. Electricity prices are much more stable; the only exceptional increase, towards the end of the period covered, was itself a result of the sudden increase in gas prices (see Figure 8 below).



Oil and gas prices drive energy inflation

Euro area inflation, annual rate of change, monthly frequency

Reading Example: Prices paid for liquid fuels, most prominently oil in the form of gasoline and diesel, are the most volatile component of household energy expenditure and hence energy inflation, followed by expenditure on gas, as this data on year-on-year changes shows. Expenditure on gas increased at an unprecedented level during the recent energy crisis, and also affected the usually much more stable consumer prices of electricity due to the role of gas plants in electricity generation.

Source: Eurostat (prc_hicp_manr)

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Figure 3 Evolution of consumer energy prices in the euro area since 1997 (annual rate of change)

There are many reasons for the volatility of fossil fuel prices, but several of them stem from the fact that fuel-importing countries are dependent on a limited number of producers and exporters for the continuous import of a vital resource. This gives the exporting countries significant market power. In the oil market, this is most evident in the collective efforts of the Organization of the

Petroleum Exporting Countries (OPEC) to manage production levels to achieve desired price levels, especially when this is done in cooperation with the OPEC+ platform, which includes Russia.

The rapid rise in fossil fuel prices during the recent energy crisis had several causes. Prior to Russia's invasion of Ukraine, energy markets were already under stress due to factors including lower Russian gas deliveries starting in the summer and fall of 2021, the rapid economic recovery from the Covid-19-induced recession, the impact of droughts and heat waves on hydro and nuclear power generation, and previous underinvestment in clean energy and energy efficiency. Russia's war then led to the full-blown crisis, given its role as the world's largest exporter of fossil fuels and key supplier to Europe (IEA 2022b).

Notably, the price spikes were not only the result of international sanctions, but also of actions taken by Russian entities, such as Gazprom's curtailment of gas supplies to Europe, as well as the general uncertainty caused by the invasion. A unique aspect of the recent energy crisis is that not only oil, but also fossil gas prices were severely affected, given Europe's historical dependence on pipeline gas imports from Russia. Europe's rapid turn to the global market for liquefied natural gas (LNG) to replace pipeline imports from Russia then drove up gas prices not only in Europe but for LNG-dependent countries around the world.

As a result, during the recent inflationary wave in Europe, higher energy prices accounted for 50 percent of year-on-year inflation over the course of 2022 (Figure 4). Even excluding electricity, higher energy prices accounted for 36 percent of the inflation rate across the year.[3] In the month with the most dramatic increase, March 2022, energy prices accounted for 66 percent of the overall 7.4 percent year-on-year inflation rate, i.e. 4.8 percentage points. Excluding electricity, the contribution still amounts to 3.6 percentage points, or 48 percent of the total. This outsized role of fossil energy in Europe's recent inflation has also been recognized by the European Central Bank (ECB). In March 2022, Executive Board member Isabel Schnabel observed "fossilflation [...] is to blame for much of the recent strong increase in euro area inflation" (ECB 2022a).

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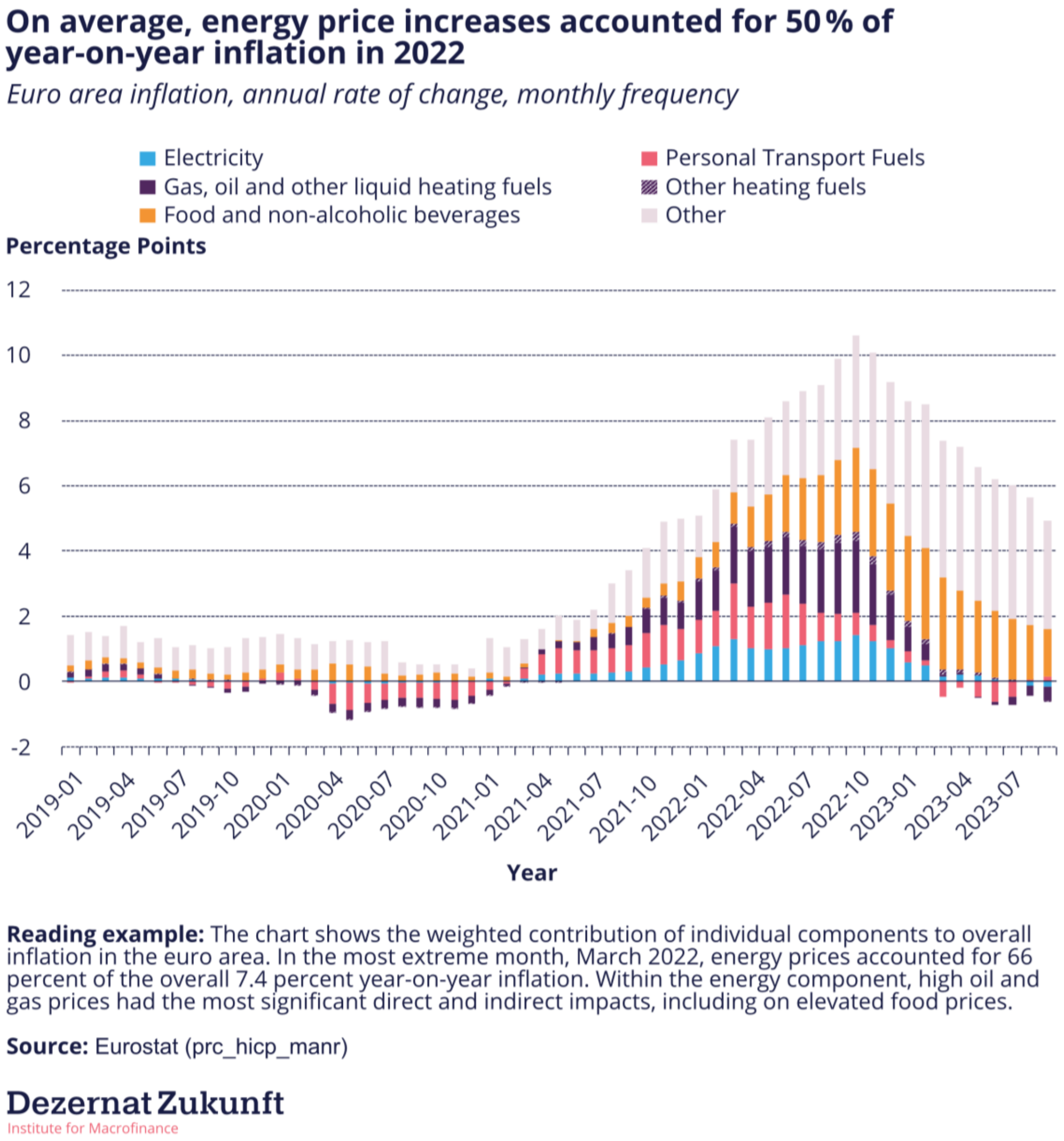
[3] Calculated as the weighted share of gas, oil and other liquid heating fuels, personal transport fuels, other heating fuels and (for the first number) electricity in all items HICP (annual rate of change, monthly frequency, euro area); summed up across 2022 and divided by 12.



Reading example: The chart shows the weighted contribution of individual components to overall inflation in the euro area. In the most extreme month, March 2022, energy prices accounted for 66 percent of the overall 7.4 percent year-on-year inflation. Within the energy component, high oil and gas prices had the most significant direct and indirect impacts, including on elevated food prices.

Source: Eurostat (prc_hicp_manr)

Figure 4 Annual inflation rate (percentage points), euro area, contributions weighted

The full inflationary impact of rising fossil fuel prices is understated in headline figures

However, though large, these numbers still understate the full impact of rapidly rising fossil fuel prices. They only show the direct effect of energy price changes on household energy expenditure. The indirect effects of higher energy prices on other goods are not included, even though high overall inflation rates in later months are in significant part driven by earlier high energy inflation.[4] This effect is particularly strong for food prices (Box 1), and remains important because, although energy inflation rates have come down in 2023, partly through expensive fiscal interventions, their prices have not returned to pre-war levels.

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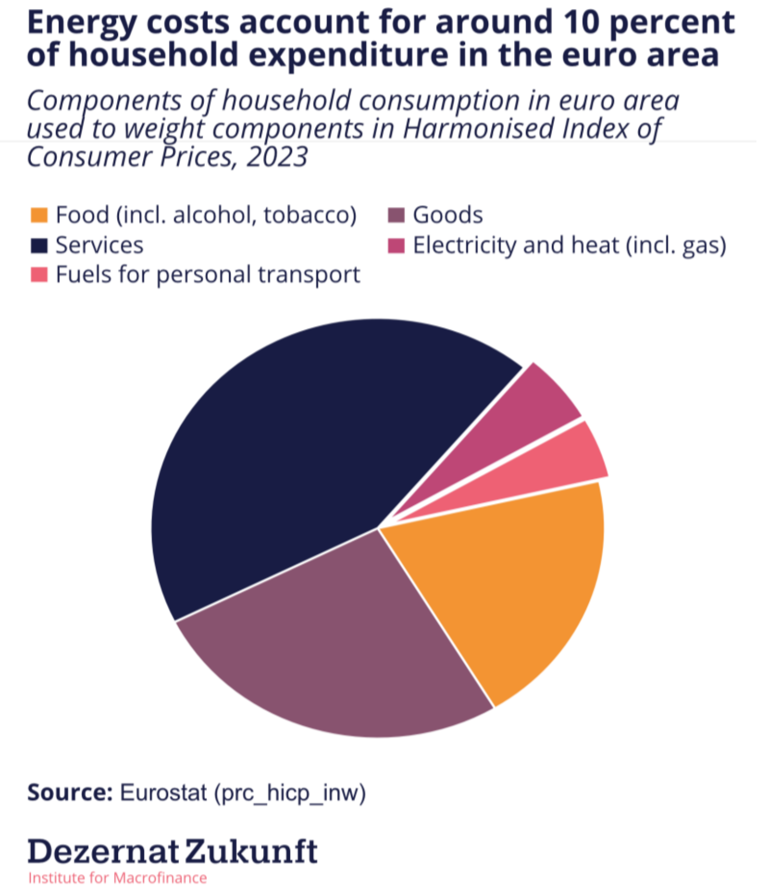
[4] See Pallara et al. (2023) for an analysis of the time lag between energy inflation and its secondary effects on the prices of other items.

