G7 Gas Reduction Plan

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Introduction

Dear readers,

Since the start of Russia‘s war of aggression against Ukraine, global fossil gas production is about to experience a new boom. While concerns about a potential disruption of gas supplies from Russia have caused prices to skyrocket, Europe and the G7 have been striving to strengthen their energy independence from Russia. For good reason, as they do not wish to continue filling the Putin government‘s war chest with billions. Yet so far, Europe’s strategy relies primarily on increasing imports of liquefied natural gas (LNG) and replacing Russian gas with fossil gas from other sources. As a result, the development of new gas fields is becoming lucrative, be it in the United States, the Middle East, Australia, or anywhere else. All the while, the focus shifts away from the urgently needed reduction of gas and other fossil fuels.

The G7 must cut down on fossil gas, not scale up!
Expanding the production of fossil gas would deal our climate protection efforts a fatal blow. Compliance with the 1.5-degree limit would require an immediate stop to the development of new oil and gas fields worldwide. More than that, the G7 countries must completely abandon fossil gas, at least in energy generation, by 2035 in order to preserve our chance of stopping global warming at 1.5 degrees Celsius. This means that we must cut back on gas, and quickly.

In view of this year’s G7 Summit under German Presidency, Greenpeace commissioned DIW Econ to calculate the gas consumption reduction potentials for Germany, France, Great Britain, Italy, Japan, Canada, and the USA, respectively. **The study shows that by 2025, the G7 could reduce their annual gas consumption by 264 billion cubic meters – only through conservation measures and by using renewables, without switching to coal, nuclear or biomass, and without declines in industrial production. These cutbacks equal 18 percent of the G7’s current consumption, and outstrip the total amount of Russia’s annual gas exports.**

The largest gas reduction potential would be achieved by an installation initiative for heat pumps and building restoration, accelerated expansion of wind and solar energy, improved energy efficiency, and the switch from industrial process heat to large heat pumps and solar thermal. **The G7 countries must seize these opportunities now to reduce gas consumption rapidly with a coordinated, joint gas reduction plan.**

Otherwise, the diversification away from Russian gas will inevitably lead to an expansion of gas production elsewhere in the world and thus, to a lock-in effect, i.e., a renewed commitment to fossil gas for several decades. This would have a dramatic impact on the climate.

What the new study does not examine are measures to cope with an EU gas embargo or a Russian gas freeze. In both scenarios it would be necessary, and also possible, to save even more energy and replace gas in the very short term – if necessary, temporarily with other fossil sources. Even then, however, it is essential that we avoid the development of additional gas reserves at all costs as we must not extend the lifespan of fossil fuels artificially by setting up new infrastructure that has no future.

Gerald Neubauer

Energy expert Greenpeace

Hamburg, May 2022

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%	percent
°C	degrees Celsius
bcm	billion cubic meter of fossil gas
CHP	combined heat and power
EED	Energy Efficiency Directive
GHG	greenhouse gas
GW	gigawatt
HVC	high value chemicals
LNG	liquified natural gas
MMBTu	million British Thermal Unit
Mt	mega tone
MWh	megawatt-hour
TWh	terawatt-hour
USD	US-Dollar

1. Introduction

1.1 Background

Since 2021, international energy markets have experienced a price increase only comparable with that of the 1970s oil crisis and the global financial crisis of 2008. Induced by an incipient economic recovery from the COVID-19 pandemic and accelerated by the war in Ukraine, prices for fossil gas increased in Europe and Asia up to tenfold within a year (Statista, 2022). Only Canada and the United States have remained the least affected among the G7 countries (EIA, 2022; Government of Alberta, 2022). As an effect of increasing fossil gas prices in 2022, EU consumption has already declined by about 7 % in the first quarter of this year and even by 20 % in April 2022 compared to the previous year (Bruegel, 2022)[1,2]. The impacts are exacerbated by the unprecedented political and economic sanctions imposed on Russia as a result of its invasion in Ukraine and the consequently mounting uncertainties about global energy supplies. Despite initial restraints, bans on coal, oil and gas imports from Russia are being included gradually into the sanction lists. The USA and Canada have already banned energy imports from Russia (The White House, 2022; Government of Canada, 2022), the UK is planning to phase out oil imports from Russia by the end of 2022 (Government of the UK, 2022) and the EU has banned coal imports from Russia, currently exploring plans to put an embargo on all energy imports (European Commission, 2022; European Parliament, 2022). Japan will impose a ban on coal imports from Russia as well (S&P Global, 2022). Hence, all G7 states are forced to restructure production and international supply chains of fossil fuels to a certain extent.

Among the G7 countries, the European states are the most dependent on fossil gas supplies from Russia. The share of Russian fossil gas in the EU gross gas consumption accounted for 32 % in 2021 (IEA, Gas Market and Russian Supply, n.d.), of which Germany (49 %) and Italy (46 %) relied the heaviest on Russian gas imports (Capital Markets Strategy, n.d.). At the same time, Russia's global exports constituted 210 bcm via pipeline and further 40 bcm as LNG in 2021, of which the EU countries made up 155 bcm, or three quarters of pipeline exports (IEA, 2022; IEA, 2022). With its REPowerEU plan from March 8, 2022 (European Commission, 2022), the EU forces the independence from Russian energy imports. According to the plan, the EU aims to drastically reduce Russian gas imports before the end

[1] Not temperature adjusted.

[2] This demand reduction is associated with an increase in the use of other fossil energy sources and partially with production declines.

of 2022 and to reach complete independence from Russian fuel imports before the end of the decade. A drastic reduction of gas imports from Russia, or even an embargo, as demanded by numerous voices (Bruegel, 2022), will affect the availability of fossil gas for the EU as a whole. Moreover, it will have considerable effects on the supply side of the global fossil gas market.

Currently, supply-side adjustment dominates the debate: an increase of fossil gas production, the redirection of LNG imports to Western Europe, the installation of LNG terminals and substitution of fossil gas by other fossil fuels. The appeal of governmental supply-side adjustments is fuelled by the massive increase in profitability of gas production for corporations. With increasing market prices for fossil gas, investing in the exploration of new gas deposits and the expansion of shale gas production becomes economically efficient for deposits that were not profitable in the past[3].

From the environmental point of view, however, there is a danger that new gas deposits will be explored to a larger extent or other fossil fuels will be used to substitute fossil gas. Both options will result in significant fossil investments and a lock-in effect with negative impacts on the remaining global carbon budget. Thus, both the attainability of sectoral decarbonatization targets and the overall 1.5 °C climate target are at risk.

The prevention of such a market response – the expansion of fossil gas supplies – requires a convincing long-term reduction in fossil gas demand that is not driven by short-term responses to rising prices but induced by a technologically determined contraction of gas consumption in all economic sectors. Such technologically determined reductions require time and investments and are limited in the short-term. However, they create the market signal needed for preventing new lock-in effects in the use of fossil energy sources.

1.2 Scope

The following study presents potential climate-neutral technology options implemented by coordinated multilateral action of the G7 states in the short term to support a reduction of fossil gas demand in the G7 states. The focus of the study is on effects of investments made between 2022 and early 2025 on the reduction of gas consumption by the end of 2025.

[3] Analyses for gas production in the USA indicate a wide range of breakeven gas prices, i.e., market prices that allow for economically viable production. This range is between -3.3 USD / MMBTU (about - 10 EUR / MWh) and 3 USD / MMBTU (about 10 EUR / MWh) and depends on whether oil and gas production run as co-processes (Energy Dynamics, 2019).

Three key elements set an adequate scope of the following analysis. Firstly, despite behavioural changes in heating of residential and non-residential buildings, no short-term demand effects induced by the current price increase are quantified. This is both due to several methodological issues related to such quantification and due to these effects being mostly reversed when gas prices fall, unlike reductions backed by technological changes in energy consumption. However, the G7 states can use the momentum created by the high prices and stimulate switching to sustainable energy solutions, which have now become more lucrative than they would have been at previous price levels. Secondly, and related to the first key element, reductions in fossil gas consumption induced by a gas price-driven decline in industrial production or sectoral production shifts are excluded from the analysis. Thirdly, only such technological measures were considered that do not substitute fossil gas by other fossil energy sources or biofuels.

The rest of the report is structured as follows: Section 2 provides a brief introduction in the current state of gas production and consumption in the G7 countries. Section 3 highlights the existing plans and policies of the G7 countries with regard to climate protection, deployment of renewable energy sources and gas use which are later discussed referencing calculated potentials for the reduction of gas consumption. Section 4 describes in detail the considered measures to reduce fossil gas demand, while Section 5 discusses the effects of these measures. Section 6 concludes.

