SCHOOL OF PUBLIC POLICY
CENTER FOR GLOBAL SUSTAINABILITY

STRATEGIES TO TRANSITION AWAY FROM RUSSIAN GAS AND DELIVER CLIMATE GOALS IN GERMANY

JULY 2022

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CENTER FOR GLOBAL SUSTAINABILITY (CGS) AT THE UNIVERSITY OF MARYLAND SCHOOL OF PUBLIC POLICY

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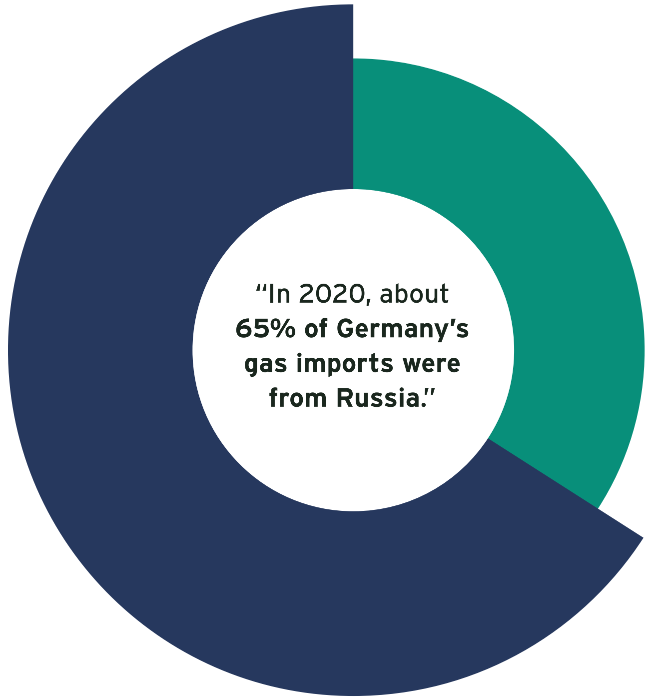
INTRODUCTION:

Europe—and Germany in particular—are facing twin challenges that link fundamentally between energy security and climate policy. On the one hand is the urgent near-term need to manage through a radically transformed gas supply situation in light of Russia's invasion of Ukraine. On the other hand is the urgent medium- and longer-term need to address climate change by accelerating the transformation of Europe's energy system to achieve a 55% emissions reduction by 2030 from 1990 and move toward net zero emissions by 2050. Addressing either one of these challenges independently could potentially lead to dramatic failure in the other—for example, if there is a massive buildout of new gas supply infrastructure that would generate higher long-term fossil demand. The critical question for Europe and Germany is whether a strategy can be devised that would not only clear a pathway to near-term energy security but also place them squarely on a pathway toward rapid emissions reductions consistent with their 2030 and 2050 goals.

This question is not only important for Europe, but in fact may point the way for advances in other contexts. The most beneficial approaches to solving the problem could potentially layer the climate solutions into the near-term and immediate infrastructure investment to address the gas supply concerns. An example of this would be the rapid acceleration of technologies such as heat pumps and smart building technologies that would put a major down payment on a strategy that would have to be accelerating rapidly to achieve 2030 goals. Such actions would, moreover, not only help deliver on Europe's goals but would also generate near-term technology cost reductions that could support accelerated action in other regions.

The challenge, however, is significant: in 2020, about 65% of Germany's gas imports were from Russia. Yet immediate action is needed to transition away from Russian gas fully or as much as possible before 2023, and fully as soon as possible thereafter. Under extreme conditions, achieving the full transition for the upcoming winter season possibly involves upsetting measures such as the curtailment of certain industrial activities. Instead, this paper focuses on feasible, sustainable pathways for Germany to safely transition away from Russian gas in the timeframe of 3 to 5 years—which also requires immediate actions and investment today to keep Germany on to a path compatible with a global 1.5°C trajectory. These pathways can feasibly replace all Russian gas quickly while staying on track with long-term climate goals.



To do this, we present actionable gas reduction strategies on both the demand and supply sides and based on these potential actions, assess the resulting implications for overall greenhouse gas emissions. In particular, the analysis consists of three main pieces: First, we develop feasible, sector-specific strategies to reduce gas demand immediately. Since EU gas consumption is focused on electricity generation, buildings, and industry, we estimate the potential reductions in each of these areas through feasible actions based on policy goals and literature. Second, we explore the potential to increase gas supply from other regions through existing infrastructure and infrastructure under development. Third, we assess the emission impacts of the strategies and the implications for keeping 1.5°C within reach. Using the global integrated assessment model (GCAM), we assess whether alternate trajectories to solve the gas problem are fully supportive of an EU-wide or global 1.5°C pathway through 2030. Detailed methods, data, and assumptions are available in the Technical Appendix.

TRANSITION STRATEGIES AND PATHWAYS

Our analysis shows that by implementing a set of strategies to lower gas demand and increase imports from other regions, Germany can feasibly and safely transition away from Russian gas by 2025 (Figure 1, medium scenario). Specifically, total gas demand declines from 84 bcm in 2021 to 51 bcm in 2025, and the non-Russian gas supply increases from 29 bcm in 2021 to 53 bcm and meets demand in 2025. As demand continues to decline to 44 bcm by 2027, supply can also be reduced after 2025. Alternative demand and supply scenarios are explored in the sensitivity analysis. More ambitious actions in demand reductions can accelerate the transition before 2024 (see additional results of the low and high scenarios in the Technical Appendix).