Box 1: Fossil Fuel and Food Prices

The indirect effects of fossil fuel inflation are particularly pronounced for food prices (shown in orange in Figure 4), which have been a second major driver of the recent inflationary wave in Europe. Food prices are strongly affected by higher fossil fuel costs: in advanced economies, direct and non-direct energy costs account for 40 to 50 percent of the total variable cost of farming, though with significant differences between crop types and locations (IEA 2022a). Generally, food and fossil energy prices tend to move in tandem, with energy prices driving overall food prices (Alnour et al. 2023). Since 2004, food and oil prices have been in the same phase (boom or bust) for 75 percent of the time (IMF 2022a, p 39).

The main reasons for this include the direct use of oil as fuel for farm equipment and transportation; the role of fossil gas as the main input of nitrogen-based fertilizers and pesticides; global economic activity being a common demand factor; and the use of some agricultural products as biofuels. Econometric modelling suggests that a 1 percent increase in oil prices increases food commodity prices by 0.2 percent, while a 1 percent increase in fertilizer prices (in turn heavily influenced by fossil gas prices) increases food commodity prices by 0.45 percent (IMF 2022b).

The outsized contribution of energy prices to overall inflation is especially noteworthy given that spending on energy represents only a relatively small share of direct total household expenditure (Figure 5): Electricity and heating costs are responsible for 5.5 percent of household expenditure in the euro area, and personal transport fuels (essentially gasoline and diesel) are responsible for another 4.7 percent.



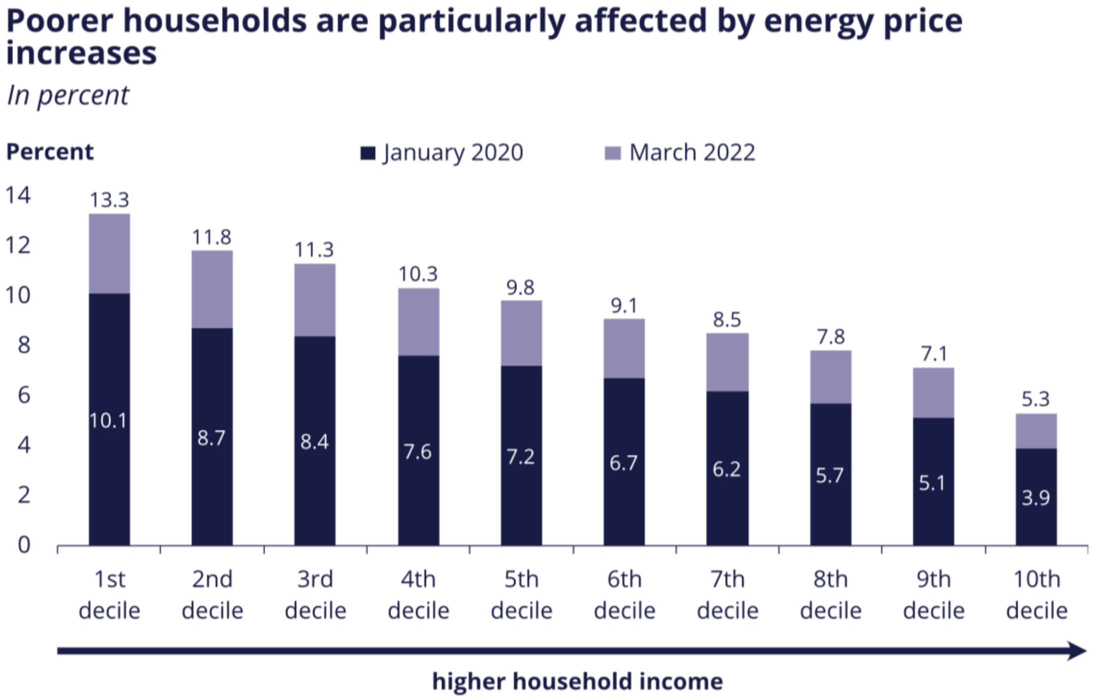
Energy costs account for around 10 percent of household expenditure in the euro area

Components of household consumption in euro area used to weight components in Harmonised Index of Consumer Prices, 2023

Source: Eurostat (prc_hicp_inw)

Figure 5 Weight of components of household consumption, euro area

Poorer households are particularly affected by energy price increases (Figure 6). Data from Germany illustrates this: The first income decile (the ten percent of households with the lowest income) spends the largest share of its household income on energy. At the upper end of the income distribution, the tenth decile (the ten percent of households with the highest income) spends the smallest share of its household income on energy, with a continuous decrease in the intermediate deciles.



Poorer households are particularly affected by energy price increases

In percent

Source: Praktiknjo & Priesmann (2022), p. 4

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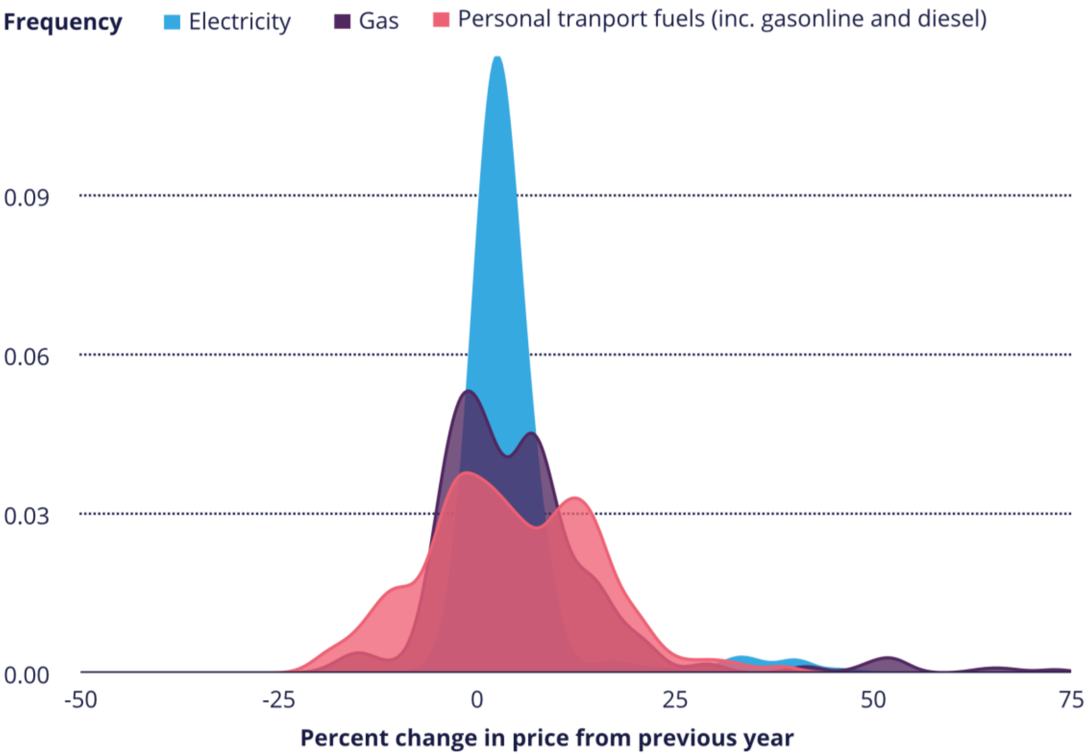
Figure 6 Average share of household income spent on energy, Germany, January 2020 and March 2022

1.1 Electricity prices are more stable than oil and fossil gas prices, and even more so when decoupled from fossil fuels

This high level of energy price volatility is not inevitable. While oil and gas prices regularly experience sudden hikes, as shown above, electricity prices have been relatively stable overall. This is illustrated in Figure 7, which shows the distribution of monthly year-on-year price changes in the Eurozone for electricity, gas, and fuels used for personal transport (especially oil) between 1997 and 2023. As the narrow and high area shows, electricity price changes mostly occur in a small range, clustered between -3 and +10 percent.



Electricity prices are significantly more stable than fossil fuel prices

Euro area inflation, annual rate of change, monthly frequency

Reading example: This graph shows the distribution of price changes for electricity, gas and fuels for personal transport (mainly oil). Electricity prices are by far the most stable, as changes mostly occur within a small range, clustered between -3% and 10%. Oil and gas prices are significantly more volatile, with transport fuels (oil) being the most unstable. Gas prices used to be more stable than oil prices, but the energy crisis has led to some significant deviations, as can be seen at the right end of the horizontal axis.

