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Sustainability & Climate

Natural gas demand outlook to 2050

MAKING AN IMPACT THAT MATTERS since 1845

Summary for Policymakers

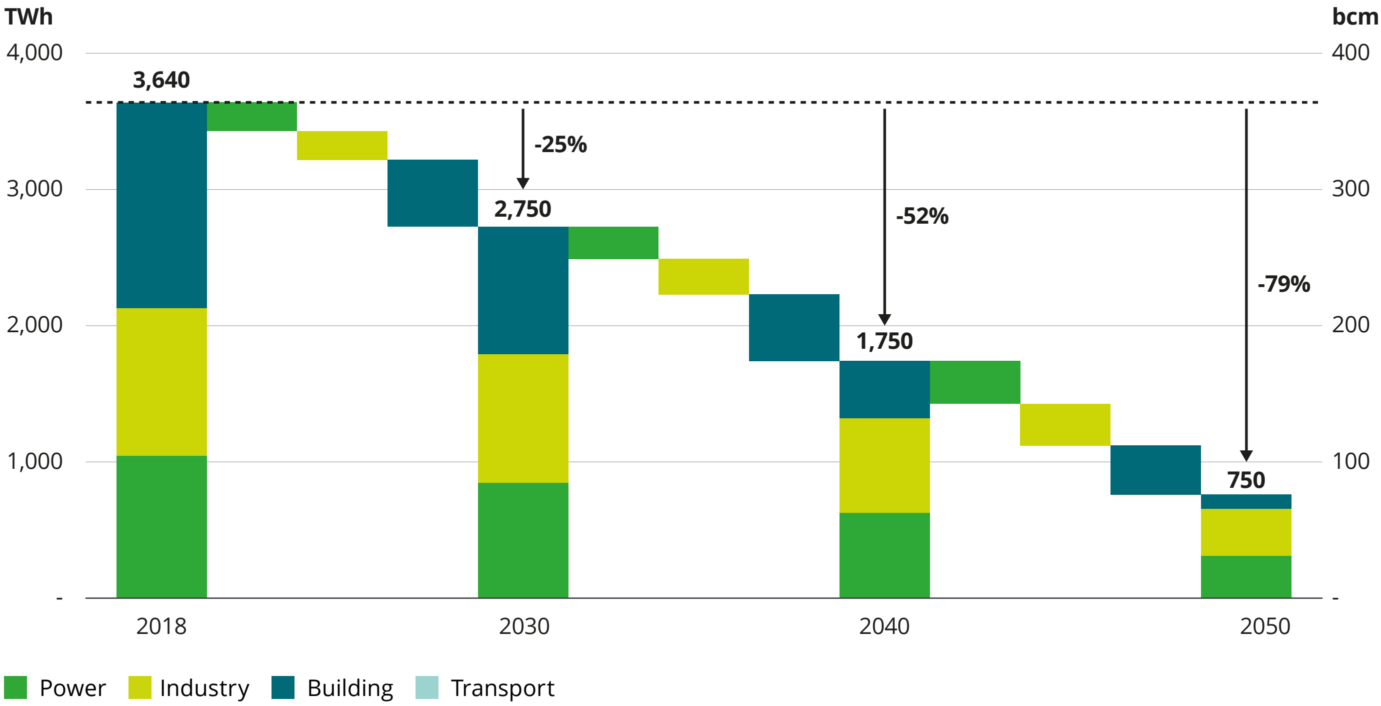
Natural gas constitutes a major component of the global energy system. This industry is facing fundamental challenges as part of the transition towards carbon neutrality. In 2020, natural gas accounted for about a quarter of the total primary energy supply at the global level, in the European Union (EU) and in Germany. Until recently, the supply mix of the EU was largely reliant on Russia, which supplied 45% of EU's imports and approx. 40% of its total gas consumption in 2021. However, reducing greenhouse gas emissions, including from natural gas, is now at the top of political agendas for many countries around the world, with both Germany and the EU aiming to achieve net zero by 2045 and 2050, respectively.

Sparked by the Russian attack on Ukraine and the subsequent geopolitical upheaval, global energy markets have undergone a significant shift, particularly in Europe and Asia. Russia wielded its natural gas exports as an economic weapon against Europe, further accelerating the long-term phase-down of natural gas in the EU in the context of the energy transition. An unprecedented energy price hike triggered an inflationary shock, inciting economic turmoil and market tightness in countries particularly reliant on Russian gas, like Germany. Against this backdrop, the EU launched in May 2022 the REPowerEU plan, a wide-ranging policy response to save energy, to secure and diversify supplies (including by increasing the shipments of Liquefied Natural Gas, hereafter LNG), and to accelerate the clean energy transition.

These geopolitical tensions, together with serious security of supply concerns, raise numerous questions about the future of natural gas. The question of whether, when, and how Russian natural gas supplies could return to global markets adds to the uncertainty. Some governments have started to consider the option of (re)engaging public support for new natural gas projects, despite previous commitments to end international public financing of unabated fossil fuel projects made at COP26 in 2021. A clear vision of the outlook for natural gas demand is the basis for a robust assessment of supply needs and the potential implications for new gas exploration and production projects.