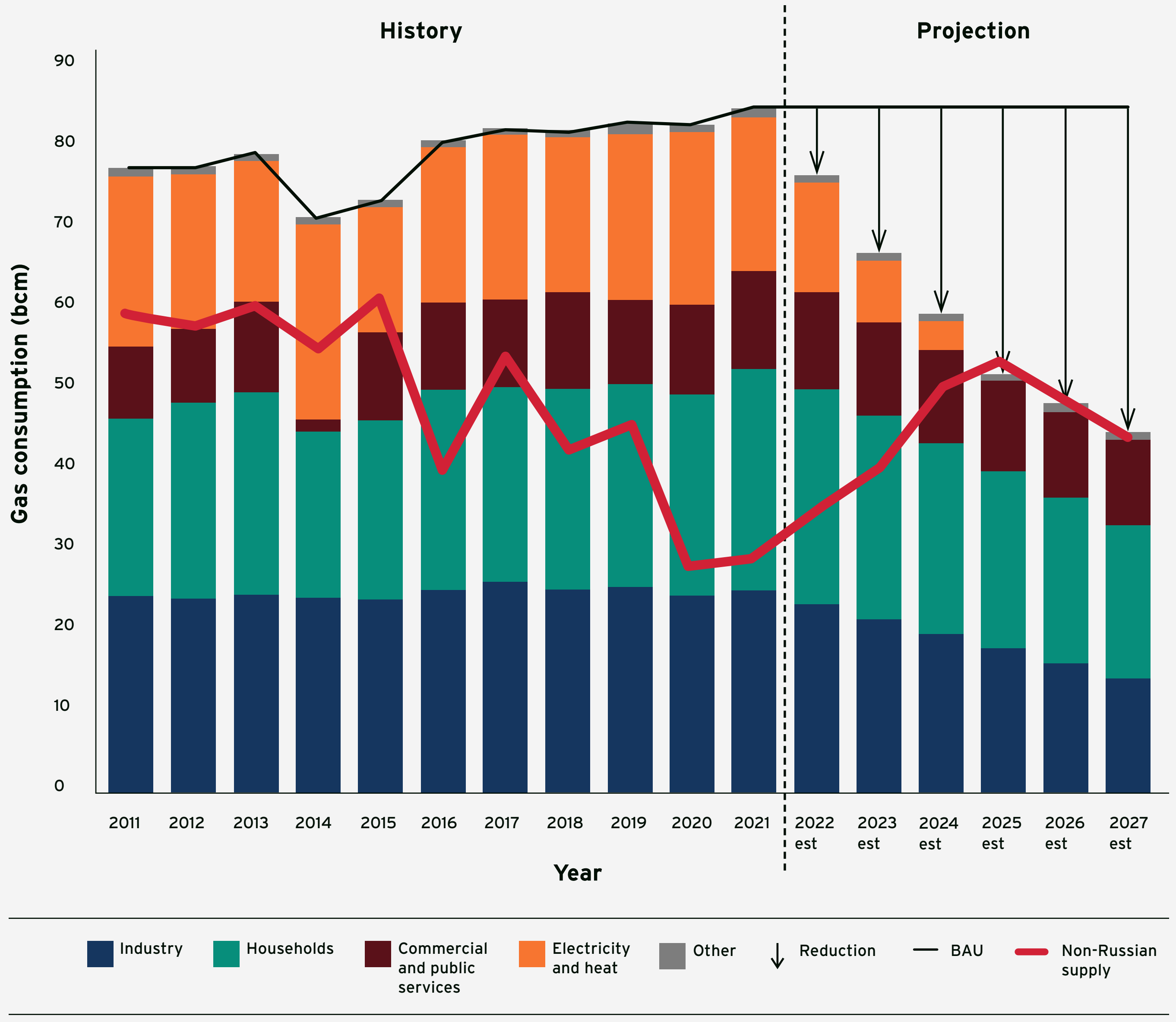
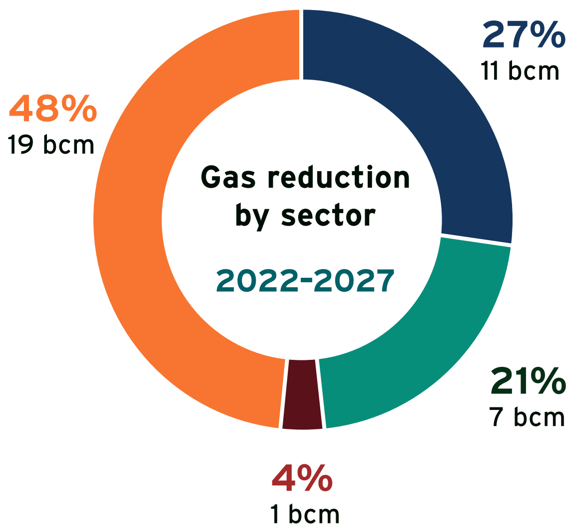


Figure 1. *Historical and projected gas consumption by sector (bars) and non-Russian gas supply (line). The figure shows historical data to 2021[1] and projections of the medium scenario from this analysis. The magenta line shows the level of non-Russian gas supply. Non-Russian gas supply meets demand in 2025 in our analysis.*

REDUCING DEMAND ACROSS SECTORS

Under the medium scenario, total gas demand in Germany can be reduced by 40 bcm over 5 years, or 47% from 2021 to 2027 (Figure 2). Gas consumption in electricity and heat production is completely phased out by 2025, contributing to approximately half of the total gas reduction through 2027. Gas consumption in industry decreases by 11 bcm from 2021 to 2027, contributing to 28% of overall reductions with different opportunities across sectors. Gas consumption in buildings decreases by 8 bcm from 2021 to 2027, contributing to 22% of overall reductions.

Key strategies to achieve these reductions include accelerating renewable development, solar and wind in particular, temporarily ramping up coal plants in power and heat generation, and electrifying activities and services in industry and buildings, while reducing the total energy demand through efficiency measures (Figure 2). Since demand changes in industry and buildings also affect electricity and heat supply, our analysis also takes into account the cross-sector interactions.



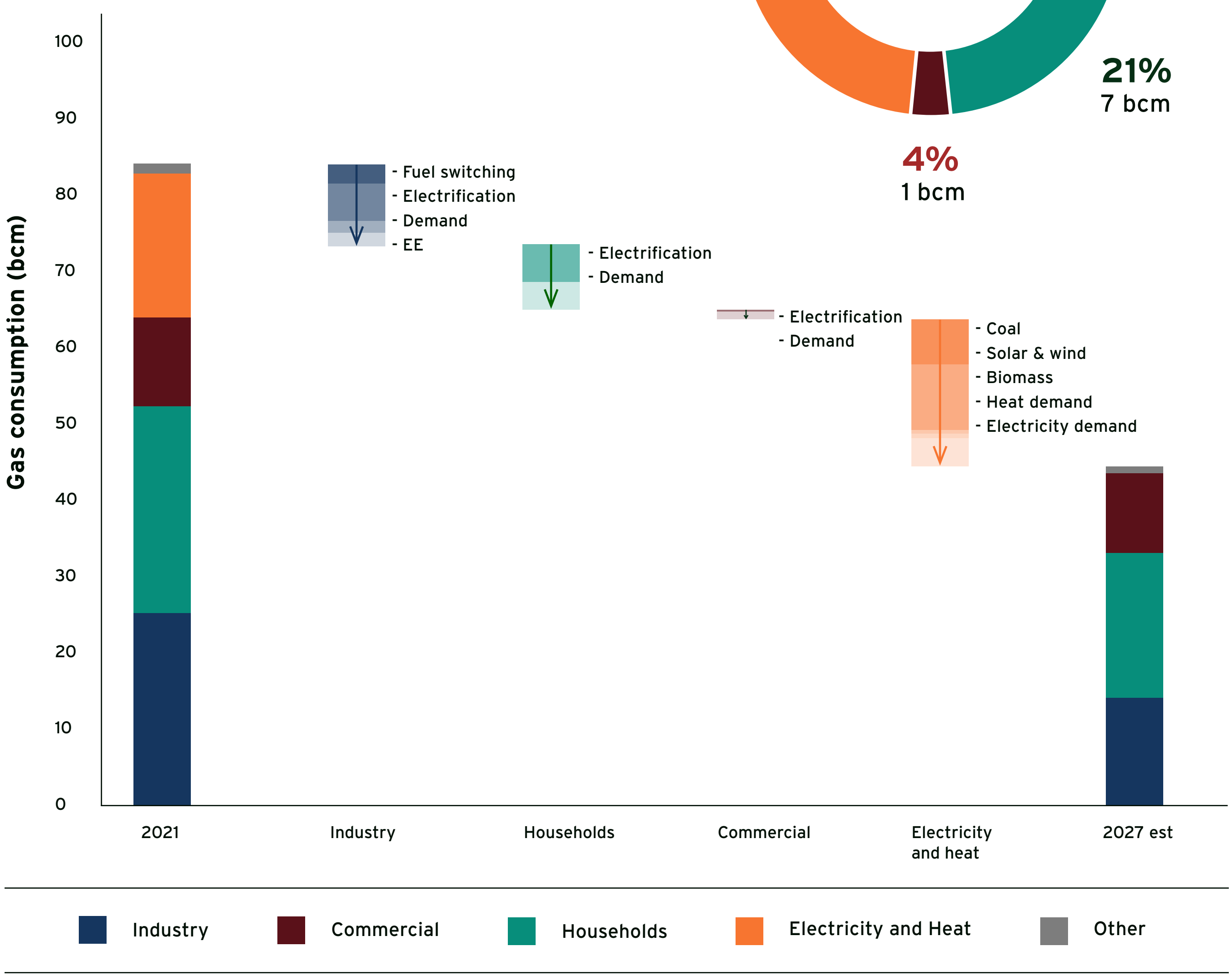


Figure 2. *Reduction in gas consumption from 2021 to 2027 by sector and strategies.*