Source: Own calculation based on Eurostat (prc_hicp_manr)

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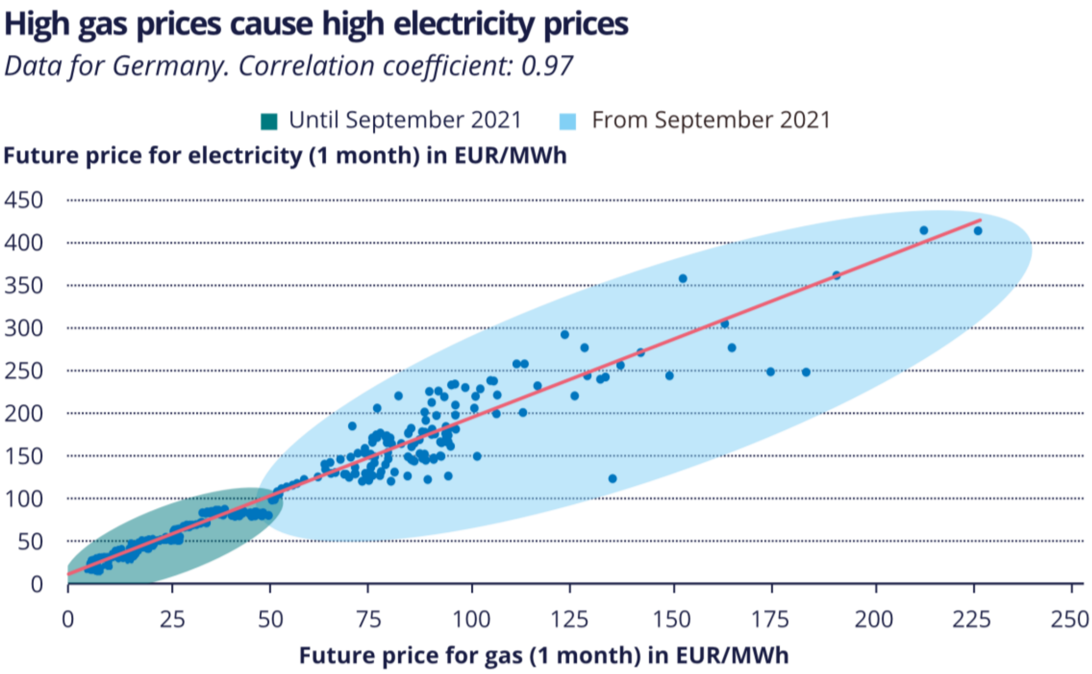
Figure 7 Frequency and distribution of annual inflation rates for personal transport fuels (including gasoline and diesel), gas and electricity

There is one exception: the notable increase in electricity prices during the recent energy crisis, as shown in Figure 3 above. However, this is an exception that proves the rule: the increase in electricity prices was primarily caused by the rapid rise in fossil gas prices (coal and oil prices temporarily rose, too), transmitted by the current reliance on fossil fuels for electricity generation.

In particular, as gas-fired power plants were often the most expensive source of generation still needed to meet demand throughout 2022 and much of 2023, they set the general electricity price in Europe's marginal pricing electricity markets during peak- and sometimes baseload-hours.

Increases in fossil gas prices therefore drove spikes in final electricity prices (EWI 2022, Gil Tertre et al. 2023).[5]

This dynamic is illustrated in Figure 8, which shows the almost complete correlation between electricity and gas prices, both before and during the energy crisis (BMWK 2022).


High gas prices cause high electricity prices

Data for Germany. Correlation coefficient: 0.97

Reading Example: There is almost perfect correlation between gas and electricity prices, as gas plants are usually the most expensive power generation source and hence set the price. Historically high gas prices (from September 2021, light blue bubble) were the key driving force behind historically high electricity prices.

Source: BMWK (2022), p. 17

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Figure 8 Correlation between gas and electricity prices (Germany)

This tight correlation between gas and electricity prices also explains the more prominent role that electricity played in European versus US inflation over the last couple of years (cf. Melodia & Karlsson 2022). While the price of gas in Europe rose almost ninefold,[6] peaking above 60 USD/MBtu, in the US it never breached 10 USD/MBtu (Figure 9). This had a direct impact on (diverging) electricity prices.

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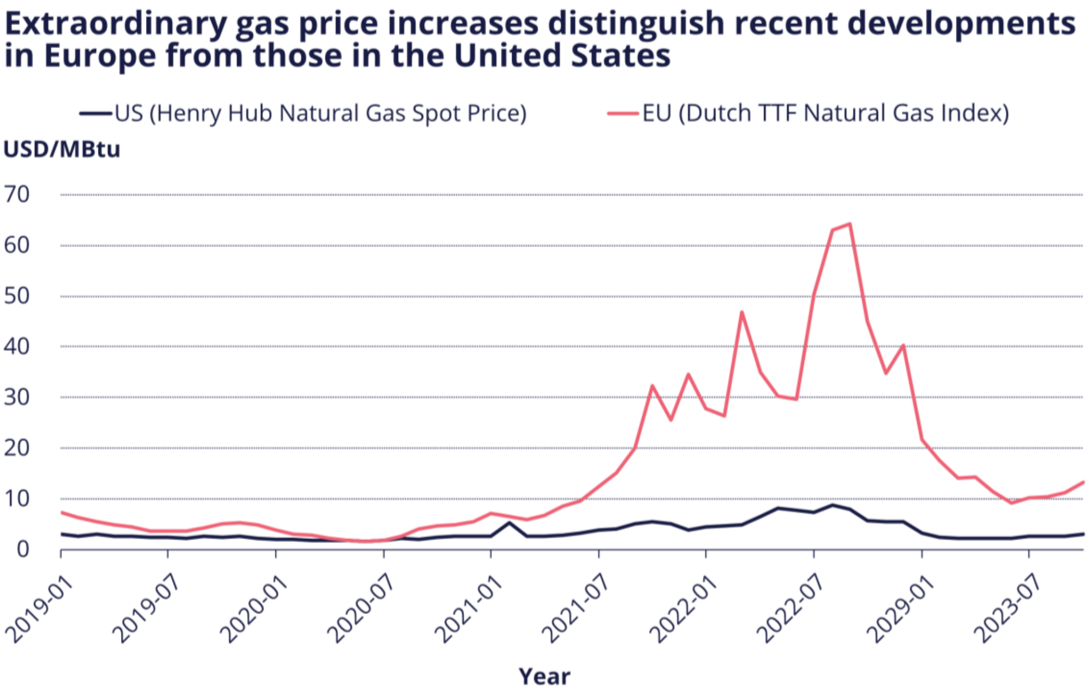
[5] Within the euro area, there were some exceptions to this, most notably the “Iberian exception”: Spain and Portugal decoupled electricity prices from gas prices by setting a price cap on gas used in electricity generation. While this measure did successfully decouple electricity from gas prices, it also had negative side-effects such as limiting incentives for energy demand reduction and distorting electricity markets. It was also enabled by the fact that grid interconnection between the Iberian Peninsula and the rest of Europe is relatively limited, creating a somewhat segregated market. This, however, is not in line with the needs of a climate neutral power system, which requires greater rather than lower interconnectivity (cf. Corbeau et al. 2023).

[6] Comparing September 2022 (when EU TTF gas prices peaked) relative to January 2019.



Reading example: While US gas prices have always been lower than EU gas prices in recent years, the consequences of Russia's invasion of Ukraine have had a disproportionate impact on EU gas prices, which are now partly determined by gas imports from the US and were and are structurally higher than US prices. The exceptional gas price increases have also affected electricity prices.

Source: EIA (2023), Macrobond (2023)

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Figure 9 Gas prices diverging in Europe and the United States

1.2 Fossil-fuel-driven inflation would have been even higher in the absence of costly anti-inflationary measures

During the energy crisis, European governments implemented large-scale support programs to dampen the impact of increased energy prices. These measures alleviated the effect of rapidly rising fossil fuel market prices on households and firms: the ECB estimated that energy and inflation compensatory fiscal measures reduced euro area inflation by 1.1 percentage points in 2022 and by 0.3 percentage points in 2023 (ECB 2022b, ECB 2023).[7]

In 2024 and 2025, however, the withdrawal of these measures is expected to increase inflation by 0.5 (2024) and 0.2 percentage points (2025) (ECB 2023). This effect could be lower if the reliance on fossil fuels has been reduced by then.

In Germany, where particularly large amounts of public money have been mobilized to respond to the energy crisis, estimates for the impact of energy price brakes range between 0.2 and 0.4

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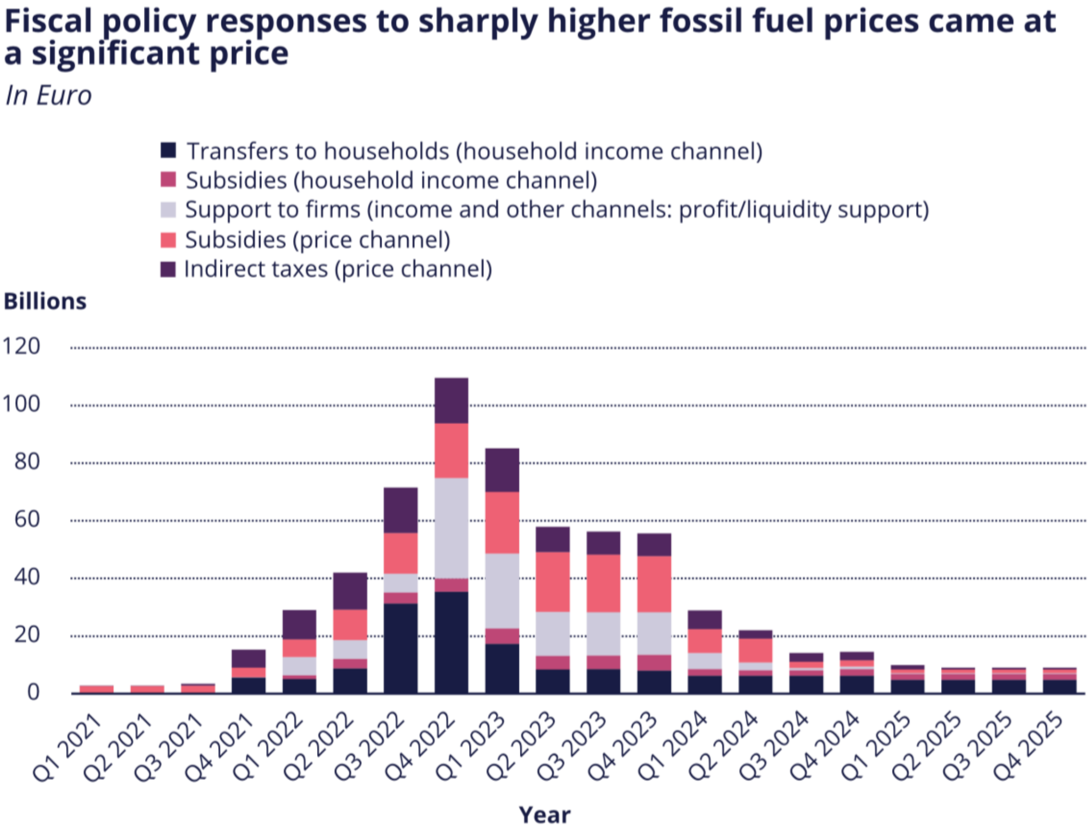
[7] For comparison, final average headline inflation came in at 8.4 percent in 2022 and is expected to come in at 5.6 percent for 2023.

percent (gas price brake only, Garnadt et al. 2023) and 0.5 percent (both gas and electricity price brake, Jannsen & Sonnenberg 2023)[8].