Leveraging a data-driven and model-based quantitative analysis, the study shows a significant decrease in future natural gas demand in the EU and Germany in the period to 2050. We rely on a scenario-based approach, in which EU member states deliver on their climate commitments. We do not impose phase-down constraints for natural gas, but adopt instead consensus assumptions on core drivers of demand. Compared with 2018 levels (taken as the reference year), the reduction in projected demand amounts to more than a quarter by 2030 in both the EU and Germany. By 2040, the reduction is in the range of one-half in the EU (see Figure SPM-1) to two-thirds in Germany (see Figure SPM-2). By 2050, natural gas consumption represents only about 4% of total primary energy demand in the EU and about 1% in Germany. The phase-out is faster in Germany, which is leveraging greater economic prosperity into higher climate ambition, with a binding target of reaching net-zero emissions by 2045, underpinning a fair and just energy transition in the EU.

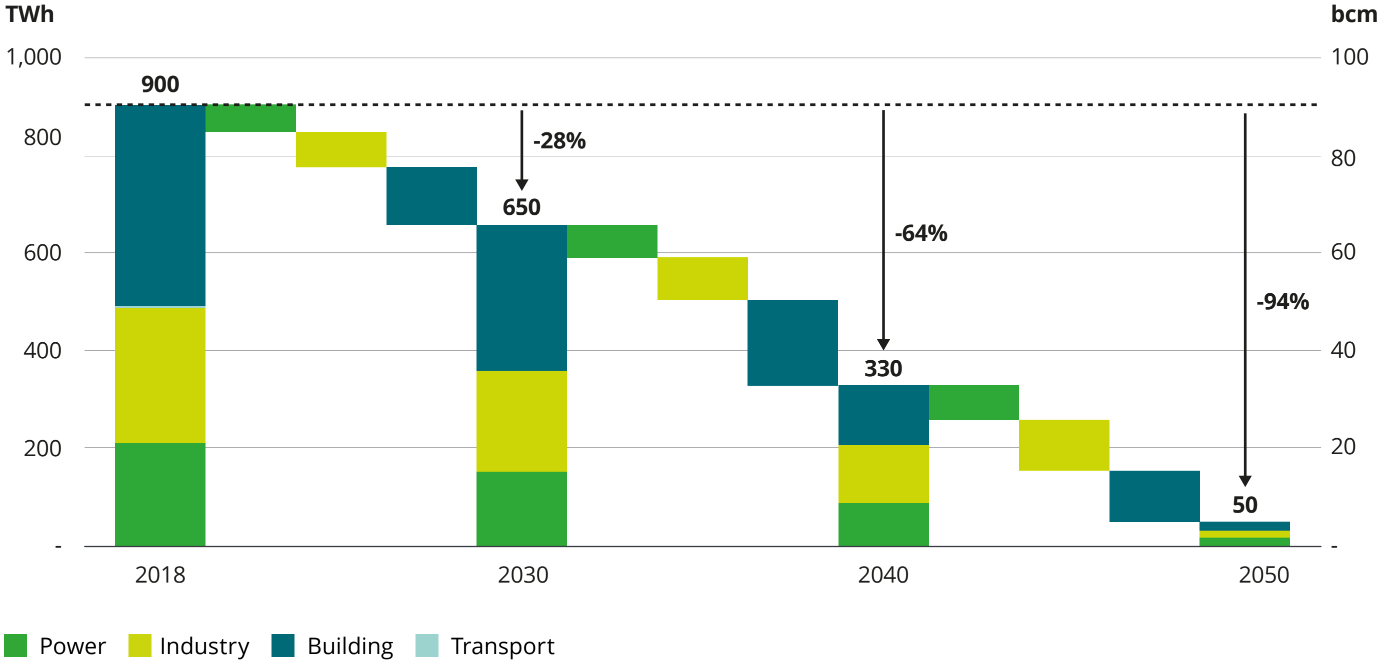
Fig. SPM-1 – Natural gas consumption in the EU, 2018–2050



Source: Deloitte analysis based on the DARE model. Reference year 2018 is based on data from Eurostat 2023a.

This outlook shows a decrease in natural gas demand in all sectors. Fallings costs of clean technologies, increasing carbon prices, and the extensive use of renewable energy sources in the power system make the transition away from fossil fuels increasingly viable. The building sector (residential, tertiary, and district heating) contributes the most to the decrease by 2030, leveraging abatement options such as thermal retrofits and heat pumps. By 2050, natural gas plays only a marginal role in buildings, mostly in district heating. Decarbonization efforts gain momentum in the power sector, with an almost full phase-out of coal from EU electricity generation by the end of this decade. Natural gas use significantly declines in industry from 2030 onwards, prompted by growing access to low carbon electricity, the dawn of the clean hydrogen market, and the deployment of biomass-based heat production.

Fig. SPM-2 – Natural gas consumption in Germany, 2018–2050



Source: Deloitte analysis based on the DARE model. Reference year 2018 is based on data from Eurostat (2023a) and AG Energiebilanzen (2023a).