INDUSTRY

In 2021, 25 bcm of natural gas, or 30% of the total, is consumed in the industrial sectors within Germany (Figure S1 in Technical Appendix). The main gas-consuming sectors are chemical, food & beverages, non-metallic minerals, iron & steel, paper & pulp, and machinery (Figure S2). Because each sector has different processes and technologies, sectoral-specific assumptions are made for the key strategies to reduce gas demand, based on one key determining factor, the heat temperature of the process (Table 1).

Four strategies are included in our analysis. Both energy efficiency measures and demand reductions through, for example, material efficiency can reduce gas consumption by lowering total energy demand. Electrification has large potential for low- and medium-temperature sectors, such as food and beverages, paper and pulp, etc., while processes of the high-temperature sectors, including chemicals, non-metallic minerals, and iron & steel, are very hard to electrify. For these high-temperature sectors, we assume moderate fuel switching to biomass (biomethane in particular) and hydrogen . Under our scenarios, the amount of biomethane to directly replace gas in industry does not exceed the estimated potential that can be sustainably sourced in Germany.[2] Detailed assumptions and data sources are provided in the Technical Appendix, including information on the low and high scenarios as well.

Sector	Heat temp	Energy efficiency (% of total energy)	Demand reduction (% of total energy)	Electrification (% of gas)	Fuel switching to biomass and hydrogen (% of gas)
Chemical and petrochemical	High	8.9%	3%	0% (limited potential by 2027)	20%
Food, beverages and tobacco	Low	8.9%	20%	50%	N/A
Non-metallic minerals	High	8.9%	3%	0% (limited potential by 2027)	20%
Iron and steel	High	8.9%	3.75%	10%	20%
Paper, pulp and printing	Low	8.9%	18.5%	50%	N/A
Machinery	Low	8.9%	3%	50%	N/A
Non-ferrous metals	Medium	8.9%	3%	50%	N/A
Transport equipment	Low	8.9%	7.5%	50%	N/A
Textile and leather	Low	8.9%	7.5%	50%	N/A

Table 1. *Assumptions for industrial strategies on energy efficiency improvements, demand reduction, electrification, and fuel switching in this analysis.*

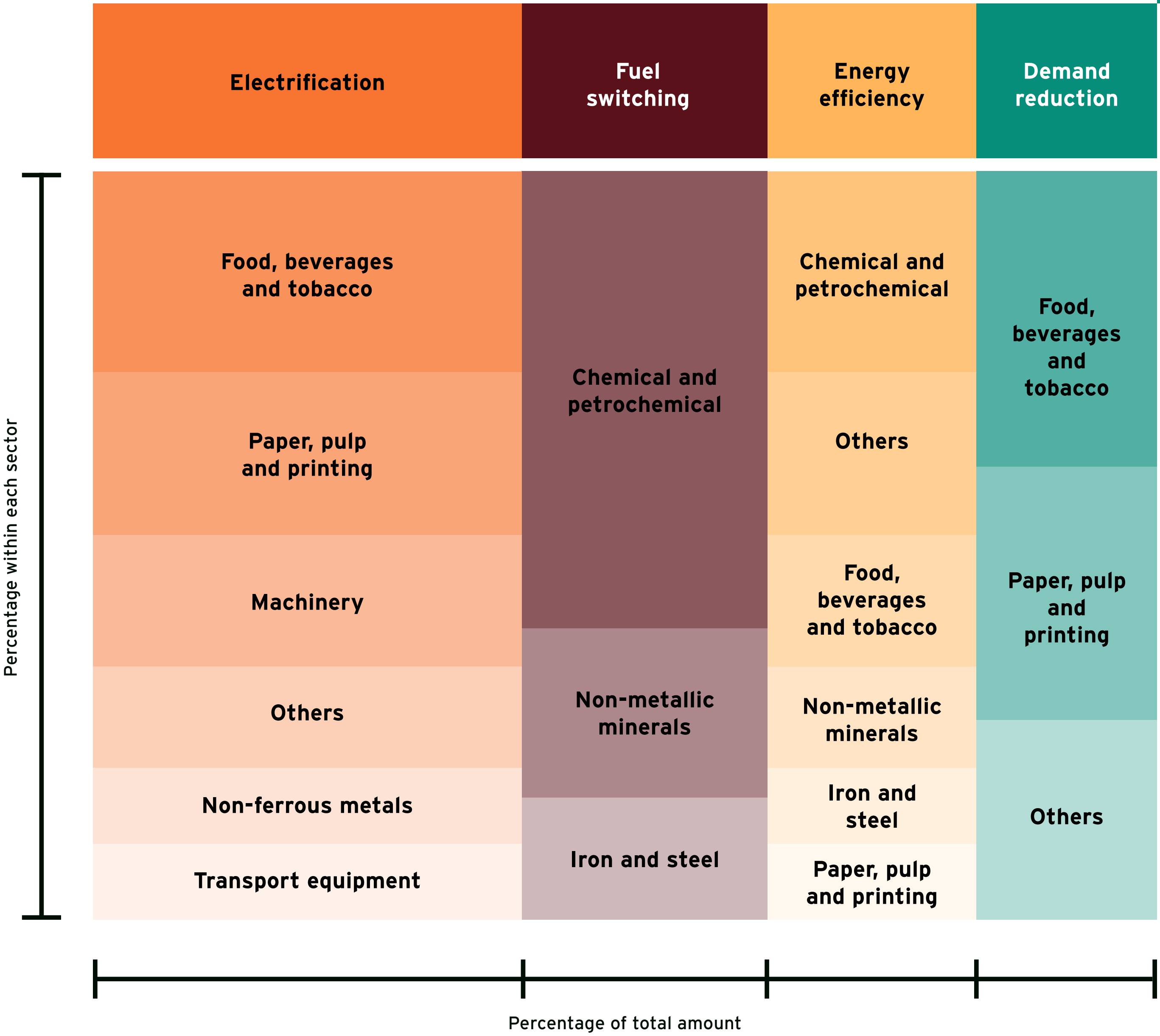


Figure 3. *Industrial gas consumption reductions by strategies and sectors from 2021 to 2027.*

As a result, total gas consumption in the industrial sectors decreases by 11 bcm under the medium scenario. Electrification in low-temperature heat sectors accounts for 47% of industry gas reductions, with the largest contributions from the food & beverages, paper & pulp, and machinery sectors (Figure 3). Switching gas to low-carbon fuels (biomass and hydrogen) in high-temperature heat sectors contributes to 21% of total reductions from chemicals, non-metallic minerals, iron & steel. Energy efficiency improvements and other energy demand reductions account for 18% and 14%, respectively.