2. Status quo of fossil gas consumption in the G7 states

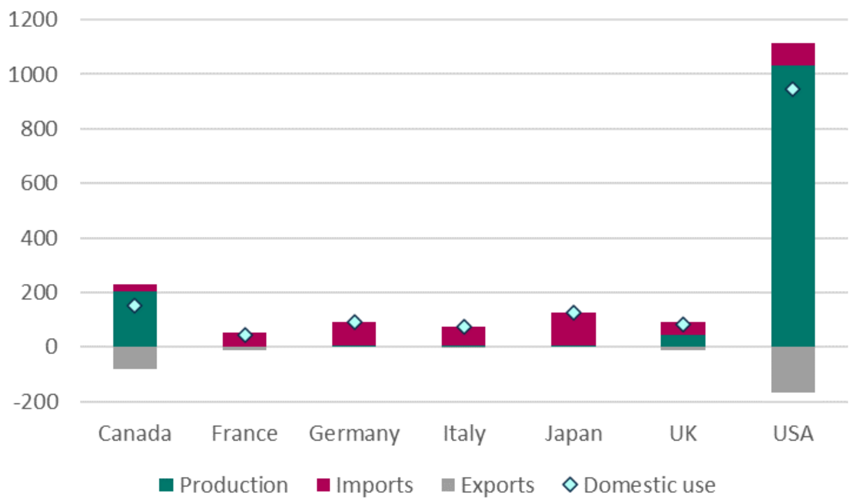
Fossil gas is used as a source for **energy** and **non-energy** applications. In 2020, fossil gas contributed about 22 % to the global primary energy supply (Halkos & Gkampoura, 2020) and is mainly used for electricity generation and heating purposes in buildings and industrial processes. In the G7 economies, the dependency on fossil gas and its imports varies significantly. Of the seven countries, only the USA and Canada are self-sufficient in their fossil gas supply and are net exporters of gas (Table 2-1, Figure 2-1). The other G7 countries are net importers and, taking into account their geographic location, there is relatively little intra-G7 trade. Japan, for example, imports most of its gas from Australia, though around 16 % of imports come from the USA (Observatory of Economic Complexity, n.d.). The EU countries mostly rely on European and North African exporting countries for their gas imports. Especially Germany and Italy respectively cover 66 % and 43 % of their imports from Russia, the second largest country of origin being Norway for Germany and Algeria for Italy (Eurostat, n.d.). Norway is also the largest source of gas for France, making up 36 % of France's imports (Eurostat, n.d.) and even 55 % of the UK's (Office of National Statistics, 2022).

Table 2-1: Production and trade balance for fossil gas in the G7 countries in 2020, bcm

	Canada	France	Germany	Italy	Japan	UK	USA
Production	205	0	5	5	3	45	1,032
Imports	26	55	88	72	125	49	81
Exports	-79	-11	0	0	0	-11	-167
Domestic use	152	44	93	76	128	83	946

Data source: (IEA, n.d.)

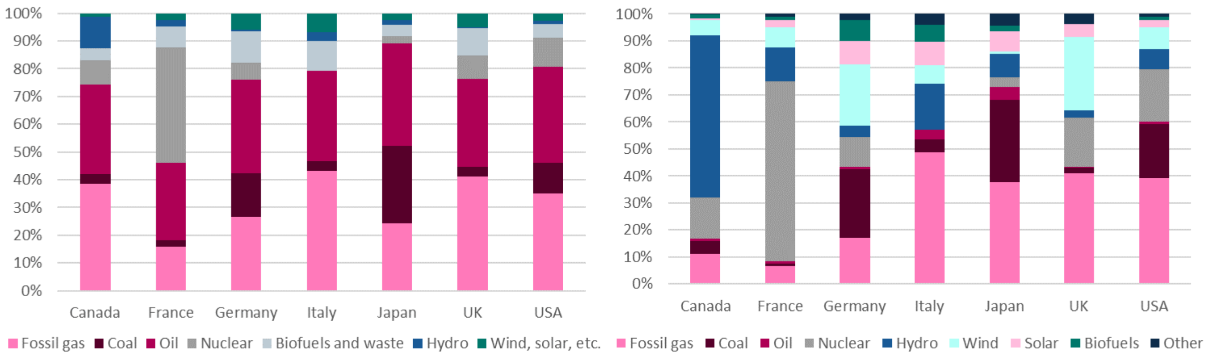
Figure 2-1: Production and trade balance for fossil gas in the G7 countries in 2020, bcm



Data source: (IEA, n.d.)

The role of fossil gas in domestic energy supply also varies. While in France only 16 % of energy supply is covered by the fossil gas, in Italy and the UK its share exceeds 40 % (Figure 2-2, left panel). This difference results to a large extent from the use of fossil gas for electricity generation. In Canada, France and Germany, the share of gas in power generation is relatively small, while in Italy almost half of electricity is produced in gas-fired power plants (Figure 2-2, right panel). In contrast, the direct use of fossil gas as a fuel in buildings and the industry and as feedstock primarily in the chemical industry makes up a relatively similar share in final energy consumption across the G7 countries, ranging between 20 % and 30 %. The only exception is Japan, where a high level of heating electrification leads to a low gas share of 10 % in final energy consumption.

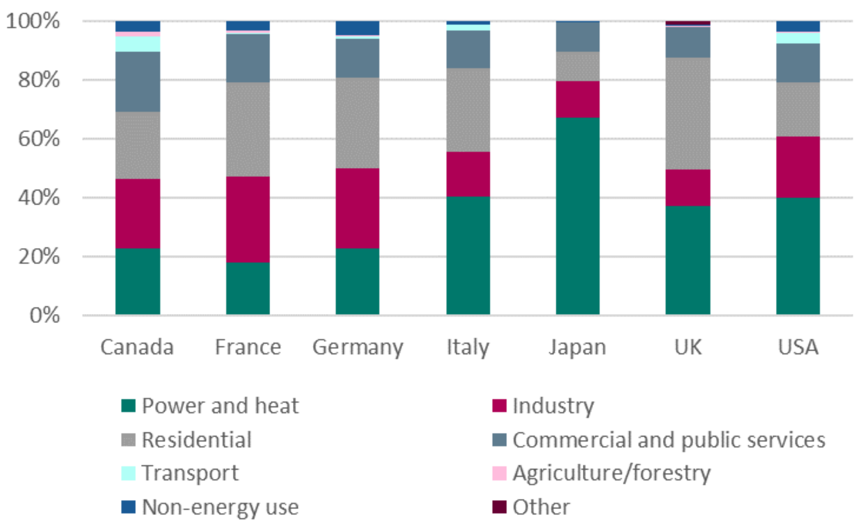
Figure 2-2: Contribution of different energy sources to total energy supply (left) and electricity generation (right) in 2020



Data source: (IEA, n.d.)

Looking at gas consumption in more detail, Figure 2-3 illustrates the distribution of fossil gas use by sector in 2019. The major consumers of fossil gas are buildings (residential as well as commercial and public services), industry (primarily for energy purposes) and heat and power generation facilities. The share of gas combusted in buildings for space heating, water heating and cooking ranges between 20 % of total gas demanded in Japan, where a large portion of heating is electrified, and 48 % in France and the UK. The share of heat and power generation, in turn, is close to 20 % in Canada, France and Germany, while at around 40 % in Italy, the UK and the USA and is highest in Japan, with 67 % of total gas consumption. Finally, the share of gas used in industry for low- and high-temperature process heat varies between 13 % in Japan and the UK and is close to 30 % in France and Germany.

Figure 2-3: Distribution of gas consumption by sector, 2019



Data source: National energy balances of the G7 countries

The share of fossil gas as a transport fuel is very small in the G7 economies. It is mostly used for transport in Canada and the USA, though even in these countries the share of this sector in total gas consumption does not exceed 5 %. Since fossil gas is not considered a transitional fuel on the pathway to net zero emissions in the transport sector (IEA, 2021), the role of transport for overall gas consumption is likely to remain insignificant in the aggregate of the G7 states[4]. Similarly, the use of fossil gas as an energy source in agriculture and other sectors is negligible.

Finally, the share of fossil gas consumption for non-energy uses is also rather small, but significantly exceeds that of transport in most G7 countries. As a non-energy source, fossil gas, together with crude oil-derived products, is a key feedstock for the chemical industry. Although data availability is limited, as non-energy use is typically reported at a more aggregated level, the available information points towards three applications that account for the vast majority of non-energy use of fossil gas:

The largest application globally is the production of nitrogen fertilisers (IEA, 2020). Nitrogen fertilisers are based on ammonia, which are predominantly produced through steam reforming of fossil gas, an emissions-intensive process in which about two thirds of the gas consumed serves as feedstock (Batool & Wetzels, 2019). Alternatives to nitrogen fertilisers include mineral fertilisers based on potash and phosphate which account for about 40 % of fertiliser consumption in the G7 (FAO, 2022) and organic fertilisers based on manure, for example.

The second largest application is methanol production (IEA, 2020), a process also predominantly based on steam reforming fossil gas (Dechema, 2017). Methanol is an important base chemical that is used in various applications in the chemical industry.

The third application, partially based on fossil gas as a feedstock, is steam cracking, a process yielding a variety of high value chemicals (HVC) necessary for the production of plastics. While in some regions, including the EU, the process is mostly based on oil as feedstock (Dechema, 2017) and requires only small amounts of fossil gas, in other regions, such as North America, fossil gas is the predominant feedstock (Allison & Mandler, 2018; Kelly, 2021). The choice of feedstock depends on the availability and price of fossil gas compared to oil, but also depends on what goods are produced.

3. National energy and climate policies

In line with the goals of the Paris Agreement, all G7 countries have committed to near zero emission no later than 2050 (G7, 2021). This includes stopping investments into new fossil fuel supply beyond what was committed to by 2021 and gradual introduction of bans on fossil fuel equipment, e.g., in

[4] An exception is Italy that plans LNG consumption for heavy duty vehicles and ships of 2.5 million tons in 2030 – about 1.5 bcm (Freight Leaders Council, 2019).

heating and transport (IEA, 2021). Among the GHG-emitting sectors, power generation is usually the biggest contributor towards a country's total emissions. For this reason, it is unsurprising that the G7 countries have set targets to expand their renewable energy generation or shift their power generation from heavy GHG-emitting resources like coal towards low-carbon fuels like fossil gas as an intermediate step towards carbon-free electricity systems. In its Carbis Bay G7 Summit Communiqué, the G7 states commit "to achieve an overwhelmingly decarbonised power system in the 2030s" (G7, 2021).