A benchmarking analysis of a dozen of recent energy outlooks confirms a consensus on declining demand for natural gas in Germany and the EU by mid-century. These studies cover scenarios with varying views on the future of energy systems, as well as the macroeconomic and climate policy contexts and technological assumptions. In Germany, all reviewed scenarios show a drastic decrease in natural gas demand from 2030 onwards. At the EU level, the reviewed scenarios with high climate ambition show a significant decrease in natural gas consumption by 2050. Our trajectories fall within the range of these studies.

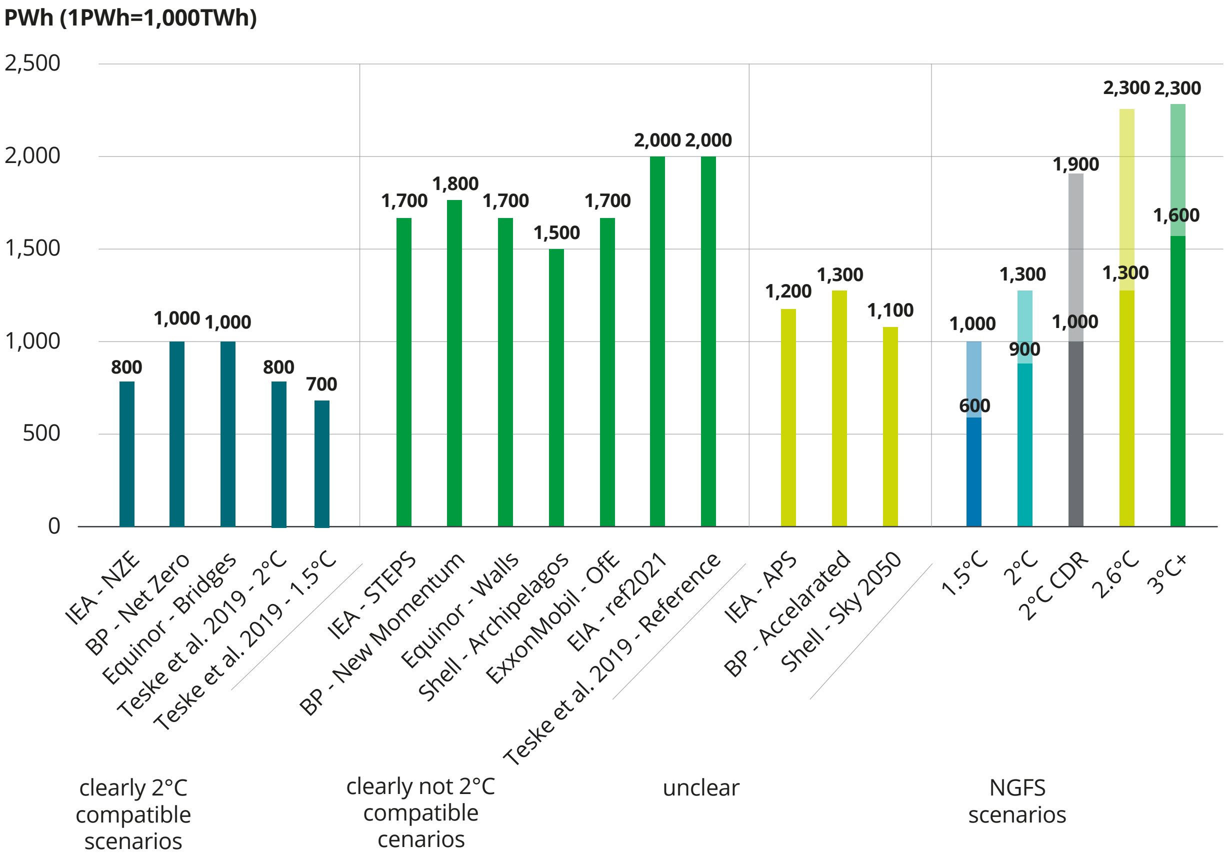
A review of more than 30 recent energy system projections on a global scale reveals that natural gas is also losing momentum in the global energy system on the pathway towards climate neutrality. In almost all scenarios compatible with keeping global warming below 2°C, the share of natural gas in the energy mix significantly decreases up to 2050 relative to 2020, with a demonstrable shift towards carbon-free energy carriers. This pattern is robust against a broad range of surveyed scenarios which rely on various assumptions about macroeconomic prospects, the availability and costs of new technologies, and the level of climate ambition.

Behind this trend of globally declining natural gas demand, different patterns emerge across regions. Pathways compatible with limiting global warming to 1.5°C show democratic industrialized countries reducing their natural gas consumption by 20% to 40% by 2030 compared with 2020 levels, followed by a strong phase-down by mid-century. By 2050, natural gas demand in these countries is between 7% and one-third of 2020 level. For the rest of the world, natural gas demand under these 1.5°C pathways broadly stabilizes at current levels before significantly decreasing from 2030 onwards, reaching a 40% to 50% drop in 2050 compared with today's demand.