However, these measures came at a significant cost. ECB staff projections estimate that government expenditure on these measures in the euro area came to a total of 1.9 percent of GDP in 2022 and 1.8 percent of GDP in 2023 (Figure 10; ECB 2023).


Fiscal policy responses to sharply higher fossil fuel prices came at a significant price

In Euro

Sources: Checherita-Westphal & Dorrucci, ECB staff calculations (2023)

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Figure 10 Fiscal policy support measures in response to energy crisis and high inflation (euro area)

In sum, energy made an outsized contribution to the recent inflationary wave in Europe: On average, 50 percent of year-on-year inflation in 2022 was directly due to energy, the vast majority of which due to fossil fuels. Additional inflationary impacts followed from indirect effects on other prices, in particular food. Short-term fiscal responses dampened the inflationary consequences for European consumers. But over the long run, these measures are costly and unsustainable. Structurally, fossil fuel dependence therefore poses a risk to macroeconomic stability and exacerbates inflationary risks. Talking about inflation without also talking about fossil fuel dependency misses a crucial piece of the puzzle.

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[8] In December 2022, Germany introduced price brakes for electricity and gas (including district heating), capping prices at 40 ct/kWh (electricity), 12 ct/kWh (gas) and 9,5 ct/kWh (district heating) for 80 percent of consumption of each energy carrier, based on the previous year's consumption (Federal Government 2022).

2. In the short- and long run: clear anti-inflationary effects

Every cloud has a silver lining. The inflationary risks of fossil fuels create a macroeconomic dividend to the green transition: increased price stability and lower energy costs.

2.1. The energy crisis boosted the roll-out of renewables, which helped cushion prices

Europe's response to the energy crisis of 2021-2022 showed the potential of renewables to fight inflation in the short run. As a result of the European REPowerEU action plan and policy actions taken at the member state level, the International Energy Agency (IEA) revised its forecast for EU renewable capacity additions in 2023 and 2024 upwards by 38 percent, compared with its December 2021 forecast (IEA 2023c, p. 21).[9] Since Russia's invasion of Ukraine, newly installed wind and solar PV capacity displaced an estimated 230 TWh of fossil fuel generation (IEA 2023c, p. 28), the equivalent of 8.2 percent of the EU's annual electricity production.[10]

This reduced electricity prices. The main mechanism for this — changing the so-called merit order in electricity markets — is explained in box 2 below. The IEA estimates that the accelerated deployment of solar PV and wind since 2021 reduced EU wholesale electricity prices by 8 percent in 2022 and 15 percent in 2023, relative to a scenario without further capacity additions (IEA 2023c, p. 28 & 30). If these wholesale savings were passed on one-for-one to consumers, this was the equivalent of a 0.2 percentage point reduction in HICP inflation in 2022, and a 0.4 reduction in 2023. In absolute terms, the IEA estimated that cost savings for EU consumers will amount to approximately 95 billion euro by the end of 2023 (IEA 2023c, p. 28).

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[9] This increase in capacity additions is largely driven by small-scale solar PV, which accounts for 74 percent of the forecast revision, and concentrated in six countries — Germany, Spain, the Netherlands, France, Italy and Sweden — which account for 82 percent (IEA 2023c, p. 21-22).

[10] Total EU electricity generation was 2795 TWh in 2022 (IEA 2023d, p. 287).

Box 2: Price formation and the merit order in electricity markets

In most places today, renewable energy technologies produce electricity at a lower cost per kWh than fossil fuels (see pp. 17-23 below for more on this). The mechanism that translates production costs into electricity prices is the merit order effect.

The merit order effect operates as follows. Depending on their variable costs, generation sources are ranked in a merit order, from the cheapest-to-operate to the most expensive. The market price of electricity is then determined by the equilibrium between demand, itself price-dependent, and the *variable cost* of the *most expensive* generation source needed to *meet that current demand* (the marginal plant). Since many renewable technologies, esp. wind and solar PV, have zero marginal cost, they rank at the top of the merit order. Whenever the wind blows and/or the sun shines, they push more expensive power plants, for example natural gas plants, out of the market. As these expensive plants are no longer needed, cheaper powerplants become the marginal plant. And since the marginal plant sets the market price, the price faced by consumers drops. In this manner, renewables can lower energy inflation or even lead to outright energy price deflation.

A separate estimate for Germany comes to a similar conclusion: Transition Zero (2022) estimates that the addition of 18 GW of solar PV plus 7 GW of onshore wind per year in 2022, 2023, and 2024, together with appropriate amounts of battery storage, cuts the electricity bill of a typical household by 9 percent in 2024 (Figure 11).[11]

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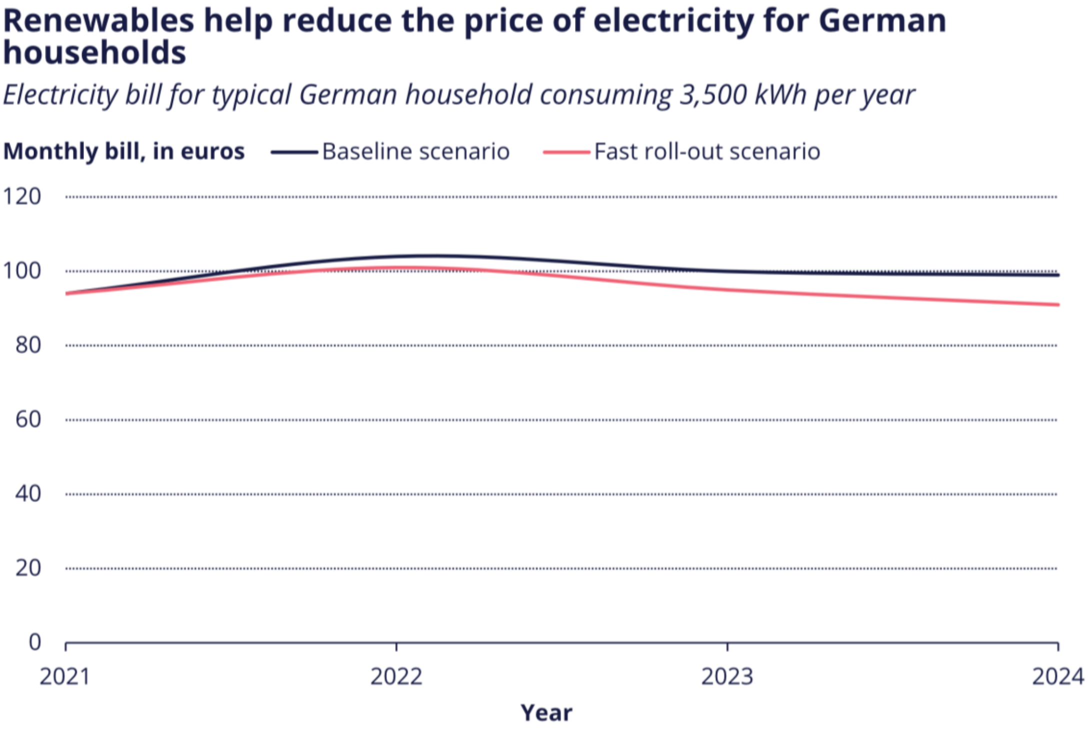
[11] These numbers should be taken as indicative. The underlying modelling is not based on a fully fledged electricity market with marginal cost pricing, but on a weighted average of the costs of i) short-run marginal costs for fossil fuel-based electricity and nuclear generation and ii) LCOE for renewable energy based electricity.



Renewables help reduce the price of electricity for German households

Electricity bill for typical German household consuming 3,500 kWh per year

Note: The fast roll-out scenario models the addition to the German energy mix of 18 GW of solar PV capacity plus 7 GW of onshore wind capacity per year in 2022, 2023, and 2024, together with appropriate amounts of battery storage.

Reading example: In 2024, the monthly electricity bill of a typical German household is 91 euro in a fast roll-out scenario, versus 99 euro in a base case with less renewable deployment.

Source: Transition Zero (2022)

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Figure 11 Electricity bills for a typical Germany household as modelled by TransitionZero

Beyond electricity, renewables also helped reduce heating costs in the short run. The IEA estimates that “clean electricity, bioenergy boilers, heat pumps, and solar thermal and geothermal technologies could displace almost 8 billion cubic metres of EU buildings-related gas consumption annually in 2023 and more than 17 bcm in 2024.” (IEA 2023c, p. 10). While there are no modelling results concerning its price- or inflation impact, this is approximately 4-8 percent of total gas consumption in the buildings sector (IEA 2023c, p. 35). At 45 Euro per MWh[12], this amounts to gross fuel cost savings of approximately 11 billion euro in 2023 and 2024. Net savings on the total heating bill are unclear, however, because no estimates were given for the costs of the replacement heat sources.