While electrification increases electricity demand, efficiency and demand measures, on the other hand, lower electricity and heat demand. Combining all strategies leads to a 43% reduction in gas consumption, a 5% net reduction in electricity demand, and a 15% reduction in heat demand within the industrial sectors. Gas consumption in the industry declines by 80% and 21% under the high and low scenarios, respectively (Figure S6 in Technical Appendix).

BUILDINGS

The building sector within Germany consumed 39 bcm of natural gas in 2021, or 46% of the total (Figure S1). Gas is mainly consumed for space heating and water heating in both residential and commercial buildings (Figure S3 and S4). Key strategies to reduce gas demand in buildings include installation of smart meters, building retrofits, and demand reduction in hot water through behavior changes like changing boiler settings and reducing use, alongside accelerated deployment of heat pumps in space and water heating, all of which contribute to reducing total energy demand in buildings (Table 2). Detailed assumptions and data sources are provided in the Technical Appendix.

Strategy		Subsector	Residential	Commercial
Demand management	Smart meters	Space heating	15% energy savings, deployment of 10% of houses a year	15% energy savings, deployment of 7.5% of buildings a year
	Building retrofits	Space heating	5% retrofit rate, 24% energy savings for retrofitted buildings	5% retrofit rate, 31% energy savings for retrofitted buildings
	Demand reduction	Hot water	7.5% total, plus 75% of the population changes boiler settings	7.5% total, plus 75% of the population changes boiler settings
Electrification	Heat pump	Space heating	6,652 TJ increase annually (2 X baseline)	457 TJ increase annually (2 X baseline)
	Heat pump	Hot water	658 TJ increase annually (2 X baseline)	55 TJ increase annually (2 X baseline)

Table 2. *Assumptions for building strategies on demand management and electrification in this analysis.*

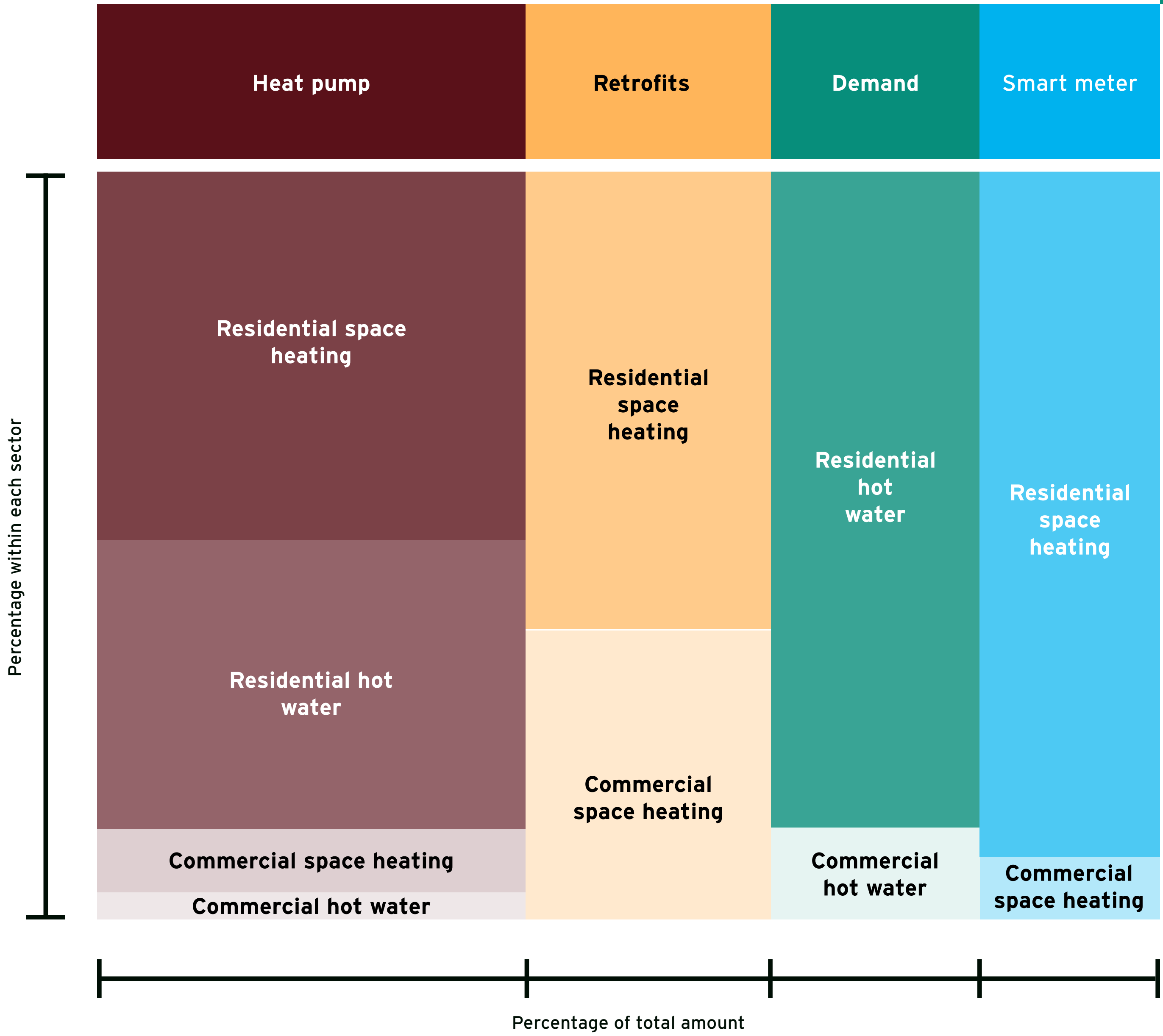


Figure 4. *Buildings gas consumption reductions by strategies and sectors from 2021 to 2027.*

Under the medium scenario, gas consumption in residential and commercial buildings declines by 8 bcm through 2025. The largest contributor is increased electrification through heat pump adoption, which allows for 53% of the gas reduction (Figure 4). Demand reduction through building retrofits and smart meters accounts for 39% of gas reduction in buildings and also helps lower electricity and heat demand.

As a result of implementing these strategies, it is estimated that there will be a 26% decrease in gas consumption within buildings, alongside the co-benefits of reducing electricity demand by 6.6% and heat demand by 13.6%. Gas consumption in buildings declines by 40% and 8% under the high and low scenarios, respectively (Figure S7 in Technical Appendix).