This section provides a brief overview of the main GHG emission reduction targets and targets regarding the expansion of renewables (primarily wind and solar) and, if available, changes in gas consumption.

The United States is by far the biggest GHG emitter among the G7 and plans to reduce its emissions by 50-52 % in 2030 compared to the 2005 levels (US Department of State, 2021). One part of this plan is to deploy 30 GW of offshore wind capacity by 2030. So far, the United States has only two operating offshore wind projects with a combined capacity of 42 MW (The White House, 2021). Additionally, the USA plans to permit at least 25 GW of renewable onshore wind energy by 2025 (U.S. Department of the Interior, n.d.). At the same time, there are currently no plans on short-term reductions in power generation in gas-fired facilities. To date, 38 % of electricity in the United States is produced with the help of fossil gas (electrek, 2021). Although declaring the goal in 2021 of reaching 100 % carbon-free electricity by 2035 (The White House, 2021), the U.S. Energy Information Administration (EIA) estimates that the share of fossil gas in the electricity production will remain unchanged until 2050 (EIA, 2021). There has been no change to these estimations since the start of the war in Ukraine, as the United States have not imported Russian fossil gas since 2019, and the embargo on gas imports is rather a symbolic measure.

Canada has pledged to reduce its GHG emissions between 40 % and 45 % below its 2005 levels by 2030 (Government of Canada, n.d.). Taking into account the already high share of renewables – primarily hydropower – in Canadian energy supply, it has set an ambitious goal of increasing the share of zero-emitting sources to 90 % by 2030 and is currently developing a regulation to achieve a net-zero electricity system by 2035 (Environment and Climate Change Canada, 2022).

Electricity regulations, however, differ across provinces and there is no single target for expansion of wind or solar power capacities (Centre for Climate and Energy Solutions, n.d.). While fossil gas makes up a significant share of total energy supply (see Section 2), there are no specific state plans on the future development of gas consumption or production, except the goals on emission reduction for the production oil and gas (Government of Canada, n.d.). However, in the economic modelling accompanying the federal government's most recent climate plan, fossil gas production is anticipated to drop 13 % below 2020 levels by 2030 as a result of climate policy measures (Environment and Climate Change Canada, 2022). As a large producer and net exporter of fossil gas, Canada has not imported Russian gas since 2019 and, similarly to the USA, its energy imports embargo is more a symbolic statement. Canada does not currently have any LNG export capacity and all of its fossil gas exports go to the United States.

The Japanese Government aims to cut Japan's emissions by 46 % in 2030 compared to the 2013 levels. To achieve this, one target is to increase the total wind power capacity from 4.6 GW in 2021 to 28 GW in 2030 of which 10 GW will be offshore wind facilities (Pinsent Masons, 2022). Japan currently uses fossil gas to produce 37 % of its electric power, planned to be reduced to 20-22 % by 2030 (METI, 2021). This plan could affect Japanese imports of fossil gas, of which 9 % come from Russia. So far, however, there have been no plans to reduce Russian gas imports as a response to the Russian invasion in Ukraine (S&P Global, 2022).

The United Kingdom has set the target to cut GHG emissions by 68 % in 2030 compared to 1990 levels (Government of the UK, 2020). This is one of the most ambitious targets set by a G7 member. To be able to achieve this goal, the UK plans to drastically expand on renewable energies. Offshore wind capacity should reach 50 GW by 2030, up from 11 GW in 2021 (offshoreWIND, 2022). Onshore wind capacity will be doubled from 15 GW to 30 GW (renewableUK, 2021). Solar power capacity is to be increased from 14 GW to 50 GW in 2030 (Financial Times, 2022). Interestingly, even though the UK aims to reduce total fossil gas consumption by 40 % until 2030, there are simultaneous plans to increase the extraction of fossil gas in the North Sea to become less dependent on gas imports. These plans, however, are barely affected by the war in Ukraine. The United Kingdom only imports about 5 % of its fossil gas from Russia and plans a complete phase-out by the end of the year (BBC, 2022).

Italy declared a new target to cut GHG emissions by 60 % in 2030 compared to 1990 levels, up from the 33 % goal made in 2019, after the EU set an emission reduction target of 55 % (Reuters, 2021). To be able to reach the goal set in 2019, the Italian government plans to increase solar power generation from 19.7 GW in 2017 to 26.8 GW by 2025 and 50.9 GW in 2030. Wind energy production is also to be increased from 9.8 GW (of which 0 GW are offshore) in 2017 to 15.7 GW (of which 0.3 GW are offshore) in 2025 and 18.4 GW (of which 0.9 GW are offshore) in 2030 (Renewables Now, 2019). This upscaling would have to be even stronger to meet the ambitious new target. There are also plans on reducing the share of gas-fired power generation from the current 50 % to 38 % in 2030, which is still one of the highest amounts pursued in the European Union (Ember, 2022). At the same time, the share of fossil gas in the primary energy mix is expected to increase slightly and, by 2030, gas will remain the major energy source with 39 % of energy supply, compared with 37 % in 2016. The predicted demand for fossil gas in 2030 is expected to be 60 bcm with an all-time peak in 2025 (MiSE, MATTM & MIT, 2019). Currently, Italy buys 45 % of its gas imports from Russia. As a response to the Russian invasion of Ukraine Italy aims to achieve independence from Russian gas by 2025. As an alternative to Russian fossil gas imports, Italy plans to both increase domestic gas production and import more fossil gas from Azerbaijan, Tunisia and Libya (The Local, 2022). So far, agreements are signed with Algeria, Egypt and the Republic of Congo (Wired, 2022).

France's current law targets to decrease GHG emissions by 40 % in 2030 compared to 1990 levels. Actions to achieve this goal include increasing solar, onshore wind and hydroelectric power generation capacity by 25 GW by 2026. Additionally, France plans to increase offshore wind capacity to 20 GW by 2030 (TaylorWessing, 2022). However, it was the only country in the EU that has not fulfilled its 2020 renewable energy target, and additional efforts and policies will be necessary to put it back on track (Reuters, 2022). Currently, France uses little fossil gas for electricity production. The 16 % share of fossil gas in the primary energy supply is also low, compared to other G7 countries. With a share of 37 %, fossil gas is currently the most important fuel for heating in France, a number also lower than in other G7 countries. France plans to further reduce its fossil gas consumption from 459 TWh in 2017 to 401 TWh in 2023 and 345 TWh in 2028 (NECP France, 2020). Because France does not use as much fossil gas as other countries in Europe, it is also less dependent on Russian gas. Only 17 % of France's fossil gas supply has its origin in Russia (see also Section 2).

In Germany, an emission reduction target of 65 % by 2030 relative to the 1990 level is stipulated by the new Climate Protection Law of 2021. The Climate Action Programme, adopted in 2019 and still to be updated, sets the target of a share of 65 % renewables in gross electricity consumption by 2030, while the Renewable Energies Act foresees renewables share of 40-45% by 2025. The latter postulates increasing onshore wind capacity from 54.4 GW in 2020 to 71 GW in 2030 and offshore wind capacity from 7.75 GW in 2020 to 20 GW in 2030 (BMWK, n.d.). In the short-term, the consumption of gas was also planned to increase, from 803 TWh in 2021 to 825 TWh in 2023 and then fall again to 766 TWh by 2030. In electricity production, the share of fossil gas was planned to grow to substitute coal power generation. These plans, however, are being changed due to the war in Ukraine. Germany imports more than 50 % of its fossil gas from Russia but is now planning to be completely independent of Russian gas by mid-2024. To achieve this, Germany aims to speed up the expansion of renewable energies, decrease the inland fossil gas usage, diversify its gas supplies and increase the use of green hydrogen (BMWK, 2022).

4. Overview of considered options for the reduction of fossil gas consumption

Taking into account the different uses of fossil gas described in Section 2, this study focuses on the sectors of **buildings, the industry as well as power and heat generation** which constitute the majority of fossil gas consumption in the G7 countries.

A reduction of fossil gas consumption requires the implementation of different sector- and application-specific technology options that can be grouped into **energy sufficiency, energy efficiency** and **fuel switching** measures for the energy use of gas and **material sufficiency** and **material substitution** for non-energy uses. Table 4-1 highlights the considered options for the reduction of fossil gas consumption in buildings, the industry as well as power and heat generation and summarises the main assumptions, which are described in more detail in the subsections below.