2.2 Over the long run, a clean energy system will be cheaper and likely more price-stable

This positive short-term picture is complemented by a likely **long-run** deflationary contribution of renewables. Despite their month-to-month and year-to-year volatility, over the longer run, the prices of coal, oil, and gas have stagnated or increased. In contrast, the prices of key renewable

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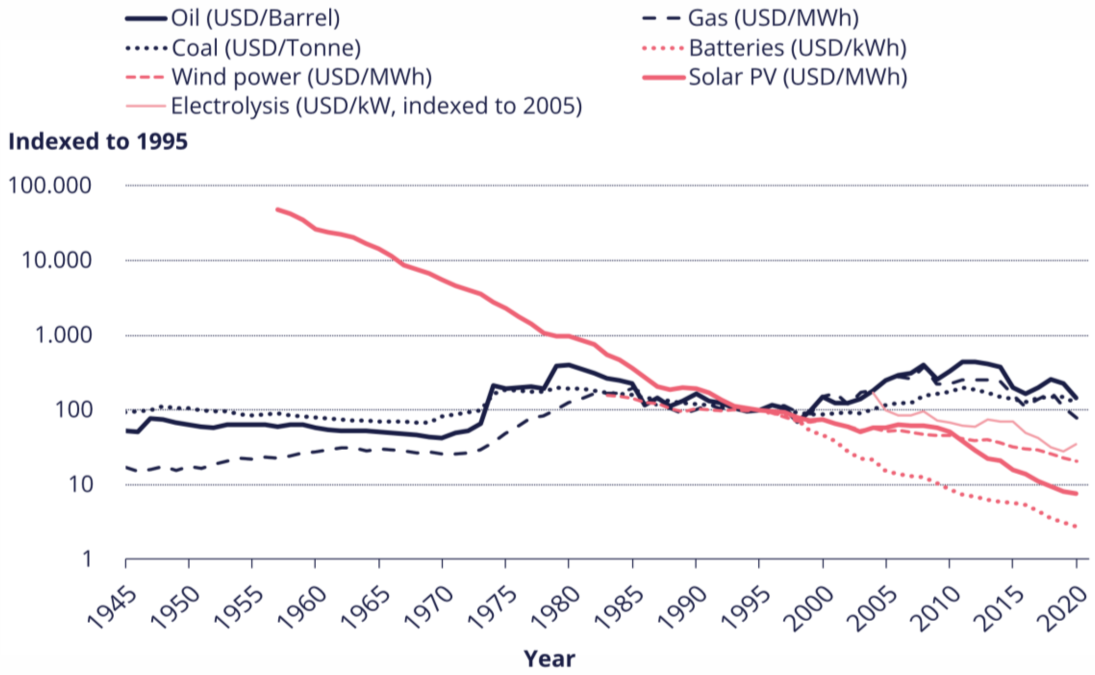
[12] The average Dutch TTF gas price for 2023 to date is approximately 42 euros per MWh. In early November, the price was moving back towards the high 40s. At the significantly higher prices of 2022 (on average 135 euros per MWh), the savings would have amounted to around 34 billion euros.

technologies — solar PV, wind, batteries, and electrolysers — have decreased significantly on this scale (Figure 12, based on Way et al. 2022). Leaving questions of grid integration and -reliability aside for now, renewables are cheaper than fossil energies in most places today (IEA 2023d, p. 147).

Clean energy costs are decreasing while fossil energy costs are stagnating

Price-adjusted values, logarithmic presentation



Fossil energy prices show no long-run declining costs, while key clean energy technology costs (solar PV, wind, short- and long-term storage) are declining considerably. These values are not directly comparable because energy conversion efficiencies are not considered and because each cost curve is indexed to its own value in 1995 (2005 in the case of electrolysis).

Source: Way et al. (2022)

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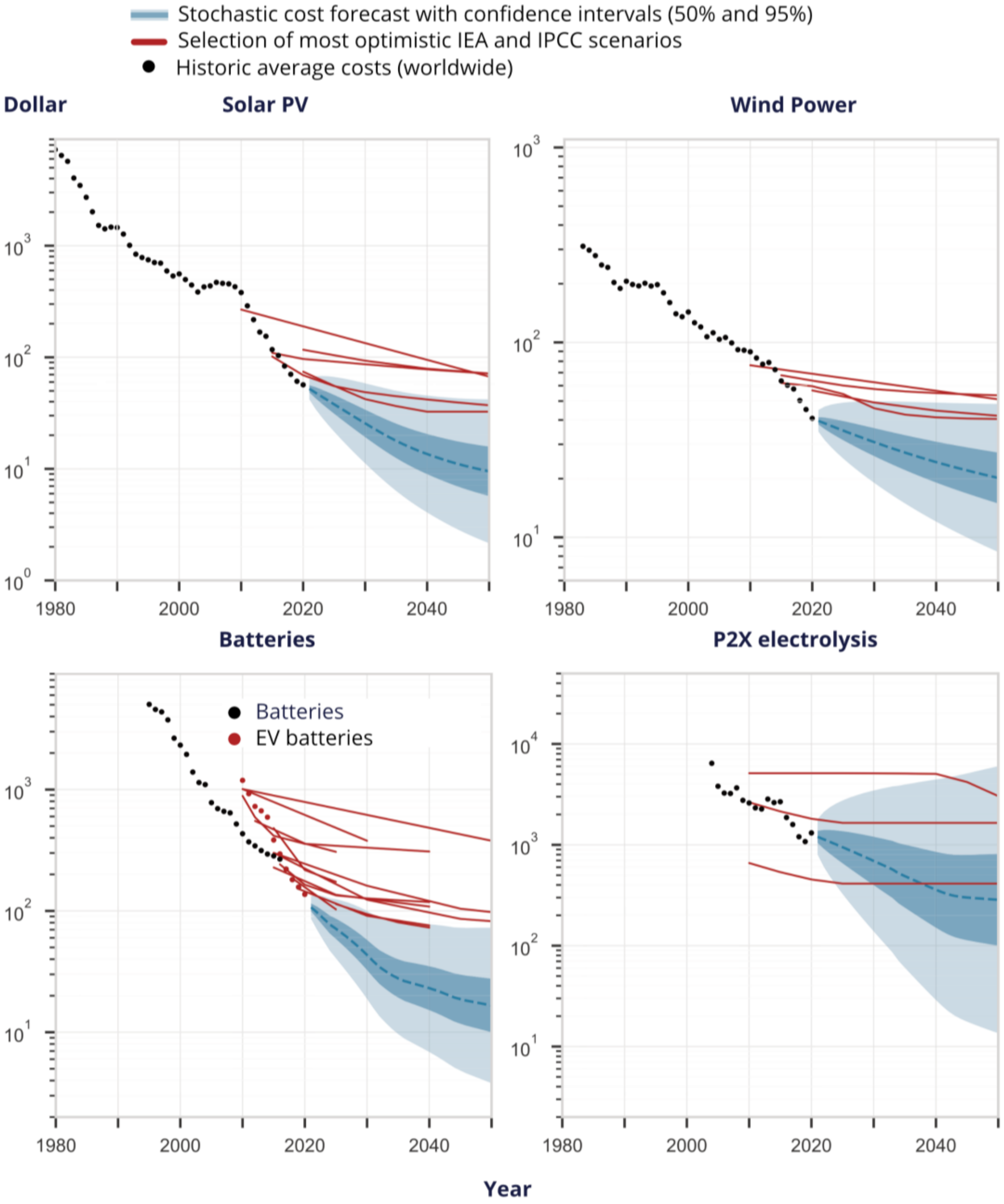
Figure 12 Long-term cost development of various energy carriers

The costs of renewable technologies have not only decreased significantly in past years, they also did so considerably faster than most analysts expected them to. Figure 13 compares cost assumptions from the most optimistic IEA and IPCC scenarios with actual cost figures over time. Actual cost decreases surprised even the most optimistic experts at the time.

Clean energy costs are falling much faster than expected

In comparison to the most optimistic IEA and IPCC scenarios. Logarithmic presentation. Generation costs (solar and wind, USD/MWh), capacity costs (batteries, USD/kWh) and service costs (electrolysis, USD/kW).



Stochastic cost forecasts for solar PV and wind power (generation costs) and batteries (capacity costs) in a fast energy transition scenario based on Way et al. (2022). None of the scenarios by the International Energy Agency (IEA) or the Intergovernmental Panel on Climate Change (IPCC) is depicting the trends that can be expected.

Reading example: In 2022, the average generation cost of wind power is 40 USD/MWh. In 2050, the cost can be expected to be 20 USD/MWh. Costs are shown in potencies (10^3=1000).

Source: Way et al. (2022), p. 2065

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Figure 13 Empirical cost projections for key clean energy technologies

While a record of better-than-expected cost decreases provides grounds for optimism, it does not directly guarantee similar decreases in the future.[13] However, three pieces of evidence provide grounds for further optimism.

First, cost decreases are often correlated with production volumes (*Wright's Law,* Wright 1936). For example, as the smartphone market boomed in the 2010s, prices for previously expensive components like miniaturised cameras, high-capacity lithium batteries, or high-quality screens dropped significantly, driven by economies of scale, R&D, and the extensive learning-by-doing that they enabled. Concerning renewables, while they have seen mass deployment already, the Announced Pledges Scenario of the IEA sees installed capacities near-tripling from 3,630GW worldwide in 2022 to 9,790 GW in 2030 (IEA 2023d, p. 273). By 2040, another doubling is expected, to 18,890 GW. This provides ample scope for further learning-by-doing.

However, not all technologies exhibit steep learning curves, and not all technologies exhibit them uniformly across time. As Malhotra and Schmidt (2020; see also McNerney et al. 2011) show, both the complexity of a technology, and the extent to which it must be customised to particular use cases, affect learning rates: low-complexity, standardised technologies generally experience the highest learning rates, high-complexity, highly customised technologies experience lower learning rates (see Figure 14).