The early and extensive deployment of carbon removal solutions to delay the phase-down of natural gas while meeting climate targets appears highly uncertain. Carbon Capture and Storage (CCS) solutions can certainly play an important role in achieving the energy transition in the long term (for instance, to reduce the environmental footprint of hard-to-abate activities, to supply carbon feedstock to the chemical industry, or to offset residual emissions). However, despite efforts over the past ten years, there is little reason to believe that a major political, economic, or technological breakthrough is imminent. Hence, CCS technologies do not seem sufficiently mature to be deployed within this decade on a scale that could enable the use of natural gas to be extended while complying with climate commitments.

Current proven natural gas reserves are sufficient to meet global projected demand in the mainstream scenarios that are consistent with the Paris Agreement. At the global level, current reserves (excluding new discoveries) are at least twice as high as cumulative global natural gas consumption by 2050 under trajectories consistent with keeping global warming under a 1.5°C pathway.

Fig. SPM-3 – Cumulative primary energy supply from natural gas from various global scenarios, 2020–2050



Source: Oeko-Institut analysis based on Global-ScenSe-DB.

If all reserves were to be completely burned and the resulting CO_2 released into the atmosphere, this alone would most likely result in an increase in the global mean temperature of 1.5°C or more above preindustrial levels. The analyses show that the global use of natural gas must be limited to less than 1,000,000TWh in the period 2020 to 2050 if the global average temperature increase is to be kept to well below 2°C (see Figure SPM-3). All exploration, production, export and import infrastructure projects should be aligned with this limit to avoid further climate impacts, lock-in effects, and stranded assets on a large scale.

The high geographic concentration of natural gas reserves in a few countries poses security of supply challenges for importers, including the EU. Except for Russia, Algeria, and Norway, none of the top 10 reserve and production countries is within significant pipeline reach of Germany and the EU. Due to supply constraints in Norway and North Africa (already connected via pipeline to the EU), in the short term, additional imports can thus only arise through the LNG route. The LNG market is dominated by three suppliers: the US, Qatar, and Australia (with global market shares of approx. 20% each). Despite political interest in improving the diversification of supply, concentration of the LNG market can hardly be reduced quickly in view of the location of reserves and the infrastructure constraints.

New investment decisions in new natural gas production projects located outside the EU and targeting the German and the EU market raise several risks.

- **Against the backdrop of declining global demand, there is a risk that new investments end up stranded.** As demonstrated by our detailed modelling of the European energy system, deep cuts in the consumption of natural gas are inevitable in the context of a speedy energy transition. The consensus established in the literature clearly indicates that, to meet climate targets, many consuming regions (including China) may have already reached peak consumption, or are likely to do so in the next 10 to 15 years, before they enter into a phase of significant demand reduction. With an operational life that typically spans several decades, new exploration and production projects barely comply with the Paris Agreement targets. As such, there is a major risk that such investments, especially if primarily aimed at exporting natural gas, end up stranded. This applies particularly to new or small-scale producing regions (especially in Africa), where the production and shipping infrastructure need to be created from scratch or greatly expanded. This, in turn, raises the broader question of how to foster growth opportunities in developing and emerging markets to ensure a fair global energy transition.

- **Beyond short-term investments to compensate for the loss of Russian gas, the contribution of new production and export projects to improve German and EU energy security and diversification appears limited.** Given the capacity constraints of existing infrastructure and high concentration of natural gas reserves, such projects would only marginally diversify supply at least in the short term. Furthermore, the sharp decline in demand envisaged by numerous outlooks is expected to reduce security of supply concerns and political pressure for diversification in the medium and long term.

- **Government support from EU countries would raise questions about consistency with climate and development goals.** It would blur the strong commitments made by EU countries to promote the global energy transition. It could also encourage beneficiary countries to embark on a development trajectory that would be either unsustainable or incompatible with curbing global emissions.

Notwithstanding these fundamental concerns, our analysis suggests two important implications for any potential policy support from EU countries for new natural gas production and export projects, and for major expansions of existing infrastructure:

- **Factor the risk of stranded assets into project design.** If new investments in natural gas are pursued, they could incorporate ex ante plans, with accountable roadmaps, on how major parts of the facilities can later be repurposed into assets that support a country's energy transition, for example towards clean hydrogen and its derivatives. The adoption of best available technologies should be another prerequisite.

- **Limit lock-in effects by promoting agile business models and high governance standards.** For instance, business models that mainly rely on long-term contracts commit projects to operating over a fixed time horizon, while destination clauses freeze exports to the same destinations. Both gas-producing and gas-buying countries have therefore an incentive to prolong the use of gas-based technologies, even if alternative cleaner and competitive solutions become readily available. To promote flexible business models, governments could refrain from supporting projects based solely on long-term contracts and/or that include destination clauses. Improving governance standards will also be key to ensuring the timely transformation of assets and business models on the road to carbon neutrality. Otherwise, long-term financial and climate risks may outweigh potential medium-term benefits.