Table 4-1: Fossil gas consumption reduction matrix

Sector \ Reduction option	Energy use					Non-energy use	
	Energy sufficiency	Energy efficiency		Fuel switching		Material sufficiency	Material substitution
Buildings	Reduction of room temperatures in residential & non-residential buildings	Thermal retrofitting of residential & non-residential buildings	Settings optimisation in heating systems	Installation of heat pumps in residential & non-residential buildings	Solar thermal energy for space & water heating		
Assumptions	-1 °C	3 % of buildings per year	5 % savings from fuel optimisation	Country-specific (linked to current installation rates), up to 4 % of existing gas boilers annually	Following EU target of 45 GW in 2025 and scaled to other G7 countries		
Industry		Use of waste heat in the industry	Production reduction: plastics & glass	Use of heat pumps and renewable energy sources for low-temperature heat	Alternative fuels for high-temperature heat	Production reduction: fertilisers and plastics	Biological feedstocks and hydrogen
Assumptions		*Sector-specific*	*Qualitative discussion*	*10 % annual replacement rate of fossil gas fired heat equipment*	*Qualitative discussion*		
Power and heat				Renewable energy sources			
Assumptions				*Doubling of current installation rates of wind and PV power plants by 2025*			

4.1 Energy use in buildings

The energy consumption of buildings accounts for about 20 % of the global energy demand, representing 17 % of global emissions in 2018 (RICS, 2020), and is dominated by heat demand. Specific heat energy demand in buildings varies across the G7 states due to differences in climate zones and the age and type of buildings (e.g., residential buildings and offices consume less heat energy per square meter than commercial and public buildings).

Currently, meeting the climate targets in the buildings sector is challenging because of low energy performance resulting from poor insulation, inefficient utilization of heat, e.g., due to inefficient user behaviour and insufficient use of metering devices, and high shares of fossil heating equipment. Addressing these issues would allow to reduce both the carbon footprint of the G7 building stock and the consumption of fossil gas.

Potential energy savings from thermal retrofitting in residential and non-residential buildings range between 50 % and 80 % (Office of Energy Efficiency and Renewable Energy, 2020) and typically result from an insulation of the walls and roofs, replacement of windows and reduction of so called “thermal bridges”. So far, low (and partially subsidised) prices for energy, high investment needs and the structure of owners’ preferences have led to low rates of thermal retrofitting in residential buildings, ranging between 0.8 % (Italy) and 1.8 % (France) in the EU G7 states. Therewith, retrofitting rates are close to the capital replacement rate of buildings (about 2 %) and do not reflect any additional investment into increasing the energy standards of buildings. Achieving the climate targets of the G7 countries would require significant upscaling of annual retrofitting rates.

Similarly, the replacement of fossil-fuel heating equipment needs to be accelerated. According to IEA (IEA, Heat Pumps, 2022), electric heat pumps (air-to-air, ground-source and solar heat pumps) could supply more than 90 % of global space and water heating in the future. The advantage of this technology is its high thermal efficiency which, depending on the climate conditions, ranges between 120 % and 600 % (Felius, 2019). Heat pumps are a carbon-neutral heating technology if the non-environmental energy input is met with electricity from renewable energy sources. Compared to fossil fuels, however, heat pumps still fulfil only a small share of residential heat demand. In 2020, about 7 % of space and water heat demand in the residential sector worldwide was covered by heat pumps and the global stock of heat pumps counted 180 million units.

An important limitation to switching from fossil fuel heating to heat pumps is that, due to high upfront investment needs, they are typically not used for ad hoc replacements of existing equipment and are rather installed during thermal retrofitting or in new buildings. This is linked to the significant impact that thermal insulation conditions of a building have on the required size of a heat pump and, thus, its costs. While a newly constructed building requires only about 0.04 kW heat pump capacity per square meter (in Central European climate conditions), the required capacity is up to 3 times higher for buildings with low efficiency standard (BWP, 2020). Therefore, installing heat pumps before thermal retrofitting is technologically and economically inefficient.

The market penetration of heat pumps varies across the G7 countries. In Canada, heat pumps account for just 4 % of the heating equipment used in residential buildings (New Canadian Life, 2022) with only 30,000 new installations reported in 2018 (Government of Canada, n.d.). In the EU, 1.8 million households purchased a heat pump in 2020. That year, the three G7 states France, Germany and Italy accounted for about 50 % (900,000 units) of total EU-wide heat pump sales. Figures for Germany indicate new installations of 154,100 units in 2021 (Carbon Brief, 2022). For France, ENEA (ENEA, 2018) report about 240,000 new installations in 2017 and for Italy – 170,000 new installations.

In newly constructed houses in the United States, the share of heat pump sales exceeded 40 % in 2020 and summed up to 3.9 million units in 2021 (Carbon Brief, 2022).

In contrast, installation rates in the UK are low and reached only about 20,000 units in 2017. Recently, the government set out a plan to offer grants supporting 90,000 households to install heat pumps (The Guardian, 2021). The UK aims at installing 600,000 heat pumps per year until 2028 (IEA, Heat Pumps, 2022).

The situation in Japan differs significantly from all other G7 states. Since 2001, the market for heat pumps has been growing steadily. In 2014, 2,723 heat pumps were installed for every 1,000 households, reflecting the frequent use of this application in single rooms of apartments for heating and cooling purposes (HTP, 2020). For 2012, REHVA (REHVA, 2012) reported annual sales of 8.2 million units in Japan. Considering that each consumer in the 2014 survey installed 2.7 units on average, about 3 million additional apartments are equipped with heat pumps annually, representing 4 % of the total stock in Japan.

In the G7 states, there are different targets and initiatives focussing on increasing the energy efficiency in the buildings stock. One group of targets relates to retrofitting. For the EU, Article 5 EED (2012/27/EU) sets a retrofitting rate for public buildings to 3 % in order to meet the minimum energy efficiency requirements. Germany aims at reducing its primary energy consumption in buildings by 50 % in 2030 compared to 2000. Under consideration of current low retrofitting rates, this target represents a retrofitting rate of about 3 % until 2030. Canada plans to retrofit 600,000 homes annually until 2050 and a total of 32 million m² of commercial property is to be retrofitted until 2040 at a cost of USD 21 billion per year.

The second set of targets focuses on zero-carbon heating technologies. For example, France aims at installing 150.000 to 350.000 m² of solar panels for heat generation per year (70 % of those in the privately-owned buildings) and 300.000 m² a year in the industrial sector.

Finally, some G7 countries concentrate on emission reduction targets for buildings. The UK plans to cut residential building emissions by 60 Mt CO2e, non-residential private emissions by 9 Mt CO2e, non-residential public emissions by 5 Mt CO2e and total building emissions by 155 Mt CO2e. Japan aims at saving 86 Mt CO2e in the buildings sector by 2030. In German law, a reduction of emissions from buildings from 118 Mt CO2e in 2020 to 67 Mt CO2e is stipulated.

Many of these targets can support the goal of reducing gas consumption in buildings, as will be visible from the overview of the considered technological options below. The following options were considered for this study:

4.1.1 Temperature reduction in residential & non-residential buildings

A reduction of indoor temperature by 1°C allows for average energy savings of about 7 % in residential and non-residential buildings (IEA, 2022). High energy prices foster such a behavioural change. For that reason, energy subsidies and financial support must be adapted and targeted only to residents in danger of energy poverty or public buildings that carry out social duties (such as schools and hospitals).

For the following calculation of a potential reduction of fossil gas consumption, a 1°C temperature decrease is assumed.

4.1.2 Settings optimisation in heating systems

In line with behavioural change, optimisation of heating systems as well as installation of appropriate metering devices and smart thermostats allow for more efficient control of heat consumption in buildings. Following DIW (Neuhoff, Weber, & Goldtha, 2022), the potential savings in energy consumption are similar to those of a 1°C temperature reduction, reaching 5 %. Investments in such an optimisation are low or negligible and typically have very short payback time. Again, subsidized energy prices hinder the adoption these measures and have to be adapted.

For the following calculation of a potential reduction of fossil gas consumption, 5 % energy savings from settings optimisation are assumed.

4.1.3 Thermal retrofitting of residential and non-residential buildings

As described above, thermal retrofitting rates are currently low and represent the annual renewal rate of the capital stock. This implies that, apart from compensation of capital depreciation, no investment in the existing building stock is taking place.

Targeting complete thermal retrofitting of the existing buildings stock in the G7 states until the mid-century requires an average annual retrofitting rate of about 3 % of the current stock (assuming high energy standards for all new buildings). This is up to three-fold of the current retrofitting rates and requires a massively increased effort.

For the following calculation, an annual retrofitting rate of 3 % is assumed.

4.1.4 Installation of heat pumps in residential & non-residential buildings

The replacement of fossil-fuel heating equipment through heat pumps allows to reduce building-specific emissions to nearly zero. This, however, requires that the electricity that powers the heat pumps has to be generated by renewable energy sources, such as wind and solar PV. It should be noted that the installation of a heat pump is more efficient in buildings with low energy consumption, i.e., in new and retrofitted buildings, which potentially prevents installations in buildings with high energy consumption. In order to switch from gas boilers to heat pumps, an installation would ideally be part of thermal retrofitting.

For the following calculation, a stepwise increase of the annual replacement rate for the existing stock of fossil gas heating equipment is assumed. For 2022 we assume a fading-in depending on country-specific installations rates up to a uniform replacement rate of 4 % for all G7 states in 2025.

4.1.5 Solar thermal energy for space & water heating

Solar heating is another technology that can be used for space and water heating in buildings. Obviously, the most efficient applications are possible at lower latitudes. However, even at sub-optimal weather conditions solar thermal energy can be used in addition to existing heating equipment and replace fossil fuels.

For the following calculation, an increase of the annual replacement rate similar to that of heat pumps in buildings is assumed.