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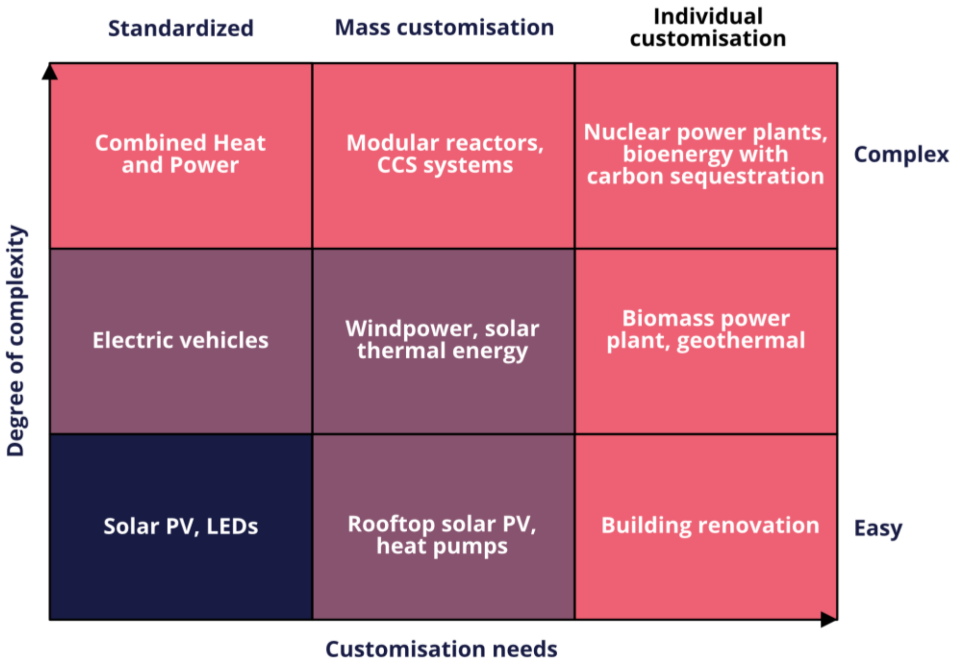
[13] Indeed, the IEA Clean Energy Equipment Price Index stopped falling in 2020 and rose slightly in 2021 and 2022. The IEA sees this "largely reflecting higher input prices for critical minerals, semiconductors and bulk materials such as steel and cement" and "signs are evident in 2023 that some of the cost pressures are easing." Overall, they "consider that clean energy technology costs will continue to trend downward, and that there is still considerable scope to reduce important cost elements through technology innovation, materials substitution, efficiency improvements and economies of scale" (IEA 2023c, p. 99-100). Nevertheless, this uptick in costs merits close attention.



Characteristics of different energy technologies

Schematic categorisation based on complexity and customisation needs

Degree of complexity	Standardized	Mass customisation	Individual customisation
Complex	Combined Heat and Power	Modular reactors, CCS systems	Nuclear power plants, bioenergy with carbon sequestration
	Electric vehicles	Windpower, solar thermal energy	Biomass power plant, geothermal
Easy	Solar PV, LEDs	Rooftop solar PV, heat pumps	Building renovation

Technologies that are neither complex nor require customisation tend to have greater optimisation potential, as production processes can be standardised and scaled up. Complex technologies with a high need for customisation (e.g. because they require extensive construction projects) tend to stagnate.

Sources: Malhotra & Schmidt (2020), Junginger & Louwen 2019

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Figure 14 Characteristics of different energy technologies

Applying this analytical lens to renewables provides a second reason for optimism regarding their long run cost saving- and inflation-reduction potential. Solar PV modules and batteries are mass-produced, standardised goods. Electric vehicles are more complex, but nevertheless highly standardised mass-manufactured products. Wind turbines and heat pumps are intermediate cases, with medium levels of complexity and some customisation required, but most of their parts and components are amenable to mass production. Geothermal power, finally, is now drawing on drilling knowledge gained through the US shale boom, and may gradually move from a complex and customised to a relatively standardised and repeatable product (Temple 2023).

Relative to thermal powerplants, where heat efficiency requires large plant sizes, which in turn drive up complexity and customisation and reduce learning rates, most renewable technologies therefore appear to be in the fast-learning quadrant.

As a result, analysts now expect the transition to a clean energy system to be cost saving in the long run. For Europe, comparing a stated policies scenario with two 1.5-degree-scenarios, Ember finds annual cost savings from reduced fossil fuel consumption of 90 billion euro in 2035 (Rosslowe et al. 2022, p. 41).[14] Per unit of electricity, these 1.5-degree-scenarios are expected deliver 23-30

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[14] Assuming an oil price of 77 to 88 USD/barrel and a gas price of 7.7 to 8.3 USD/MBtu or 26-28 EUR/MWh (EMBER 2022, p. 47, in conjunction with IEA 2021, p. 101, table 2.2). At higher or lower fossil prices, savings would be correspondingly greater or lesser.

percent cost savings (Ember 2022, p. 47) in 2035, relative to the stated policies scenario. Using a similar methodology for China, He et al. (2020) show net cost savings from a transition to renewable energies of around 11 percent in the electricity sector, even before avoided climate damages and other environmental benefits are accounted for (He et al. 2020). In Way et al. (2022), the cost comparison is limited to direct engineering costs: neither avoided CO_2-prices (as in Europe's Emission Trading System), which feature in Ember's modelling, nor avoided climate impacts are considered. But even ignoring the massive cost savings that a clean energy system delivers on those dimensions, a clean energy system achieves straightforward engineering savings, too, over the long run: in a "Fast Transition" scenario, annual global energy system costs in 2050 are approximately 500 billion dollars lower than in a no transition scenario (Way et al. 2022, p. 2069).

Finally, in addition to reasons related to technology cost curves, there is a third reason to believe that clean energy systems will be deflationary over the long run. In a global clean energy system, critical trade flows will shift from fuels (which are continuously needed to keep the current system running) to equipment and the resources needed to build new facilities, most prominently critical raw materials. As the former are a one-off input into production facilities, and the latter will be recycled at growing rates, disruptions in their supply have a less severe and immediate impact on energy security (Krane & Idel 2021, IRENA 2023).[15] Overall, the transition to clean energy is therefore expected to make energy relations more horizontal and polycentric, reducing monopoly- or oligopoly rents for upstream producers and resulting in lower energy prices, especially for countries that currently import large quantities of fossil fuels (IRENA 2019, Scholten et al. 2020).

The case is strong, in other words, that over the long run, a clean energy system will be cheaper than a fossil-fuel based one.

More variable prices in the short run, but more stable prices over time

Will a European clean energy system also produce *more stable* energy prices? On a scale of days to weeks, electricity prices will likely become more variable, to coordinate demand-side flexibility; cheap but weather-driven wind and solar; and dispatchable but more expensive energy storage, hydrogen- and other firm power sources.

Nevertheless, in contrast to this microeconomic variability, there are reasons for optimism concerning macroeconomically significant prices swings. The cost base of a clean energy system will be dominated by fixed costs, rather than variable costs.[16] Insofar as capital expenditure can be smoothed out over time, this boosts medium- and long run price stability. Moreover, a European clean energy system will be significantly less energy import-dependent. This translates into lower exposure to international energy price shocks, whether driven by geopolitical events or economic developments abroad. Finally, the production of renewables-based gases and fuels will likely be more decentralized compared to the production of fossil fuels (see above). As a consequence, the reliance on single producers is likely to be much lower and unanticipated supply disruptions in one

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[15] One possible exception to this pattern may be the global hydrogen trade (Van de Graaf et al. 2020). But since its scale will be significantly smaller than today's oil and gas trade, this is unlikely to flip the general picture.

[16] Broken down to the household level, the IEA estimates that relative to a business-as-usual scenario, the energy expenditure of advanced economy households would not just decline by around 500 dollar per year, but also witness a significant shift from bills (down by around 2500 dollar) to investments (up by around 2000 dollar) (IEA 2023d, p. 187). Utilities and many energy intense industries will likely see similar shifts: here, too, investments in wind, solar, energy efficiency, energy storage, and energy flexibility technologies will likely rise, fuel and other operating costs decline.

location will likely have less severe consequences for global prices. Relative to a fossil fuel based energy system, a clean energy system is therefore likely to exhibit greater macroeconomic price stability.

3. In the mid-transition: a more complex picture

Both in the short- and in the long run, renewable energies are likely to reduce inflation. In the medium run, however, the picture is more complex. Three kinds of challenges, briefly explored below, appear salient for the mid-transition. However, these risks are not set in stone. The extent to which they will materialize will depend on today's policy choices, especially around grid investment and regulation; supply- and demand-side flexibility; and the speed of ramping up renewables and ramping down fossil fuel consumption.

3.1 Fossil fuel price volatility may increase mid-transition

First, past a certain threshold, the roll-out of renewables may increase both the volatility and, potentially, the level of inflation that emanates from fossil energies. This constitutes a temporary risk to price stability in the mid-transition. As with the other two risks, the policy choices of today can help to control it: the faster policy makers reduce the share of fossils in the European energy mix, the faster any remaining fossil fuel price swings become economically immaterial.