ELECTRICITY AND HEAT PRODUCTION

Electricity and heat production consumed 19 bcm of natural gas in 2021, or 23% of the total (Figure S1). The majority of gas-based electricity and district heating are produced by combined heat and power (CHP) plants in Germany, and therefore need to be assessed jointly. Four strategies are assessed in this analysis (Table 3). First, as discussed above, efficiency measures and electrification in end-use sectors affect overall electricity and heat demand. Second, accelerated deployment of solar and wind capacity can replace gas in electricity generation. Following the plan laid out in the "Easter Package" by the national government, Germany aims to achieve 80% carbon-free electricity generation by 2030 and 100% carbon-free by 2035, where the total installed capacity reaches 215 GW of solar, 115 GW of onshore wind, and 30 GW of offshore wind by 2030.[3] This requires adding 91 GW of new solar capacity and 46 GW of new wind capacity by 2027. Third, building biomass CHP plants contributes to both electricity and heat generation. District heating has fewer alternative options available in Germany, mainly including coal, non-renewable wastes, and biomass, where biomass is the only low-carbon option. Under our scenarios, up to 9.8 TWh of biomass-based electricity and heat generation is added between 2022 and 2027, about a 13% increase from 2020. It is important that the needed biomass for the CHP plants are obtained from sustainable feedstocks.[4] And lastly, the remaining gap to electricity and heat demand is filled by temporarily increasing the utilization of existing coal plants, which can be lowered in later years as more renewables come online and electricity demand declines with efficiency improvements. Detailed assumptions and data sources are provided in the Technical Appendix.

Sector	Demand change	Solar & wind deployment	Biomass CHP deployment	Change in existing coal plants utilization
Electricity	Net demand reduction from industry and building analysis Demand increase from transport EV deployment	Follow the plan in the "Easter Package" for renewable deployment: - Adding 91 GW solar 2022-27 - Adding 46 GW onshore wind 2022-27	2022: accelerate projects under development 2023-27: double the deployment capacity	Increase coal plants CF to fill the electricity gap Retire coal plants w/ increasing RE and declining demand after all gas are replaced
District heat	Demand reduction from industry and building analysis	N/A		Increase coal plants CF to fill the heat gap Lower utilization w/ increasing biomass and declining demand after all gas are replaced

Table 3. *Assumptions for power and heat generation strategies on demand changes, solar and wind development, biomass CHP deployment, and change in coal plants utilization.*

Natural gas contributed to 16% of total electricity generation in 2021. Under the medium scenario, gas electricity generation declines by 26% in 2022, by 60% in 2023, and is completely phased out by 2025 (Figure 5). While continuing to add renewable capacity, the near-term gap can be filled by temporarily increasing coal power generation. Specifically, addressing the gap implies an 8-15% increase in coal electricity from 2022 to 2024, through a combination of delaying the planned retirement of 3.2 GW of hard coal plants in this period to 2025 (Table S9 and S10 in Technical Appendix) and increasing hard coal plants' utilization from about 1900 hours in 2021 to 4260-5860 hours between 2022 and 2024 (Table 4).

These changes only affect a portion of the operating coal plants. It does not require restarting the 6.2 GW of coal plants standby or deactivated in 2022; it does not delay the scheduled retirement for lignite plants; it does not require increasing the utilization of lignite plants; and it does not delay the retirement schedule after 2025. In fact, as Germany's ambitious solar and wind deployment plan takes place, coal power generation declines after 2025, and coal plants can retire even more rapidly compared to the existing plan (Table S9 and S10 in Technical Appendix). By 2027, coal electricity generation decreases by 60% (Figure 5), and all of the 20 GW of existing hard coal plants (16 GW operational + 4 GW standby/deactivated) and 4.6 GW of lignite plants (2.3 GW operational + 2.3 GW standby/deactivated) can be retired (Table 4). This is potentially on track to deliver the 2030 coal phaseout target with continued retirement of the 15 GW lignite plants in 2028-2030.

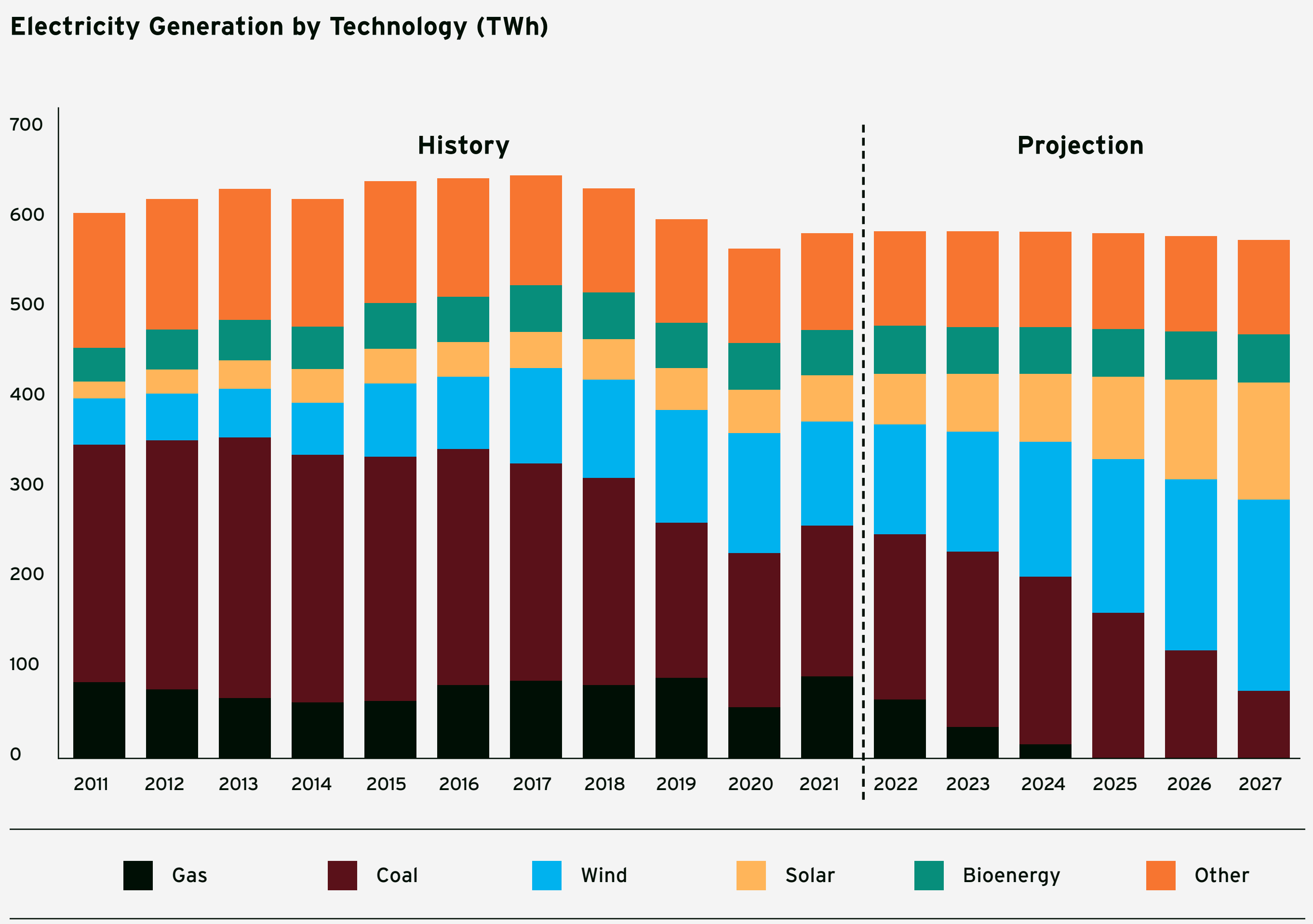


Figure 5. *Electricity generation by technology in Germany 2011-2027. The figure shows historical data to 2021*[5] *and projections of the medium scenario from this analysis.*