4.2 Energy use in the industry

Final energy consumption (FEC) in the industry of the G7 states is heterogenous. Solid fossil fuels (primarily, coal) account for a significant portion of FEC in Japan (24 %), but only for only 1-6 % in the other G7 countries (Table 4-2). Fossil gas plays a major role in the Canadian industry, there it dominates the FEC with 58 %. In contrast, Japan has the lowest fossil gas share in FEC of industry with 13 %.

Table 4-2: Structure of final energy consumption (FEC) in industry in G7 states (% of total)

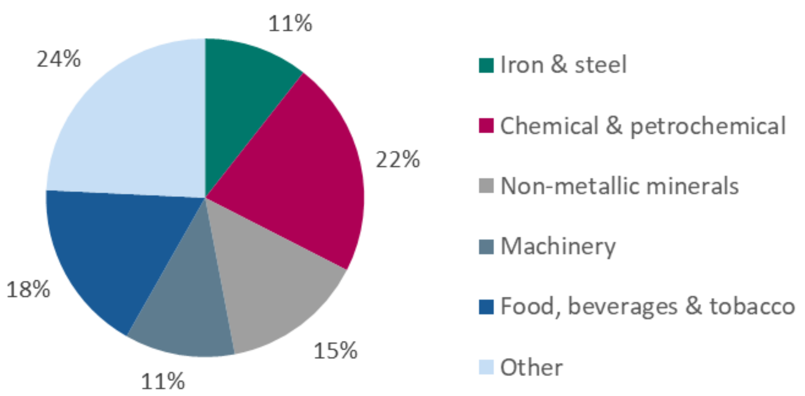
	Canada	France	Germany	Italy	Japan	UK	USA
Solid fossil fuels	1%	3%	6%	2%	24%	4%	4%
Fossil gas	58%	39%	36%	34%	13%	39%	41%
Oil and petroleum products	11%	10%	6%	7%	22%	10%	33%
Electricity	26%	35%	33%	42%	37%	34%	12%
Heat	1%	6%	7%	11%	0%	3%	
Further (e.g. waste & RES)	3%	7%	11%	4%	4%	9%	10%

Source: national energy balances

Fossil gas consumption takes place in all industrial sectors. Due to different structures of the industries in the G7, relative fossil gas consumption within the industry varies. However, in all countries fossil gas has a dominating role in the chemical and petrochemical industry, food industry and in the non-metallic mineral industry (Figure 4-1).

Both, the current level of fossil gas utilisation in each sector as well as the sectoral structure in the seven economies determine the fossil gas saving potential in the short and in the long run. The majority of gas used in the industry is to generate process heat of different temperatures. Consequently, different needs for process temperatures across the sectors and processes determine options for technology and fuel switch as well as what alternatives are available and when.

Figure 4-1: Shares of fossil gas consumption in industry for the aggregate of European G7 members & Japan



Source: Own calculation based on national energy balances

4.2.1 Use of waste heat

A large portion of energy used in the industry is for thermal processes, such as furnaces, reactors, boilers and dryers. The share of energy use for heat generation in the EU industry is estimated at 70 %, and up to a third of it is lost as unused excess heat, or waste heat (Agathokleous, et al., 2019). This excess heat results from both process inefficiencies, such as insufficient insulation, and thermodynamic constraints, such as high-temperature exhaust gases in smelting furnaces (Aydemir, Fleiter, Schilling, & Fallahnejad, 2020). There is a number of technologies that allow to capture the waste heat and recycle it for lower-temperature processes, power generation, cooling, or supply of low-temperature district heating (Bianchi, et al., 2019).

There is little information on how much waste heat is already being used, though the current market size and its future projections, together with growing research estimating the potential for waste heat recovery, suggest there is enough room to increase energy efficiency in the industry through the use of excess heat. The market for waste heat recovery is estimated to surpass USD 65 billion in 2021 (Bianchi, et al., 2019) which is about 7 % of the market for other renewables (Allied Market Research, 2021).

The potential for energy recovery from waste heat differs by sector and is estimated between 6 % of energy consumption in wood production to 11.4 % in the iron and steel industry (Agathokleous, et al., 2019). Although the economic potential is currently somewhat lower due to several barriers, it can be assumed that by 2050 the technological and policy development will allow for the full use of the recovery potential.

For the following calculation, it is assumed that the use of the waste heat recovery potential will grow steadily and, by 2025, 10 % of the industry-specific potential will be exploited.

4.2.2 Use of heat pumps and renewable energy for low-temperature heat

Current state-of-the-art heat pumps can supply temperatures in the range between 100 °C and 150 °C (Zuhlsdorf, 2019). This range is well below the required temperature of most industrial processes such as cement, glass or metal production. While further technological developments and breakthroughs can be expected in the coming years, in the short-term, only low-temperature processes in the industry can be equipped with commercially available heat pump systems. Estimations for the EU show that the share of low-temperature heat (below 100 °C) in industrial final energy consumption is about 30 % in the food industry, 20 % in the chemical and petrochemical industry and 8 % in paper production (Rehfeldt, Fleiter, & Toro, 2017). On average, about 35 % of industrial final energy consumption relates to the temperature range up to 150 °C (Rehfeldt, Fleiter, & Toro, 2017; IEA and IETS, 2014). At the same time, fossil gas is used for all temperature ranges industrial processes operate in, but, in the EU, only about 5 % is used for applications operating below 100 °C and 20 % for a range of up to 200 °C (Rehfeldt, Fleiter, & Toro, 2017).

Beside heat pumps, solar thermal applications can provide heat for low-temperature processes. Currently, the majority of applications for solar thermal heat can cover the temperature range until 120 °C. However, in the short-term, their use is likely to be limited to the use in small enterprises requiring temperatures under 100 °C, e.g., for water heating, steam generation or drying processes (Fraunhofer ISI, n.d.; Solare Prozesswärme, n.d.).

For the following calculation, it is assumed that 10 % of low-temperature processes applications in the industry can be replaced annually by heat pumps and solar thermal units.

4.2.3 Reduction of plastics and glass production

Plastics and glass production rely heavily on fossil gas use (in the case of plastics, both as an energy source and as a feedstock), and are both characterized by high shares of packaging products. About half of global plastic production consists of plastic designed for single-use purposes, of which 98 % are primary, or "virgin" plastics (UNEP, n.d.). In global glass production, about a half is comprised of container glass, of which three quarters are used for beverages (Westbroek, Bitting, Craglia, Azevedo, & Cullen, 2021). In Europe, this share reaches 60 % (European Commission, n.d.). Therefore, production reduction of both plastics and glass is possible by switching to reusable products and will not only affect energy use and emissions in production, but also contribute to reducing waste pollution.

Reduction of single-use product consumption is often seen through the prism of emission reduction. It is estimated that switching to reusable glass bottles can reduce emissions by 85 % relative to single-use glass bottles, 57 % relative to single-use aluminium cans and 70 % relative to single use PET bottles, mostly stemming from the production phase (Reloop & Zero Waste Europe, 2020). Estimations for energy savings from switching to reusable products vary, depend on the energy needs along the complete value chain (from raw material production to distribution), and reach 65 % (Coelho, Corona, Klooster, & Worrella, 2020). A quantitative assessment of potential fossil gas savings for the G7 countries was not made in this study because of both uncertainty in possible savings and missing statistical data on energy, fossil gas in particular, and data on consumption in the plastics production in EU countries and the UK.

Switching to reusable products can be stimulated by a variety of measures, from awareness campaigns to bans on specific products or product groups. For example, the EU has enacted a ban on single-use plastics products for which sustainable alternatives are easily available and affordable (such as cotton buds, cutlery, plates, straws, etc.). Bans were also put on certain products made of expanded polystyrene and on all products made of oxo-degradable plastic (European Commission, n.d.). There are additional regulations on product designs to increase reusability and recyclability of their products as well as several national targets on the shares of packaging reuse (du Lou, 2019). Among the G7 members, Germany has set a target of 70 % of its beverage packaging to be reusable by 2022 and France – a target of 5 % of all packaging to be reusable by 2023 and 10 % by 2027 (Break Free From Plastic, 2022).

Similar to the EU, the UK has banned microbeads in rinse-off personal care products, restricted the supply of single-use plastic straws, stirrers and cotton buds and proposed a ban on a number of other products already banned in the EU (Government of the UK, n.d.; House of Commons Library, 2022).

In the USA, there is no federal legislation on single-use plastics though the respective *Break Free From Plastic Pollution Act* is currently under review with several states having banned certain single-use plastic products (UrthPact, 2021; US Congress, n.d.). Similarly, in Canada, single-use plastics prohibition regulations are currently under review (Government of Canda, 2022). Finally, in Japan, the plastic resource recycling promotion law has recently entered into force, requiring businesses using large amounts of plastic to reduce said use, though no specific reduction measures were defined (The Mainichi, 2022).

Coordinating the efforts and raising ambition on regulating single-use plastics and increasing the shares of reusable products will serve a multitude of goals and, inter alia, contribute to reducing consumption of fossil fuels in the G7 economies.

4.2.4 Alternative fuels for high-temperature heat

Many industries use high-temperature heat (over 500°C) for their production processes. Currently, renewable sources such as heat pumps or solar collectors are not capable of generating heat with such temperatures (see also Section 4.2.2). Instead, producers in cement, aluminium, glass, steel and chemical industries rely heavily on fossil fuels. Especially in the cement production and chemical industry, significant amounts of fossil gas tend to be used resulting, inter alia, from the recent trend to decarbonize production by switching from coal-fired to gas-fired heat generation (The Pembina Institute and Environmental Defence, 2014; Rothermel, 2020). This, however, varies strongly among the G7 countries. In addition to these two industries, glass production processes usually use fossil gas to generate temperatures between 1000 °C and 1600 °C (Wulf & Zapp, 2022).