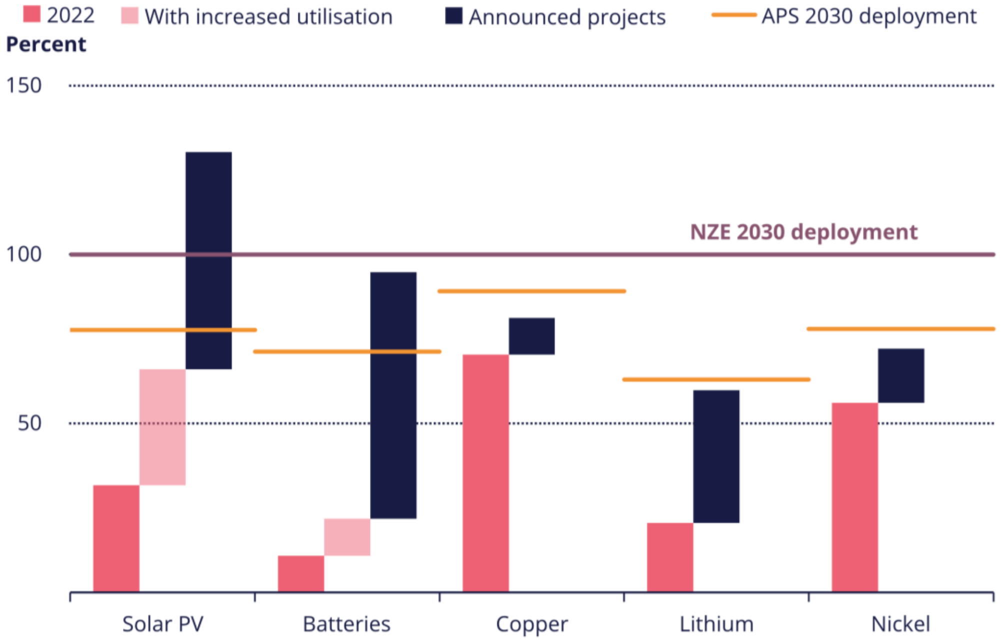
What may cause increased fossil price instability in the mid-transition? As long as "private extraction companies, pipeline operators, and other supply chain actors (that might not have a positive obligation to serve) continue to participate in the system despite clear messaging that there is not only no growth expected, but active decline, in these high capital intensity industries" (Grubert and Hastings-Simon 2022, p. 8), the inflation pressures from fossils should not deviate fundamentally from their historical pattern. However, it is unclear whether that assumption will hold in the future. Deviations are possible in two directions: fossil decision makers may *overestimate* the pace of the transition. This may lead them to reduce investments in the fossil energy system prematurely, leading prices to become more volatile and higher. Depending on electricity market design — an element notably under the control of policy makers —, this can bleed over into electricity markets (see Figure 8 above).

Alternatively, if fossil decision-makers *underestimate* the pace of the transition, they may invest excessively in fossil assets. Once the transition picks up speed, this would lead to abruptly lower prices, as higher marginal cost producers exit the market, and an abundance of stranded assets. While this would reduce the costs of fossil energies, it could contribute to price volatility via a disorderly transition and financial instability.

3.2 Supply chains should be monitored for bottlenecks and geopolitical risk

Second, in addition to more pronounced fossil fuel price swings, the mid-transition may also lead to higher and more volatile prices along renewable energy supply chains. This would partly be a problem of success: Renewables supply chains may become tight if the rollout of wind, solar PV, and other renewables proceeds according to a Net Zero by 2050 scenario, but upstream firms (in mining, mineral refining, and other upstream projects with long lead times) invest more in line with an announced ledges or even a business as usual Scenario. Based on IEA projections, this risk appears relevant for lithium, nickel, and to a lesser extent copper; though less so for solar PV and battery manufacturing capacity (Figure 15). Note, however, that future lithium demand appears uncertain and depends on policy choices, e.g. on recycling or EV size regulation, and technological developments, e.g. sodium-iron batteries. An accurate estimate of lithium supply chain risks is therefore difficult (Riofrancos et al. 2023).[17] The same goes for many other materials: future policy- and technological developments, potentially in response to price spikes and bottlenecks, may greatly affect their demand, so that current projections should be carefully interpreted.

Policy-wise, this strengthens the case for closely monitoring supply chains.[18] If shortfalls between required and planned capacities become visible, a range of policy options is available, ranging from an increased emphasis on recycling to reducing alternative uses of critical minerals, from supporting research into substitute materials to increasing upstream investment.



Lithium, nickel, and copper supplies may become scarce in a fast transition

Needs and expected supplies of key renewable technologies and materials

Note: Announced projects include both committed and preliminary projects. For critical minerals, the "Net Zero by 2050" Scenario deployment needs refer to the primary supply requirements (total demand less secondary supply, mainly recycling).

Reading Example: Lithium production capacity is expected to more than double between today and 2030, based on announced projects. Expected 2030 capacity is just short of expected needs in an "Announced Pledges Scenario", but approximately 40% short of expected 2030 needs in a "Net Zero by 2050" scenario.

Source: IEA World Economic Outlook 2023, p. 179

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Figure 15 Projected supply and demand of key renewable technologies and materials

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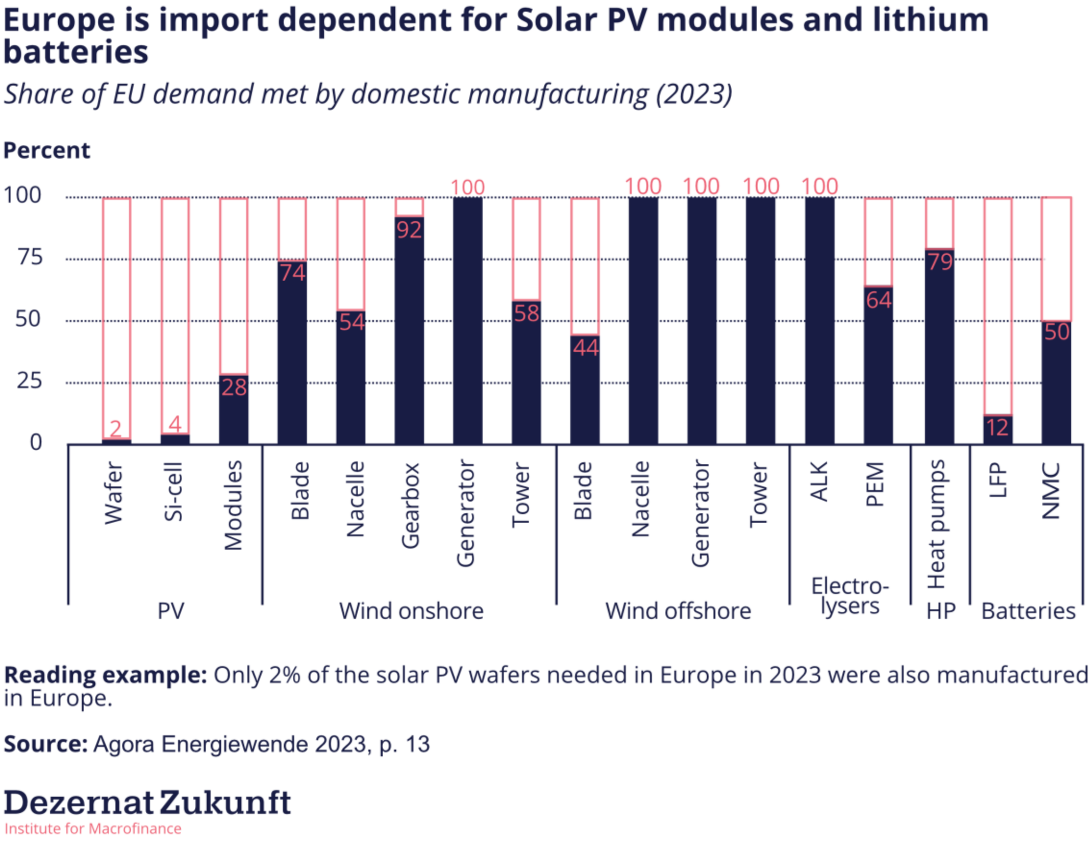
[17] On this, as well as on cobalt demand forecasts, see also Giurco et al. 2019 (in Teske ed., 2019, ch. 11 and esp. figures 11.6 and 11.8)

[18] Encouragingly, the IEA recently integrated critical minerals into its global energy and climate model. Going forwards, it will regularly update demand- and supply projections for, among others, copper, major battery metals (lithium, nickel, cobalt and graphite) and rare earth elements in line with the IEA energy scenarios, reflecting both policy and technology advances (IEA 2023a, p. 4).

Besides the “problem of success”, certain renewables supply chains also exhibit geopolitical risks. Europe is highly import-dependent, mostly from China, with respect to Solar PV modules and lithium batteries (Figure 16).



Europe is import dependent for Solar PV modules and lithium batteries

Share of EU demand met by domestic manufacturing (2023)

Reading example: Only 2% of the solar PV wafers needed in Europe in 2023 were also manufactured in Europe.

Source: Agora Energiewende 2023, p. 13

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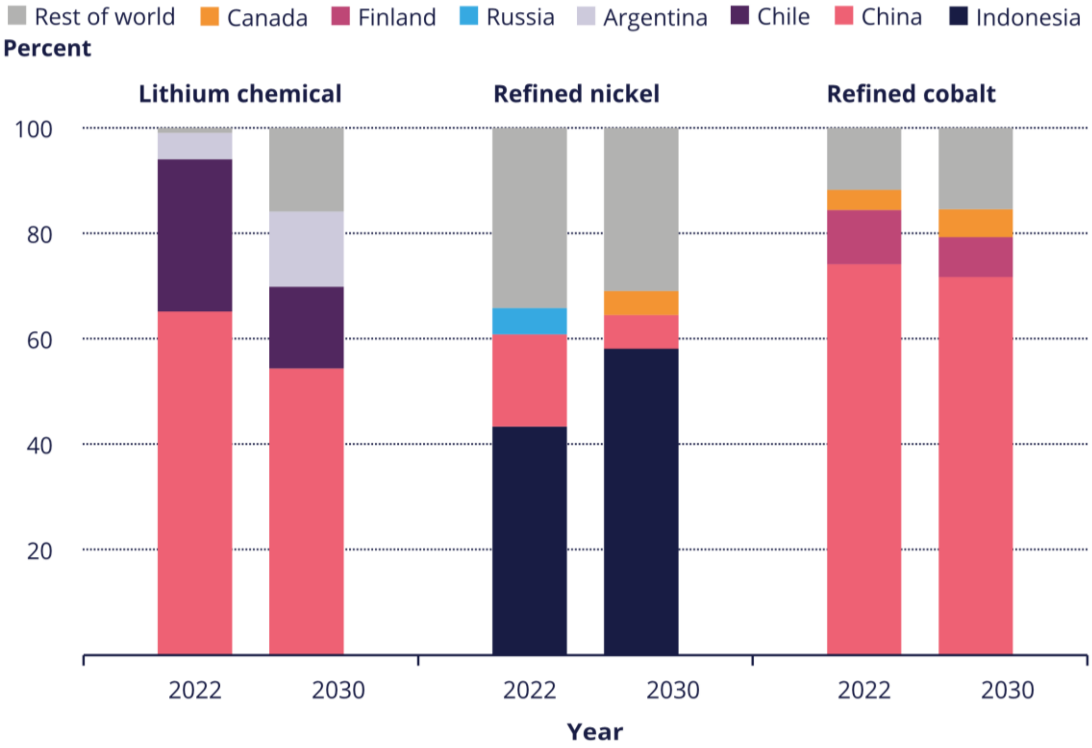
Figure 16 Europe’s import dependency regarding key renewable energy technologies

In addition, global lithium and cobalt refining capacities are concentrated in China, while both nickel mining and refining is concentrated in Indonesia (Figure 17). The recent self-restrictions on Chinese gallium and germanium exports demonstrate the salience of this risk.