1. Introduction

1.1. Context

Natural gas is a major component of the global energy system. This versatile fuel is easy to store, transport (through pipelines or shipped as liquefied natural gas, hereafter LNG) and use. Various applications can be identified as a feedstock (production of chemicals, fertilizers, hydrogen, etc.), to produce heat (in residential and industrial applications), or for power generation. In 2020, it represented about a quarter of the total primary energy supply at the global level, in the European Union (hereafter EU[1]), and in Germany (IEA, 2023a). Until recently, the natural gas supply mix of the EU was largely reliant on Russia, which accounted for 45% of its imports and about 40% of its total gas consumption in 2021 (IEA, 2022a). In Germany, the share of natural gas imported from Russia reached 55% of total consumption in 2021 (BDEW, 2022).

The natural gas industry is facing fundamental changes as part of the global energy transition to carbon neutrality. Greenhouse gas emissions from various economic activities, including the use of natural gas, must drastically decrease over the coming decades to achieve the objectives of the Paris Agreement. Since then, countries around the world have started introducing policy measures and elaborating plans on how they intend to achieve climate neutrality. Climate commitments are especially strong in the EU, many having launched ambitious policies and national targets.

There is an ongoing debate as to whether natural gas can be a transition fuel. The direct CO_2 emissions related to the combustion of natural gas for power generation and for some industrial processes are lower compared to other fossil fuels such as oil and coal.[2] Bottlenecks in the scale-up of renewable energy sources could also prolong the need for natural gas. For instance, industrialized emerging markets may rely on this fuel during their phase-out of coal so as to meet rapidly rising energy demand (BP, 2023a). However, an important argument against natural gas as a transitional fuel are methane leakages, resulting primarily from the extraction and transport stages of the value chain. These methane emissions, which substantially raise the global warming potential of natural gas, must be properly considered to fully assess their impact on global warming.

Global energy markets have recently undergone a significant shift, especially in Europe and Asia, sparked by the Russian attack of Ukraine and the subsequent geopolitical upheaval. In 2022, Russia wielded its natural gas exports as an economic weapon against Europe, by withholding its supply. The resulting unprecedented energy price hike triggered an inflationary shock, inciting economic turmoil and market tightness in countries particularly reliant on Russian gas, such as Germany.

- The ensuing EU political reaction under the REPowerEU plan (2022) aims to reduce dependence on Russian gas well before 2030, including by leveraging the deployment of renewable energy sources. In March 2023, the EU provisionally agreed to raise its binding renewable target for 2030 from 32% to 42.5%, with the ambition to reach 45% (Council of the European Union, 2023a). This would double the existing generation capacities. Complementary interim saving measures were adopted including improving energy efficiency and expanding LNG import infrastructure.

- In Germany, the federal government introduced a €200 billion package in 2022 (German Federal Government, 2022) to protect households and industry by introducing price caps on both electricity and natural gas prices. A revision of the Federal Buildings Energy Act is also underway to phase out oil and gas heating systems in Germany as of 2045.

These geopolitical tensions, together with serious security of supply concerns, raise numerous questions about the future of natural gas. Whether, when and how Russian natural gas supplies could return to global markets adds to the uncertainty. Political advocates stress the need for energy security amidst the high prices faced by consumers and industries, in addition to the general challenges raised by the transition to renewable energy

[1] In the report, EU refers to the 27 countries of the European Union.
[2] In the power sector, for example, the CO_2 intensity of natural gas is 0.483 tCO_2eq/MWh, compared to up to 0.961 tCO_2eq/MWh for coal (IPCC, 2014).

sources. The situation is especially acute in Germany, where authorities had to react rapidly to secure alternative gas suppliers to mitigate the risk of shortage. Discussions are being held at German and EU levels as to the option to (re) engage government support for natural gas exploration projects. Such support would be aimed primarily at easing tensions over security of supply but may also be driven by geopolitical considerations. This is despite previous commitments to end international public financing of unabated fossil fuel projects made at COP26 in 2021.

A clear vision of the outlook for natural gas demand is the basis for a robust assessment of supply needs and the potential implications for new gas exploration and production. This, in turn, raises questions about the adequacy of current natural gas reserves to meet projected demand and to ensure sufficient diversification of suppliers. This study provides such a natural gas demand outlook to 2050 and explores the implications for future projects targeting the German and EU markets.

1.2. Objective and methodology

This study aims to provide a natural gas demand outlook within the framework of the global energy transition and the recent energy market crisis. Through Deloitte's in-house modelling asset, DARE (see Box 1), Öko-Institut's analysis tool for a wide range of global energy scenarios, Global-SenSe-DB (see Appendix 2), a comprehensive analysis of literature and a series of complementary analyses, the study sheds light on the need for new natural gas exploration and production.

The study proceeds as follows:

Chapter 2 provides an overview of the historical trends of natural gas consumption and production in Germany, in the EU and globally. Developments from 1990 to 2022 are documented and analyzed, including the role of natural gas in the energy mix and the associated sectoral and regional consumption patterns.