In the short-term, the substitution of fossil gas with alternative, carbon-neutral energy sources, is very limited. It is, therefore, discussed qualitatively in this section.

For most high-temperature processes, hydrogen is seen as the main "green" alternative to fossil gas, however, its short-term deployment is unlikely due to both long investment cycles and lacking availability of green hydrogen supply. The availability of this solution is expected rather by 2030 or beyond (Rothermel, 2020; Wulf & Zapp, 2022).

Other options are to substitute fossil fuels in existing equipment with the combustion of biomass or waste, primarily in cement production (Verma, Mazumdar, & Ghosh, 2021). However, these are limited too. Switching to alternative fuels might require technical modernisation (de Beer, Cihlar, & Hensing, 2017) and, in view of longer-term prospects of switching to hydrogen, investments into modernisation run the danger of turning into stranded assets in a few years. Moreover, the use of biomass is a sensitive question due to its environmental impacts and potential competition with food production. **Consequently, biomass use for energy purposes is not considered in this study**.

The potential for the remaining alternative to fossil gas in cement production – waste combustion – varies significantly across the G7 countries, due to both the variation in gas use and the different current levels of waste use. For example, in Canada, Germany and Japan, the share of fossil gas in the energy mix of cement production is negligible, while in France, Italy and the UK, the potential of waste-derived fuels is limited due to technological constraints or market saturation. In the USA, the current share of waste-derived fuels is relatively low and the share of alternative fuels is expected to increase (Portland Cement Association, 2019), suggesting the largest possibilities for reduction in gas consumption through switching to waste combustion. However, even in the USA, the largest cement producer among the G7 states, this would have only marginal impacts on total gas consumption in the economy.

Importantly, energy recovery should be limited to waste streams that cannot be covered by more preferable waste management options. EPA classifies waste management strategies from most to least environmentally preferred in the following order: source reduction and reuse (avoidance of waste); recycling and composting (circular economy); energy recovery (waste combustion for renewable energy to replace fossil fuels); and treatment and (landfill) disposal as the least preferred option (EPA, n.d.). Consequently, reduction of waste generation and enhanced circularity are a priority in waste management, and only unavoidable non-recyclable waste forms the potential for fossil fuel replacement.

4.3 Power and heat production

The consumption of fossil gas in the power and heat generation takes place in "electricity-only plants", "heat-only plans" and "co-generation" (CHP) plants. While fossil gas consumption can be reduced in "electricity-only plants" through the scaling up of renewable sources such as wind and solar PV, the replacement of gas in heat production requires either a direct reduction of heat demand in the buildings or industry sector, a fuel switch in these two sectors or a replacement in supply by biofuels or synthetic methane and hydrogen.

The measure considered in this study focuses on replacing fossil gas in the generation of electricity. Fossil gas savings from a reduction in heat demand or a fuel switch through, e.g., heat pumps, are analysed in the respective consumption sectors buildings and industry. A supply-side fuel switch through biofuels or other alternatives is not analysed, because of either contradictory environmental impacts (in case of biofuels) or the limited time horizon of 2025 (in case of hydrogen).

The role of fossil gas in power generation differs across the G7 states. In the aggregate of centralized heat (heat-only plants and CHP) and power generation, the share of fossil gas is about 67 % in Japan, close to 40 % in Italy, the UK and the USA and just about 20 % in Canada, France and Germany. In Italy and Germany, about 60 % and in France about 35 % of the fossil gas used in the energy sector is consumed in co-generation facilities (CHPs).

Existing targets regarding the use of fossil gas in the electricity sector have to be seen in the context of the overarching decarbonisation strategies of the G7 states. In the transition of the electricity sectors, fossil gas plays a role twofold: On the one hand, it supports a coal phase-out, resulting in lower emissions compared to those of coal combustion; on the other hand, electricity generation from fossil gas is used as a balancing option for fluctuating renewable generation, which avoids the installation of additional expensive storage capacities.

Therefore, the policy plans for using fossil gas in electricity generation vary significantly, depending on the contribution of other energy sources. While in Germany the electricity generation based on fossil gas is to increase until the mid-decade and fall afterwards, the U.S. gas share in power generation is predicted to remain constant or even decline, while in Japan there are plans to significantly reduce the gas share by 2030 (see Section 3 for more detail).

In order to determine the potential effects of replacing fossil gas by wind and solar capacities, it is assumed that Canada, Italy, the UK and USA double their installations, compared to the average of 2019 – 2021. In contrast, Germany and France – which both are characterised by high shares of renewables and low shares of fossil gas in the system – are assumed that only installations in the order of magnitude of previous year affect a fossil gas consumption[5]. In Japan, on the contrary, the current installation rates are very low and ambitions have to grow significantly in order to fulfil the climate and energy targets. Therefore, the installation rate is assumed to triple.

Taking into account that existing plans for the expansion of renewables are often meant to replace coal-powered generation, the installations described in this measure either have to come *in addition* to already planned installations or would *pause* the planned phase-out of coal and nuclear generation in some countries. Furthermore, the calculation considers the current level of power generation, i.e., more capacity expansion would be necessary to cover additional electricity demand from E-mobility or new installations of heat pumps. Finally, the time for planning and installation of renewable power generation facilities is taken into account, which results in a net time for action of 2 years to lead to fossil gas savings in 2025.

For the following calculation, it is assumed that all countries increase their annual installations of wind and solar PV capacities by 30 % in 2023, 60 % in 2024 and 100 % in 2025, compared to the average of 2019-2021. These new capacities replace coal and fossil gas in electricity generation proportionally to the relative shares of both fuels in 2020 in the respective countries. It is further assumed that only renewable capacities that are in operation by mid-2025 will affect the fossil gas consumption in 2025.

4.4 Non-energy use in the industry

4.4.1 Biological feedstocks and hydrogen

Low-carbon alternatives to the conventional fossil gas-based production processes for ammonia, methanol and HVC are available for implementation over the time frame considered in this study (Chiappinelli, 2021). These different climate-neutral options have in common that they all require significant amounts of green hydrogen as feedstock. To produce ammonia with a low carbon footprint, green hydrogen is combined with nitrogen, while for methanol production CO_2 is required as an additional feedstock. HVC can be produced directly from green hydrogen-based methanol through a Methanol-to-Olefin (MtO) process, which is the established production process for HVCs in China, although the hydrogen is produced using fossil gas. Given the significant demand for low-carbon

[5] Independent of those fossil gas affecting investments in renewable sources, the overall development of wind and solar PV plants is assumed to follow national targets.

electricity of these processes and the limited availability of green hydrogen, the scope for gas savings through additional implementation of these processes up to 2025 is likely very limited.

Another option for substituting non-energy use of fossil gas in the chemical sector is using biomass as a feedstock. Technologies for the production of ammonia, methanol and HVCs are established, but considered to be a very expensive option (Batool & Wetzels, 2019; Dechema, 2017). In particular, the investment needs, e.g., for the implementation of gasification would be significant, while in the long run other options are considered to be less costly for the decarbonisation. Therefore, forcing investments in these options to induce short-term fossil gas savings would be inefficient from the long-term perspective. Furthermore, a key issue is the availability of sustainably sourced biomass as a feedstock. Not only would there be competition with other sectors seeking to substitute fossil gas and decarbonise their processes, but an expansion of land use for biomass production may also exacerbate the food crisis emerging as a result of the Ukraine-Russia war.

4.4.2 Production reduction: fertilisers and plastics

The limited scope of substitutions for fossil gas as a feedstock thus leaves overall reduced production as a viable option to save gas in the G7 countries. Starting with plastics, lower production levels could firstly be achieved through higher material efficiency, i.e., reduced demand. In particular, this could entail less plastic packaging but also more efficient use in industrial production processes and waste prevention through more repair and reuse. As discussed in Section 4.2.3, significant reductions can be achieved by phasing out single-use plastics.

Second, primary production of plastics could be substituted through enhanced recycling of end-of-life plastics. This has the potential to not only save the oil and fossil gas used as feedstocks for virgin plastic, but also reduce demand for energy use of fossil gas, as recycling processes are much less energy-intensive and easier to electrify (Chiappinelli, 2021). Recycling rates of plastics are currently very low: e.g., in Europe it is estimated that 15 % of end-of-life plastics were recycled in 2020 (Material Economics, 2022), while the U.S. recycling rate has even decreased from 9 % in 2018 to only 5-6 % in 2021 (Beyond Plastics & The Last Beach Cleanup, 2022). Furthermore, plastic recycling is limited by component mixture (of different plastic types or with paper) and polymer properties leading to high downcycling shares (Earth5R, 2020). Increased recycling rates and, thus, substitution of primary plastics with secondary material are considered feasible yet require purer waste streams and hence investments in enhanced sorting and recycling facilities as well as an implementation of designs for recycling practices (Sun, Lettow, & Neuhoff, 2021).

With respect to fertilisers, the emerging food crisis makes a reduction in fertiliser production a difficult issue. Next to being an important supplier of food exports, accounting for 30 % of wheat exports together with Ukraine in 2021, Russia is also the leading exporter of nitrogen fertilisers and the second and third largest exporter of potassium and phosphorous fertilisers, respectively (FAO, 2022). A shortage of fertiliser supply is already ensuing with prices of fertilisers reaching all-time highs, most notably for fossil gas-based nitrogen fertilisers. Reducing the production of fertilisers in such a situation may exacerbate the shortage and leave less developed countries less able to afford sufficient fertilisers to maintain yield levels.