In terms of district heating, natural gas contributed to 49% of the total generation in 2021, and the remaining half was delivered primarily by coal, biomass, and non-renewable wastes (Figure 6). Under the medium scenario, heat production from gas CHP plants declines by 51% in 2022 and is completely phased out by 2023. Due to limited alternative options in Germany's district heating system, heat production by gas is mainly replaced with increased generation from coal CHP plants, which doubles in 2022 and triples in 2023. Since coal CHP plants can produce more heat than electricity, the needed amount can be well covered from the increased utilization of hard coal CHP plants for electricity. As heat demand decreases with the implementation of efficiency and demand management measures in buildings and industry, and the accelerated deployment of biomass CHP plants, heat production from coal gradually declines, but still increases from 23 to 32 TWh (or 39%) by 2027 (Table 4). While coal-based heat production is at a much lower level compared to coal electricity, it presents challenges for delivering the 2030 coal phaseout in Germany. Additional strategies and policies need to be developed, for example, excess and waste heat from industrial processes or CHP plants can be recovered and recycled into the district heating system.[6]

Yr	Total from this analysis		Hard coal			Lignite		
	Coal electricity generation (TWh)	Coal heat generation (TWh)	Capacity (MW)	CF (hours)	Electricity generation (TWh)	Capacity (MW)	CF (hours)	Electricity generation (TWh)
21'	169	23	19,339	1,900	37	19,417	6,800	132
22'	182	47	15,463	4,261	66	17,088	6,800	116
23'	195	70	15,083	5,862	88	15,669	6,800	107
24'	185	63	15,083	5,295	80	15,502	6,800	105
25'	163	55	13,751	4,378	60	15,162	6,800	103
26'	120	45	3,743	4,611	17	15,124	6,800	103
27'	76	32	0	0	0	15,124	5,018	76

Table 4. *Resulted coal retirement and utilization from this analysis.*

Heat Generation by Technology (TWh)

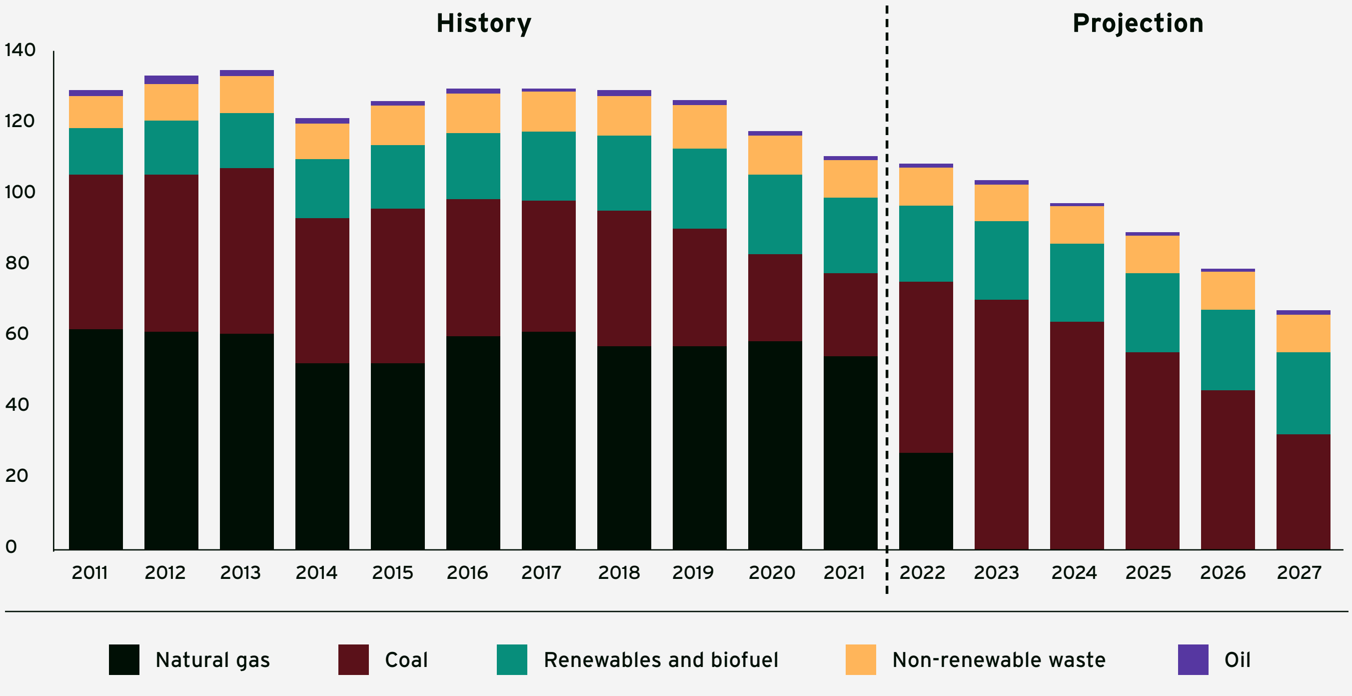


Figure 6. *Heat generation by technology in Germany, 2011-2027. The figure shows historical data to 2021*[7] *and projections of the medium scenario from this analysis.*

ENERGY COST SAVINGS FROM REDUCED GAS CONSUMPTION

Gas prices have been rising rapidly in the last year, in particular, by 105% for households from April 2021 to April 2022, and by 150% for industry over the same period.[8] By reducing gas demand through the diverse set of strategies laid out here, Germany can potentially save energy costs by 30 billion Euros through 2027 (up to 42.6 billion Euro under the high scenario), if gas price stays at the current high level.

INCREASING SUPPLY THROUGH AVAILABLE INFRASTRUCTURE

Germany is one of the world's largest natural gas importers. In 2020, about 95% of Germany's total gas consumption was imported, where nearly two-thirds came from Russia (Figure 7). The remaining imports are primarily from Norway and Netherland, accounting for 21% and 12% in 2020, respectively.

To increase supply from other regions, pipeline natural gas (PNG) is constrained by infrastructure availability from the potential exporting countries, such as Nigeria, Algeria, Qatar, while existing partners with pipelines connected to Germany have limited potential for additional exports. A 6% increase is assumed for Norway based on recent plans to open new gas fields (see Technical Appendix for more details).

Liquefied natural gas (LNG) is another option to import gas from other countries. Without existing LNG terminals, Germany can rent floating LNG hubs–assuming a short-term contract is possible–while completing the construction of two of its own LNG terminals. Between 2022 and 2024, four floating terminals, based on a signed contract, can provide 20 bcm capacity to import LNG from the United States and other countries, such as Qatar, Nigeria, Algeria, and Egypt (Figure 7 and see Technical Appendix for more details). In 2025 and 2026, two LNG terminals currently under construction are expected to start operating and replace the floating LNG terminals (Table 4). Considering the risk of locking into long-term contracts, an alternative low import scenario is explored, where short-term rental floating LNG hubs are not available, and the phaseout of Russian gas is delayed to 2027 under the medium demand reduction scenario (Figure S9 in Technical Appendix).