Chapter 3 describes major energy and climate policies and regulations that have implications on the speed of the energy transition and, accordingly, on the phase-out of fossil fuels, including natural gas.

Chapter 4 develops and describes a demand outlook at the German and EU scale, that leverages DARE, Deloitte's state-of-the-art model of the energy system. We consider a central scenario in which both Germany and the EU succeed in achieving their climate commitments. The chapter also reviews the main energy outlooks to identify the common trends within the literature about projected demand for natural gas at the German and EU scale.

Chapter 5 analyzes the regulatory framework for the forthcoming development of global natural gas demand and explores future price dynamics based on two timeframes: the impact of the recent energy crisis, and an in-depth understanding of the long-term role of natural gas in a decarbonized world.

Chapter 6 undertakes an analysis of energy projections at the global level and for specific world regions, taking in a wide range of scenarios and analyzing the projected trends for selected regions. We also assess the role of natural gas in the global energy transition, including the implementation of technology options such as Carbon Capture and Storage (CCS).

Chapter 7 examines the adequacy between quantities of recoverable natural gas with projected demand in the period to 2050, and the underlying risks and vulnerabilities raised by the location of these reserves.

Chapter 8 examines the relevance of governance indicators for natural gas. It considers tensions between short- and medium-term security of supply, and ambitious climate policy in the medium and long term.

Chapter 9 analyzes the implications of potential political support of natural gas exploration and production activities, considered in terms of technological and geopolitical implications including with regards to climate policies.

Presentation of the DARE model

The DARE (Deloitte Applied Research on Energy) model provides a detailed view of the joint evolution of the main energy-consuming and energy-producing sectors in Europe. It is a bottom-up energy system model, featuring highly detailed and data-driven tool optimizing pathways towards climate neutrality in 2050. The model represents the interconnected energy system of all EU countries, the United Kingdom, Switzerland and Norway, enabling exchanges between the neighboring countries.

The optimization relies on several sets of data and policies:

- Data-driven demand prospects for the products or services of energy consuming activities in different economic sectors (such as cement or paper consumption, residential heating, passenger car travel) are considered as input for the modelling.

- Techno-economic datasets including technology costs and characteristics, resources availability and policy roll-out.

- Political constraints, such as the achievement of carbon neutrality by a certain date.

Based on this input, the DARE model identifies energy demand and determines the cost-efficient mix of technologies to meet this demand, taking into account various economic, technical and environmental constraints. This provides a comprehensive view of the whole energy value chain.

The use of primary energy sources (for instance wind, oil, biomass) is notably shaped by their costs and availability. The model then chooses between different energy and feedstock transformation technologies (including hydroelectric dams, refineries, electrolyzers), as well as between primary and transformed energy carriers (such as electricity or hydrogen).

The power sector is modeled with great spatial and temporal granularity to account for local specificities and national strategies (such as renewable endowment or commissioned projects). The equilibrium between load and generation is computed on an hourly basis while factoring in energy storage options (such as batteries, hydrogen storage, pumped hydro storage), and power interconnections (including batteries).

The endogenously supplied energy carriers then supply the many final uses in buildings, industry and transport. In each sector, various competing technologies are evaluated for each end-use product (such as industrial processes, engine options for each class of vehicle). The model selects an optimal mix of technologies to satisfy final demand at least cost.

Finally, a carbon value chain offers the possibility to capture, store and use (e.g., for e-fuels or chemicals production) carbon from various industrial processes and power plants. Carbon Capture and Storage (CCS) units and Direct-Air-Capture (DAC) are considered, in accordance with the EU regulation on Carbon Capture and Usage (European Commission, 2023a).

2. Historical trends in the natural gas sector

Driven by economic growth, historical and socio-economic factors, the role of natural gas in the global, European and German energy system has undergone a significant dynamic since the 1990s.

2.1 Natural gas consumption and supply in Germany

The natural gas segment of the German energy supply has witnessed considerable dynamics since 1990, often determined by historical and socio-economic developments (see Figure 2-1).[3]