Options to relieve pressure from the global fertiliser market exist but have to be carefully considered and coordinated. First, more efficient use in agriculture as well as reductions in food waste and a shift to less animal protein-intensive diets could reduce demand for nitrogen fertilisers (Material Economics, 2019). Better practices in fertiliser treatments have the potential to significantly reduce its use without risking losses in yields (Ritchie, 2021). The scope of gas savings through these options by the end of 2022 is limited, but the potential for the period up to 2025 should be used as far as possible.

Another option would be the substitution of fossil-gas based nitrogen fertilisers with organic fertilisers. In fact, this is considered to be a required measure for the successful transition to a sustainable and low-carbon food system (Material Economics, 2019).[6] Finally, certain practices of organic farming can contribute to replacement of mineral fertilisers. These include cultivation of nitrogen-fixating protein crops (legumes), which promote humus formation and soil fertility, as well as catch-cropping and undersowing, which reduce the risk of soil erosion (Bundesumweltamt, 2018).

Substantial reductions in fertiliser production and use that would risk lower yields may not be desirable as long as the food crisis is present. In order to produce enough fertiliser to secure the global food supply despite significantly higher prices and tendencies to curtail industrial production first, the focus on saving gas in other sectors should be intensified. Another option to reduce pressure in regions most affected by shortages in fossil gas, i.e., in Europe and other LNG-importing countries such as Japan, is to temporarily reduce production of fertilisers in these regions and compensate these amounts at least partially through increased production in countries with better availability of fossil gas, in particular, the United States and Canada. This would reduce the needs for LNG imports, which are limited by capacity constraints anyways. Considering the negative environmental impacts of the transportation

[6] E.g., in the scenario modelling for the global food system, the sustainability scenario of the FAO assumed a complete phase-out of nitrogen fertiliser consumption up to 2050 and drastic reductions of fertiliser consumption already by 2030 (FAO, 2018).

of fertilisers, however, such production shifts should be limited to a minimum and only be implemented in case of severe shortages of fossil gas in the most affected regions.

5. Effects of the implemented measures

5.1 Total savings potential

As shown in Table 5-1, by the end of 2025 about 18 % fossil gas consumption can be saved, relative to 2020. These measures and their respective applicability will be discussed in more detail for each sector in the three subsections below.

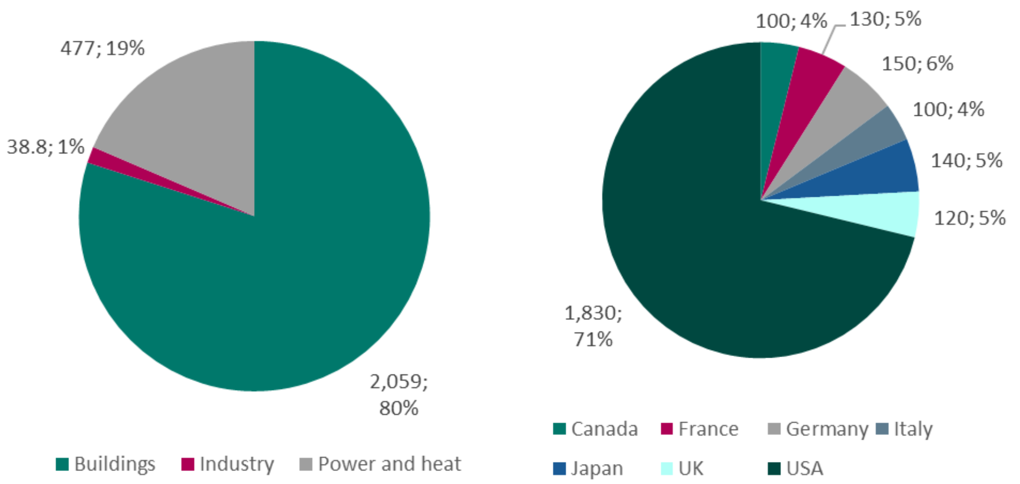
Table 5-1: Total fossil gas savings in 2022 and 2025 across all sectors (TWh, bcm and % of gas consumption)

All measures	Canada	France	Germany	Italy	Japan	UK	USA	Total G7 (in TWh)	% of total G7 consumption 2020	Total G7 (in bcm)
Fossil gas consumption 2020	1,212	406	868	678	1,044	800	9,167	14,175		1,451
Total consumption savings in 2025	**99**	**133**	**155**	**103**	**136**	**123**	**1,827**	**2,576**		264
Percentage of total fossil gas consumption 2020	8%	33%	18%	15%	13%	15%	20%		**18%**	

Source: Own calculations

Figure 5-1 (left panel) shows the contribution of each sector to the reduction of fossil gas consumption in 2025. By far the largest contributor is the sector of buildings, with 2,059 TWh (211 bcm, 80 %). The considered measures in the industry will have limited effects in the next three years due to lack of short-term options for carbon-free process heat. Fossil gas consumption reductions in electricity generation can contribute up to 477 TWh (49 bcm), or 19 %, to the total reduction.

Figure 5-1: Distribution of gas savings in 2025 by sector (left) and country (right) (TWh and % of total)



Source: Own calculations

Figure 5-1 (right panel) compares the contributions of each of the G7 countries to the total savings potential in 2025. As the largest energy consumer of the G7 states, USA can contribute about three quarters of the total consumption reduction. Other countries can contribute similar shares of 2-6 % to the total savings.

5.2 Energy use in buildings

If efforts increase and a 3 % rate of thermal modernisation in residential and non-residential buildings can be implemented in the G7 states, energy consumption of buildings can be reduced by about 10 % until 2025. This corresponds to a reduction in fossil gas demand of 210 TWh (21 bcm) or 1.5 % of the total G7 economy-wide fossil gas demand[7].

Energy sufficiency and energy efficiency measures (reduction of room temperature and optimisation in heating systems) allow to save about 490 TWh (50 bcm) or 3.5 % of total G7 consumption each. The expected effect of fuel switching (installation of heat pumps and solar thermal applications) on fossil gas demand reduction is about 870 TWh (89 bcm), which amounts to about 6 % of total G7 gas consumption. All building-related measures combined represent a decline in fossil gas reduction of about 14.5 % of 2020 aggregated fossil gas consumption in G7 states.

Reaching a 3 % retrofitting rate as well as 4 % installation rate for heat pumps and solar thermal applications by 2025 are ambitious targets. The most critical macroeconomic challenges for reaching these targets are the current distortions in international value and trade chains, rising inflation, growing prices for construction materials and availability of a qualified workforce.

Table 5-2: Fossil gas savings in 2025 in the buildings sector (TWh, bcm and % of gas consumption)

Measure	Canada	France	Germany	Italy	Japan	UK	USA	Total G7 (in TWh)	% of total G7 consumption 2020	Total G7 (in bcm)
Reduction of room temperature in residential & non-residential buildings	23	13	27	20	9	21	379	491	3.5%	50
Settings optimisation in heating systems	23	13	27	20	9	21	379	491	3.5%	50
Thermal retrofitting of residential & non-residential buildings	13	7	15	12	5	13	145	210	1.5%	21
Installation of heat pumps in residential & non-residential buildings	19	41	37	21	51	16	367	552	3.9%	56
Solar thermal energy for space and water heating	9	16	15	13	13	9	240	315	2.2%	32
Total	86	91	121	85	85	81	1 509	2 059	14.5%	211
Percentage of total fossil gas consumption 2020	7%	22%	14%	13%	8%	10%	16%			

Source: Own calculations

[7] Focussing the retrofitting only on the buildings that consume fossil gas can double the savings because the average fossil gas share in heating is 50 % in the G7 countries.

Microeconomic challenges result from expectations about individual profitability of proposed investments. Currently, the economic efficiency for users of installing a heat pump is low, which explains the low market penetration in Western Europe and North America. The leverage in final energy consumption – electricity consumption of a heat pump being much less than gas consumption of a boiler – is not able to compensate for the price spread between electricity and (cheaper) fossil gas. Hence, variable costs for both applications are typically similar with installation costs of heat pumps currently exceeding those of fossil heating equipment by the factor of three. Addressing these challenges requires governmental action.

Following policy measures can promote the reduction of fossil gas consumption in buildings:

- *Obligatory replacement of fossil heating equipment of a specific age;*
- *Obligatory retrofitting requirement for buildings of a specific age and / or binding energy standards for buildings of a specific age;*
- *Government campaigns, jointly agreed saving targets, and definition of saving norms;*
- *Ambitious retrofitting of public buildings;*
- *Supported loans and / or grants for thermal retrofitting and replacement of heating equipment;*
- *Support of construction companies in training their workforce to* implement modernisation measures*;*
- *Phase-out of universal energy price subsidies to eliminate distortions in price signals and focus on targeted support instead;*
- *Promotion of the usage of environmentally friendly construction (e.g., insulation) materials, which do not require fossil energy as raw material input;*
- *Promotion of investments in domestic production capacities for heat pumps (similarly to the Tesla Gigafactory in Germany, "Heat Pump Gigafactories" are needed).*

5.3 Energy use in the industry

As explained in Section 1, demand reduction (of all sectors) in the first quarter of 2022 already accumulated to about 7 %, compared to 2021[8]. The current increase in inflation and the challenges in international value chains will affect the economic output of all G7 countries. This will decrease the energy consumption and therewith also fossil gas demand. However, this effect is not sustainable, as economic recovery and price decreases in the future will again increase the demand. Moreover, these market mechanisms do not ensure that demand reduction is carbon-neutral (in fact, in many instances the opposite is the case). At the same time, the economic downturn hinders investments on capital replacement, and so action has to be taken now to stimulate carbon-neutral modernisation.