Year	Non-Russian supply needed (bcm)	New capacity (bcm)	Total additional capacity (bcm)	Import gap (bcm)	Infrastructure	Supply
2022	76	+1+5	29+6=35	41	Existing pipeline	Norway (1) US (5)
2023	66	+5	40	26	Rented float ships	US (11)
2024	59	+5+5	50	7	Rented float ships	US (14.3) + others (13.8)
2025	51	+8 -5	53	-2	Brunsbüttel LNG Terminal	US (14.3) + others (18.2)
2026	48	+6 -5-5	49	-1	Stade LNG Terminal	US (14.3) + others
2027	44	-5	44	0	Stade LNG Terminal	US (14.3) + others

Table 5. *Gas supply with new LNG capacity and from non-Russian regions.*

While increasing LNG imports can help fill the near-term gaps, it is not a long-term solution to keep Germany on track for meeting the climate targets. Moreover, methane leakage tends to be at higher rates from both LNG production[9] and transport–ships that are powered by LNG, leaking significantly more methane to the ocean compared to other conventional fossil fuels.[10] On the other hand, capturing gas leakage and using it on site can not only reduce methane emissions but also increase gas availability. More analysis is needed to understand the magnitude of the potential. The increased demand of LNG in Europe may impact other countries that also import LNG, such as India, Pakistan, and Bangladesh, due to potential cost increases.[11]

Gas Import by Region (bcm)

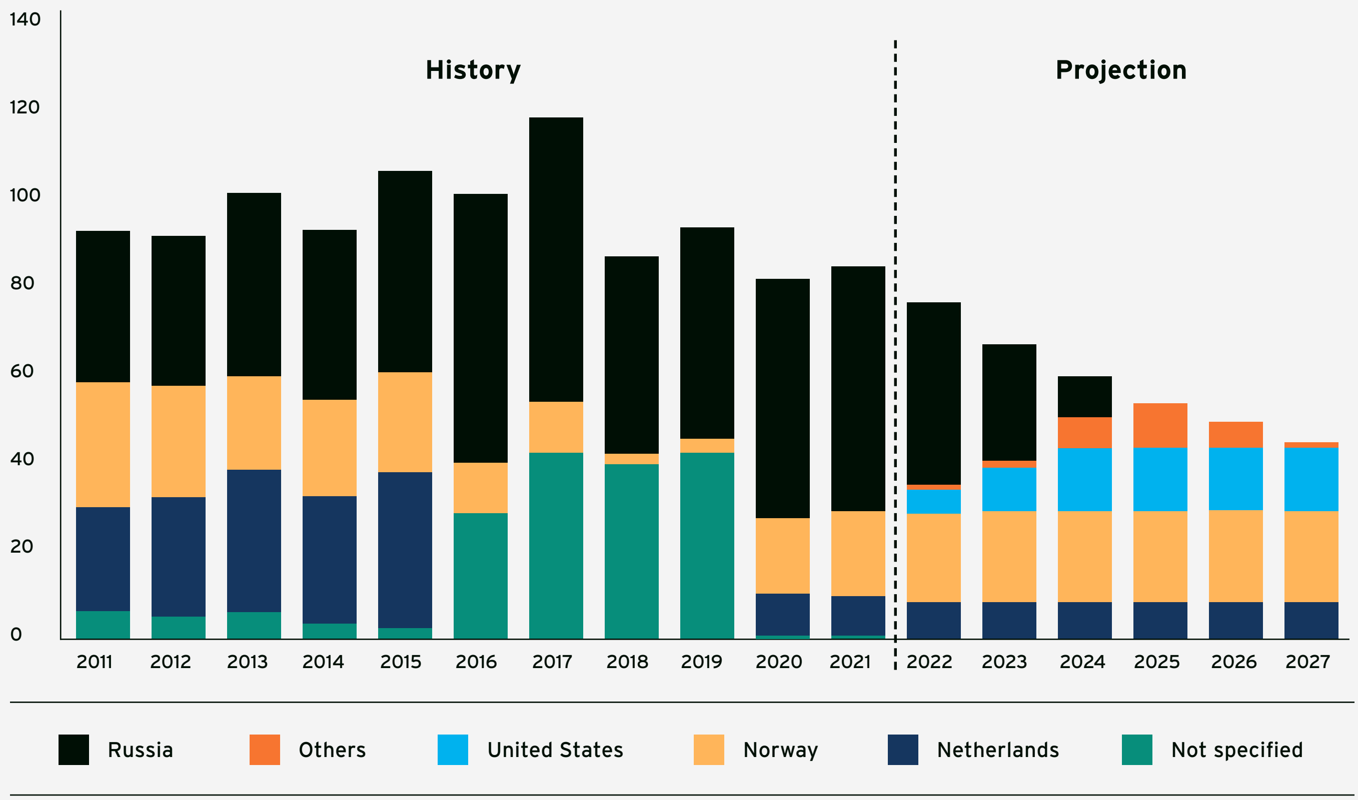


Figure 7. *Gas imports by region, 2011-2027. The figure shows historical data to 2021[12] and projections from this analysis.*

EMISSION IMPACTS

To assess the implication to Germany's and global climate goals, we estimate the emissions impacts of individual strategies laid out here, based on the resulted changes in different fuel consumption and emission coefficients.[13] Overall, energy CO_2 emissions from electricity and heat generation, industry, and buildings[14] decline by 177 $MtCO_2$ from 2021 to 2027. It represents a total of 43% reduction in the three sectors (Figure 7A).

While emissions increase from the ramp up of coal power and heat generation, it is offset by larger reductions from reduced gas and total energy consumption across sectors, even in 2022 (Figure 7B). As a result, net emissions change is always negative through 2027. Emissions increase from coal heat production through 2027, which leads to a cumulative increase of 62 $MtCO_2$ from 2021 (Figure 7C). Emissions increase from coal electricity in 2022-24 but rapidly decline afterward due to accelerated coal phaseout, resulting in a cumulative reduction of 75 $MtCO_2$ from 2021. Replacing gas in electricity and heat generation contributes to a total of 265 $MtCO_2$ reductions between 2022 and 2027, and strategies in the industry and building sectors contribute to 91 $MtCO_2$ and 75 $MtCO_2$ cumulative emissions reductions, respectively.

Using a global integrated assessment model (GCAM, see Technical Appendix for more details), we show that under the 1.5°C-compatible pathway, EU-wide energy CO_2 emissions decline by 12% in 2025 and by 30% in 2030 (Figure S13 in Technical Appendix). In comparison, our analysis shows a roughly 28% reduction in energy CO_2 emissions between 2021 to 2027 in Germany, generally on track with the 1.5°C trajectories.