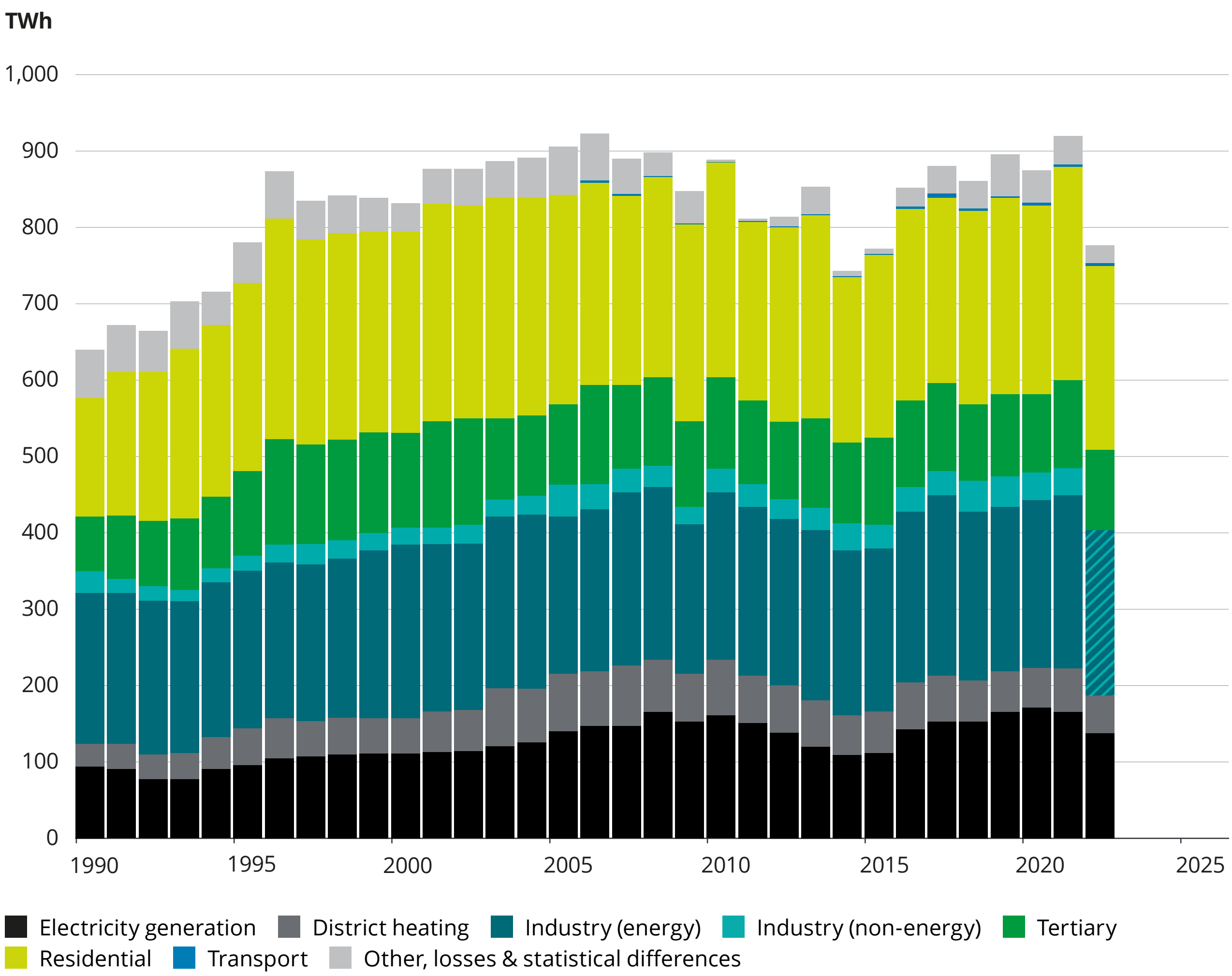
- The years following German reunification in 1990 were initially characterized by the modernization of East German energy industry. From 1990 to 1995, the use of natural gas increased by more than a fifth (22%). It continued to increase until reaching a level of about one-third above the 1990 baseline at the turn of the millennium. By 2005 and despite some fluctuations, natural gas use was approx. 42% above the 1990 level.

- From 2005 onwards, natural gas consumption stagnated, remaining at approx. 40% above the 1990 level, despite growing macroeconomic activity. The only exception was the fall-out from the financial crisis, when natural gas consumption fell in 2009 by about 6% compared with 2008, or by 8 percentage points compared with the starting level in 1990. This is attributed to a very significant decline in the use of natural gas in industry.

- From 2010 onwards a very uneven trend emerges, with consumption levels fluctuating between 16% and 44% above the 1990 baseline. In 2021, natural gas consumption reached its second highest level in German history; only in 2006 was it slightly higher, by 0.5%.

- In 2022, total natural gas consumption fell by around 16% compared with 2021, after Russia partially halted supplies to Germany (this corresponds to a decline of almost 23 percent compared with 1990 consumption levels). By far the largest reduction was within the industrial sectors (one-third of the total decline of gas consumption), while gas consumption for electricity generation, in the district heating sector and in the residential sector also declined but to a lesser extent. A continued decrease in German natural gas consumption is expected in 2023.

Fig. 2-1 – Natural gas demand trends in Germany, 1990–2022



Source: Oeko-Institut analysis based on AG Energiebilanzen (2023a).

[3] All energy-related values reported for natural gas refer the net calorific value (NCV) of natural gas in this study.

In contrast, the sectoral structure of natural gas use in Germany has changed little over time.

- The largest consumption sector is industry, with a share of about 30%. Of this, non-energy use as feedstock in the chemical industry accounts for about 4 percentage points.

- The second largest share, currently also around 30%, is the residential sector, where natural gas is used mainly for space heating, which varies depending on weather conditions.

- The share of electricity generation in total natural gas consumption has increased slightly since 2005, representing an average of 13% between 1990 and 2004. From 2008 to 2022, the share of natural gas in total electricity consumption remains constant at around 18%, excepting small fluctuations.