[8] This number is not temperature-adjusted and arises partially due to the warm winter and early spring weather in 2022, which made heating less necessary during this time.

Without considering reduction in demand for fossil gas induced by the price increase and structural changes or a decline in industrial production related to the high prices, the contribution of this sector to the overall fossil gas saving remains limited until 2025. The two proposed measures can contribute to a reduction in fossil gas consumption of 0.1-0.3 % of total gas consumption, depending on the country. The savings are smallest in Japan and the UK and largest in the USA (Table 5-3).

Table 5-3: Fossil gas savings in 2025 in the industry sector (TWh, bcm and % of gas consumption)

Measure	Canada	France	Germany	Italy	Japan	UK	USA	Total G7 (in TWh)	% of total G7 consumption 2020	Total G7 (in bcm)
Use of waste heat in industry	1.4	1.0	2.0	0.8	1.0	0.7	14.5	21.4	0.0	2
Use of heat pumps and renewable energy sources for low-temperature heat	2.4	0.1	0.3	0.1	0.3	0.1	14.1	17.4	0.1%	1.8
Total	3.9	1.2	2.2	0.9	1.2	0.8	28.6	38.8	0.3%	4.0
Percentage of total fossil gas consumption 2020	0.3%	0.3%	0.3%	0.1%	0.1%	0.1%	0.3%			

Source: Own calculations

In addition, the proposed measures do not include technological options for decarbonisation of high-temperature heat in industrial processes, such as in steel manufacturing or glass production. As discussed in Section 4.2.3, the respective technological options are either not yet market-ready, currently too expensive or require long planning time and, therefore, will not affect the results for 2025. Similar to the buildings sector, governmental actions, partially already implemented, can stimulate the adoption of the proposed measures.

The possible government interventions include:

- *Avoidance of energy price subsidies for the industry sector to foster the impact of price signals;*
- *Obligatory retrofitting requirements for heat equipment of a specific age;*
- *Promotion of investments in national production capacities for heat pumps ("Heat Pump Gigafactories").*

5.4 Power and heat production

The main source of demand reduction in power generation is the expansion of renewable energy capacities. For the period until 2025, new offshore and onshore wind and solar PV capacities can contribute to a significant reduction of fossil gas generation in all G7 states. Based on the assumptions described in Section 4.3, reaching – at least – the double of the current installation rates by 2025 can generate fossil gas savings in power generation from 4 % in Canada all the way to complete phase-out in France (Table 5-4). However, as discussed in Section 3, it is important that the replacement of fossil gas with new installations does not undermine the existing goals for coal and nuclear phase-out.

Table 5-4: Wind and solar PV installations 2019/20, new installations until 2025, share of gas in electricity generation in 2020 and gas savings in 2025 (GW, % of current rate and % of gas consumption)

Measure	Canada	France	Germany	Italy	Japan	UK	USA
Average new installations 2019/2020	1.0	3.8	7.0	1.4	7.5	3.4	35.0
Installed wind & solar PV capacities until Q2 in 2025	3.9	14.8	27.3	5.5	29.3	13.3	136.5
Share of fossil gas in electrcity generation 2020	11%	6%	15%	50%	32%	40%	38%
Percentage of fossil gas savings in electricty generation compared to 2020	4%	100%	48%	16%	7%	18%	10%

Source: Own calculations, (Our World in Data, 2022)

At the economy-wide level, the effect of fossil gas replacement in electricity generation is comparable to savings in buildings. Until 2025, between 2 % and 10 % of the national gas consumption can be replaced, representing about 8 % of the total fossil gas consumption of the G7 countries in 2020 (Table 5-5).

Table 5-5: Fossil gas savings in 2025 in the power and heat sector (TWh, bcm and % of gas consumption)

Measure	Canada	France	Germany	Italy	Japan	UK	USA	Total G7 (in TWh)	% of total G7 consumption 2020	Total G7 (in bcm)
Renewable energy sources	9	41	31	16	50	41	289	477	3.0%	49
Total	9	41	31	16	50	41	289	477	3.0%	50
Percentage of total fossil gas consumption 2020	1%	10%	4%	2%	5%	5%	3%			

Source: Own calculations

The discussed increased effort with respect to installing new wind and solar PV capacities is ambitious but possible for the G7 economies. However, production constraints for wind turbines and solar PV in light of growing demand, production constraints and vulnerable value chains might hinder the achievement of the proposed targets. Significant efforts will be needed to scale up the installation rates in the short term. Furthermore, the discussed measure focuses only on the replacement of fossil gas, which for its own part is – especially in Germany – currently seen as the key for delivering flexibility to the decarbonising energy system in the middle run. Therefore, replacing fossil gas with renewable electricity generation requires consideration of other, carbon-neutral flexibility options.

Following governmental actions, partially already implemented, can support the adoption of the proposed measures:

- ☐ *Implementation of national fossil gas and renewable targets for the electricity sector;*
- ☐ *Minimisation of administrative hurdles for planning and construction of renewable energy facilities;*
- ☐ *Development of an appropriate strategy for fostering the development of storage and flexibility options.*
- ☐ *Fostering capital investments in wind and solar PV production facilities*

6. Conclusion

The recent geopolitical developments have again shown how geographic concentration of fossil fuel production creates global dependencies and affects economies worldwide, from local energy prices to global food and manufacturing supply chains. Among other issues, the debate around reducing the dependency of industrialised economies on imports of fossil fuels is brought to the forefront. At the same time, the unfolding crisis is a triple one, where the disruption of supply chains due to the Ukraine-Russia war is coupled with an uneven recovery from the COVID-19 pandemic and simultaneously the necessity to tackle climate change. Against this backdrop, reducing the consumption of fossil fuels with carbon-neutral measures contributes both to the reduction of GHG emissions and to the decoupling of industrial economies from fossil fuel imports, as most of the carbon-neutral renewable energy is produced locally. Multilateral coordination and cooperation can significantly increase the efficiency of implementing such measures.

This study assessed the potential for the reduction of fossil gas consumption in the G7 countries in the short-term (until 2025), specifically focusing on carbon-neutral options and leaving out the substitution of gas with other fossil fuels or environmentally questionable biofuels. By 2025, total annual fossil gas consumption of the G7 economies can be reduced by up to 18 %, or 264 bcm, overshooting Russian pipeline gas exports of 2021 by about 25 %.

The proposed measures focus on sustainable reductions in fossil gas demand and do not include demand contraction induced by increasing gas prices. Fostering thermal retrofitting of buildings, implementation of heat pumps in buildings and industry and accelerated deployment of renewables in electricity generation facilities can reduce the gas demand without the need for environmentally harmful fossil substitutes.

The depicted reductions will require ambitious policies and a coordinated procedure of G7 states to support behavioural change and "green" modernisation in buildings, the industry and power sector. The required attention for G7 members is twofold: Firstly, binding commitments on national sectoral fossil gas consumption reduction targets will, on the one hand, influence expectations on international gas markets with positive effects on future gas prices and, on the other hand, signal the accessibility of fossil gas to the G7 partners for sectors where a fast fuel switch is not possible. Secondly, coordinated technology targets (RES development and heat pump installation) will positively influence market penetration of such technologies. Coordination among seven of the largest democratic economies, will, on the one hand, allow for benefits due to price decreases from learning effects (e.g., for heat pumps) and, on the other hand, help to avoid global production capacity constraints (e.g., for wind and solar PV facilities). Furthermore, coordination in global gas imports and exports (e.g., via LNG) in the short term will help all those G7 states (and other EU countries) that will be affected by reducing gas imports from Russia. Therewith, stronger affected countries could detain from devolving new gas delivery agreements or development of own production. This avoids the lock-in effects that would undermine the 1.5 °C target.

It should also be noted that the measures proposed here assume no imminent disruptions in fossil gas supply. In the case of an interruption, significantly greater savings would be necessary and certainly possible, if efforts are increased. However, this extreme situation will eliminate the question of what environmentally friendly and socially bearable fossil gas savings can be made. Instead, it would put to the forefront the question of where and how the savings are made to distribute the constrained supply with least losses and in the most equitable manner.

The policies to promote "green" reductions in fossil gas consumption should not only include direct stimuli for reducing fossil gas consumption, increasing energy efficiency and switching to renewable energy sources, but also support capacity expansions in the related markets that can put constraints on the transition speed, e.g., production of heat pumps, waste management or supply of trained workforce for implementing the modernisation measures.

Finally, the policies to promote a fast reduction in fossil gas consumption should take into account the existing trade-offs with other socioeconomic goals. For example, from the environmental perspective, all energy subsidies must be removed as soon as possible. From the economic perspective, this would fuel the already high inflation and may further slow down the recovery from the recession caused by the pandemic. Moreover, the existing disruptions in global supply chains put further constraints on the action space. These issues need to be addressed when specific policy measures are designed.

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