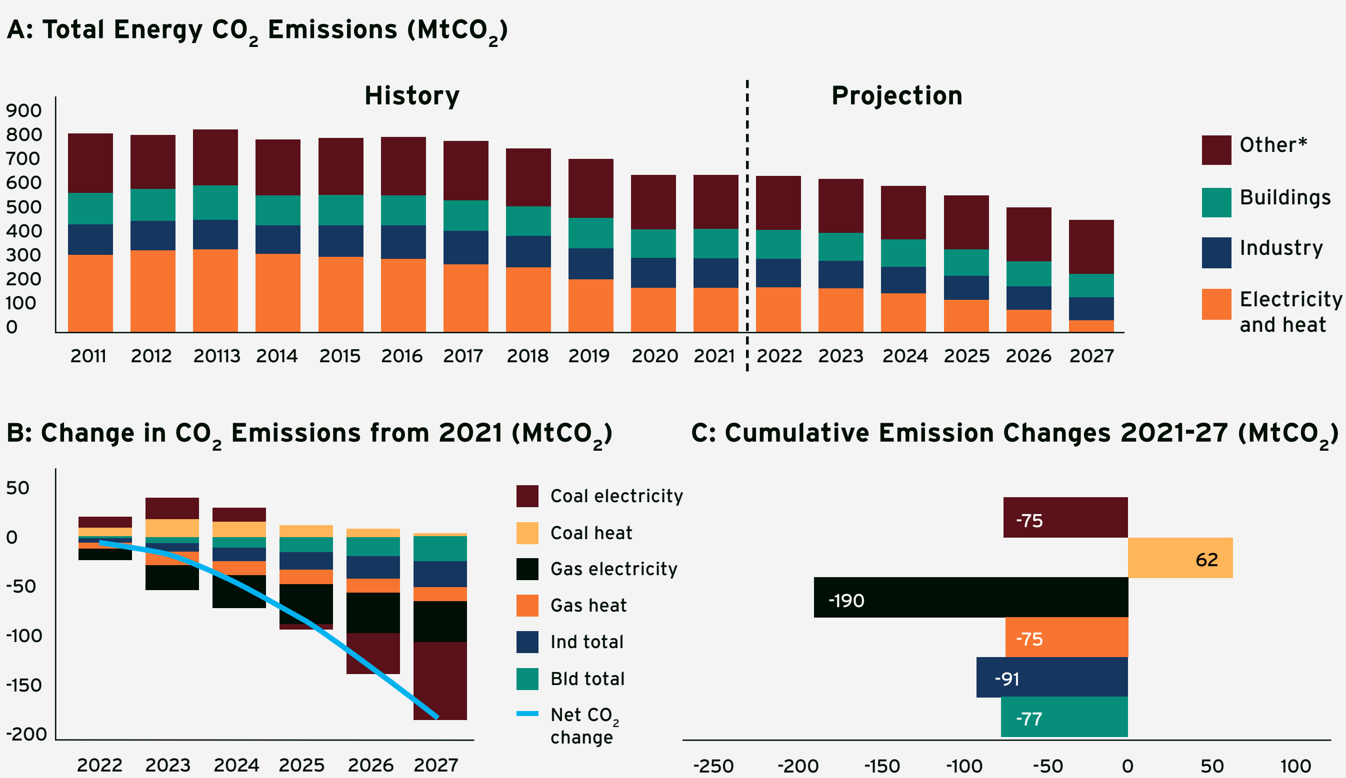


Figure 8. *Emission impacts from the different strategies to transition away from Russian gas in Germany. (A) Total energy CO_2 emissions by sector, historical data to 2021[15] and projections of the medium scenario from this analysis; annual (B) and cumulative (C) changes in CO_2 emissions from 2021 to 2027.*

DISCUSSION AND CONCLUSION

Germany and Europe more broadly are being forced to confront two critical challenges of energy security and climate policy in parallel. Our assessment shows that successful pathways to address both challenges effectively do exist—and, moreover, can be mutually reinforcing. **Through a set of sector-specific strategies to reduce gas demand and parallel strategies to increase gas supply from other regions, Germany can safely move away from Russian gas before 2025, continue to reduce gas consumption thereafter, stay on track to deliver a 2030 coal phaseout, and secure the emissions reductions needed to be on track towards net-zero.**

The key to success requires **immediate actions and investments** in a diverse set of feasible technologies and policy approaches that must be pursued quickly and simultaneously. The ten strategies for sustainable gas reductions, from largest to smallest reductions, include:

1. Invest heavily in renewable electricity generation, adding 97 GW of solar and 46 GW of onshore wind through 2027, following the plan announced in the Easter Package by the German government;
2. Electrify 50% of the gas-based low-temperature heat industrial processes by 2027, including food and beverages, paper and pulp, machinery, and other sectors;
3. Double the deployment of heat pumps in residential and commercial buildings for space heating and hot water;
4. Retrofit 5% of existing building stock every year to achieve an average of 30% reduction in total energy consumption for the retrofitted buildings;
5. Switch 20% of gas consumption in high-temperature heat industrial processes to low-carbon fuels (biomass and hydrogen) by 2027, including chemical and petrochemical, non-metallic minerals, and iron and steel sectors;
6. Improve energy efficiency in industrial processes to lower total energy demand by 9% through 2027;
7. Improve material efficiency through the economy to reduce food waste, demand for paper and pulp products, and transport equipment;
8. Install smart meters for 10% of households and 7.5% of commercial buildings every year to lower total energy demand in space heating; combined with building retrofits (strategy 4), space heating demand decrease by about 14% from 2015 to 2027, in line with the 18% EU-wide reduction target by 2030;
9. Change the boiler settings in residential and commercial hot water for three-quarters of the total population by 2027;
10. Double the existing biomass combined heat and power (CHP) deployment to replace gas in electricity and heat generation.

All these actions can sustainably reduce gas demand, lower emissions, and save energy costs. While some of them require time to implement, temporarily ramping up the operation of existing coal plants and increasing gas supply from other regions could help fill the near-term gap. Specifically, addressing this gap implies an 8-15% increase in coal electricity generation from 2022 to 2024, a two-year delay in the planned retirement of 3.2 GW of coal plants during the same period, and up to 22 bcm of new gas supply through available infrastructure by 2025.

When combined with the ten strategies listed above, **emission impacts from these short-term coal increases can be offset by a larger reduction in overall energy demand with efficiency improvement and demand management efforts** outlined here, even in 2022. Moreover, overall emissions continue to decline with these efforts in combination with rapid renewable deployment and are potentially accelerated in the medium and long term in line with 1.5°C trajectories. As a result, energy CO_2 emissions from electricity and heat generation, industry, and buildings decrease by 177 $MtCO_2$ or 43% from 2021 to 2027. Last but not least, the reductions in gas consumption through 2027 can save nearly 30 billion Euros if gas prices stay at the recent high level.

These results show the potential major benefits of a concerted and well-coordinated strategy for implementing emergency energy security actions in a way that also prioritizes climate outcomes. Seizing this opportunity will require significant near-term investments in infrastructure that may not see all benefits realized today. Joint work across the EU will be needed to ensure that enhanced investments for climate-friendly strategies are not offset by support for long-term fossil-intensive infrastructure in other areas.

Our analysis also points the way toward the possibility of driving down global costs for critical efficiency technologies that will also be important in many other regional contexts. Future analysis should investigate additional potential opportunities for expanding the set of renewable supply options beyond the EU's borders—for example, through expanded renewable deployment in the Middle East and North Africa. Supply chain bottlenecks in technology manufacturing, shipping, and deployment (construction) also present a major challenge to the rapid scale-up needed, and an analysis of the potential impacts and solutions to such disruptions would be valuable. Finally, an assessment of the cascading, beneficial impacts of regionally specific technology investment strategies would be helpful for understanding how a concerted European drive on installing efficient technologies might improve methods and costs of deploying those technologies in other locations.

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[14] Other sectors have additional emissions reduction potentials but are not included in the analysis

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