Lithium and cobalt refining is highly concentrated in China

Percentage of refining capacity by geographical location

Note: 2030 numbers refer to expected total production capacities in 2030 from all existing and announced projects to date.

Reading Example: In 2022, China accounted for approximately 65% of total global lithium refining capacity. By 2030, this share is projected to fall towards 55%.

Source: IEA World Economic Outlook 2023, p. 182

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Figure 17 Refining capacity of lithium, nickel, and cobalt by country

However, the geopolitical risks of renewable supply chains can be overstated: Europe's import dependency is generally low for onshore and offshore wind, as well as for electrolysers, heat pumps, and lithium nickel manganese cobalt oxide (NMC) batteries (Figure 16). Concerning lithium, China's share of global refining capacity is expected to decrease over time (Figure 17). And with the Net Zero Industry Act (NZIA) and the Critical Raw Material Act (CRMA), two important European policy measures are already underway — notably in response to a geopolitical risk materialising. Seeing these measures through the legislative process and ensuring they are backed by adequate funding may go a long way towards managing this particular risk.

Adequate investment is needed in grid expansion and demand- and supply-side flexibility

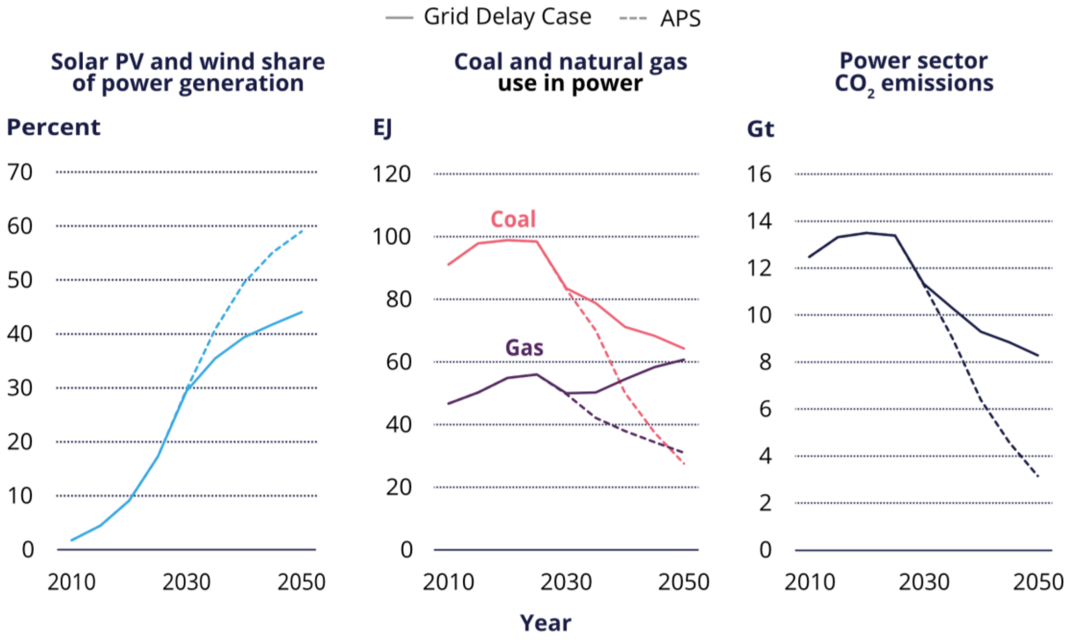
Third, whether renewable energies can contribute to reducing inflation and inflation volatility in the mid-transition will also depend on timely grid expansion and demand- and supply-side flexibility investments. In their absence, renewable deployment rates may be lower and an increasing amount of electricity generation from installed wind turbines and solar PV may have to be curtailed in order to preserve grid stability (IEA 2023c, p. 12).

Zooming in on Germany, a recent study highlighted the need to double gas power plant capacity, from 30 GW (2022) to 61 GW (2035), to be operated first with fossil gas and later hydrogen, in order to achieve a carbon neutral electricity system by 2035 (Agora Energiewende et al. 2022, p. 9).[19]

In Europe, the need for additional flexible electricity supply interacts with the EU Emission Trading System. Where investment in clean flexible supply is too low, coal and gas plants will be run to meet demand and assure grid stability. Since they require emission allowances to operate, this drives up demand for EU ETS certificates. In a cap-and-trade system, this pushes up their price, causing inflation. To prevent this, rapidly scaling up flexible, low-emission electricity supply is key.

A quantitative estimate of the consequences of insufficient grid investment is given in the first IEA global stocktake of grids (IEA 2023b). In a “grid delay” scenario (IEA 2023b, p. 103), lower investment in, and higher curtailment of, renewables leads to significantly higher fossil fuel consumption after 2030 on (see Figure 18 below). For the European Union, “the Grid Delay Case leads to over eight times the level of natural gas use in power in 2050 than in the APS [Announced Pledges Scenario], leading to 80 Mt higher CO_2 emissions” (IEA 2023b, p 103).

Delays in electricity grid expansion significantly delay the phase-out of fossil electricity generation



Reading example: If the expansion of electricity grids is delayed ("Grid Delay Case"), the expansion of renewables is slowed down, while the use of fossil fuels for electricity generation and power sector emissions increase relative to currently announced climate pledges ("APS").

Source: adapted from IEA (2023), p. 104

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Figure 18 Effects of grid expansion delays on electricity generation and emissions

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[19] Even with such a doubling of gas power plant capacity, however, grids were identified as a future bottleneck (Agora Energiewende et al. 2022, p. 12).

Avoiding a Grid Delay Scenario is in the hands of policy makers today: there are no fundamental engineering obstacles to constructing an adequate grid infrastructure on time (IEA 2023b). Integrating planning processes, streamlining regulation and permitting, advancing digitalisation and better grid management, and ensuring adequate investment in grid extension should all be priority items today (IEA 2023b, chapter 4).

Today's policy choices will shape the mid-transition

The mid-transition presents three main challenges to price stability: increasing volatility in fossil prices; the potential for malcoordination in renewable supply chains; and underinvestment in grids and demand- and supply-side flexibility.

The extent to which these challenges will be mastered depends on policy choices taken today. The IEA (2020) lists the following as important actions: investments in grids[20] and flexibility services, for example via smart meters, curtailment contracts, virtual power plants, and synthetic inertia; the integration of electricity, gas, and hydrogen grid planning; the coupling of different sectors, esp. transport (EVs) and electricity; a "grid code", which refers to "a set of rules and specifications" that cover "connection codes, operating codes, planning codes and market codes"; and appropriate market design for electricity and adjacent markets.

For Germany, a study by Agora Energiewende and others (Agora Energiewende et al. 2022) highlight four priority actions: doubling (hydrogen-ready) gas power plant capacity; additional transmission grid investment of around 2.5 billion euros per year (ibid., p. 63, chart 30);[21] Ensuring that heat pumps and other time-flexible demand sources can react flexibly to scarcity signals (ibid., p. 19); and electricity market reform, especially the introduction of regional price differentiation to incentivise the grid-appropriate locating of hydrogen electrolysers and other energy intense and potentially flexible users (Agora Energiewende et al. 2022, p. 17-18).

In sum, while the mid-transition presents significant challenges, including to energy price stability, there is no reason why they should be insurmountable. Further research is needed, however, to get a clearer grasp of these challenges and to identify the right policy responses to manage them.

Conclusion

Fossil fuel prices made an outsized contribution to recent inflation in Europe. On average, 50 percent of year-on-year inflation in 2022 was directly due to energy, the vast majority of which due to fossil fuels. Additional inflationary effects followed from indirect impacts on other prices, especially food.

Renewable energies helped fight inflation in Europe in the short run, and can likely do so in the long run, too. In the short run, they have saved European consumers around 95 billion euro between 2021 and 2023 and reduced electricity prices by up to 15 percent. In the long run, the

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[20] The IEA estimates that, in their Announced Pledges Scenario, 80 million kilometres of electricity grids must be added or refurbished worldwide, the equivalent of the entire existing global grid (IEA 2023b, p. 7). This requires a doubling of global grid investment, from approximately 300 billion dollars p.a. to over 600 billion (IEA 2023b, p. 9)

[21] This study did not model distribution grid investment needs. An earlier study identified an additional investment need of around 10 billion euro a year between 2020 and 2030 for Germany's distribution grid to be renewables-ready (Eurelectric 2021)

secular downwards trend in their costs curves, repeatedly underestimated in the past, suggests further potential for savings and, once the energy transition is done, better price stability.

The situation is more complicated in the mid-transition. As the brief overview in section 3 highlighted, three risks appear particularly salient: as long as electricity prices remain linked to fossil fuels, especially gas, increasing instability in fossil fuel markets will spill over into the pricing of electricity; supply chain risks may materialise as renewable energy deployment speeds up further; and investments in grids, energy storage, as well as supply- and demand-side flexibility may fail to keep up, creating bottlenecks and price spikes.

However, these risks are not set in stone. The policy choices of today will shape how they will unfold in the future. While further research is required on the mid-transition, both to grasp the risks more clearly and to identify the best option to control them, and while taking the appropriate policy actions is key, the overarching message is simple: fossil fuels added to the economic and political instability of recent years. Renewables can become a pillar of future stability.

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