- The tertiary sector (approx. 13% on average since 1990) and district heating (7%) have smaller, yet overwhelmingly constant, shares. The transport sector accounts for only 0.3% of total natural gas consumption, the highest ever recorded in 2011/2012.

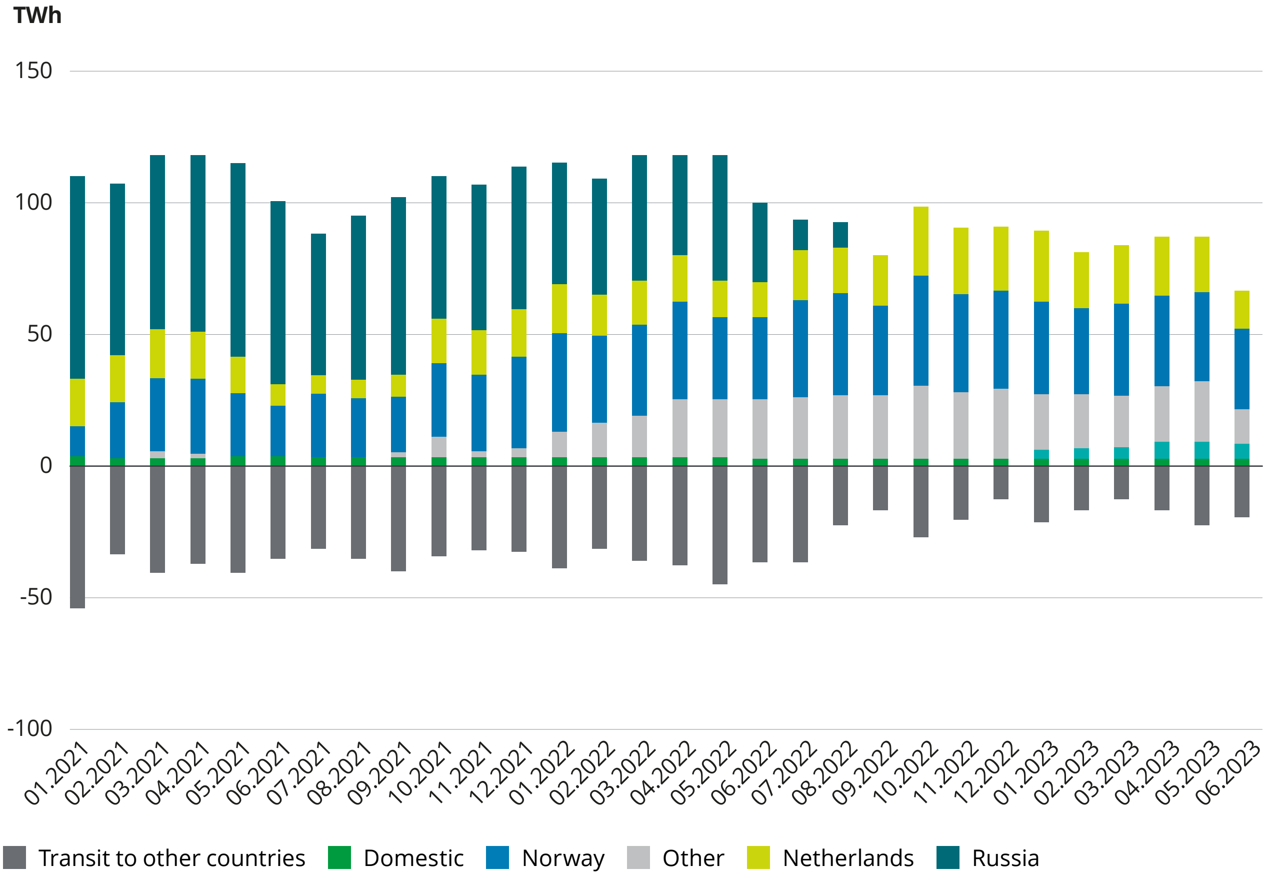
- The largest share of natural gas consumed by final consumers in Germany is therefore used for space heating (approx. 50%), water heating (approx. 10%), and process heat in industry (approx. 36%).

Germany is not only a major importer of natural gas, but also an important hub for European natural gas supply. Figure 2-2 shows this, using the monthly natural gas balance since 2021:

- Of a total volume of domestic production and imports of 1,300TWh (Net Calorific Value), more than 400TWh were re-exported to neighboring countries in 2021; i.e., re-exports came to more than 30%. Monthly re-exports remained at about the same level as in 2021 (approx. 40TWh) until June 2022, but fell by around 40% after the partial cessation of supplies from Russia since July 2022. Since then, about 20TWh have been exported each month.

- With domestic production accounting for only 4% of total supply, natural gas imports from Russia (60% of supply), Norway (23%), and the Netherlands (13%) dominated in 2021. Monthly imports from Norway and the Netherlands have each increased by more than 40% since 2022, resulting in supply shares from Norway (41%, or just under 110TWh) and the Netherlands (24%, or just over 60TWh) in Q2 2023. In order to meet the slightly declining consumption with sharply reduced re-exports, imports from neighboring Western European countries increased from virtually zero to a supply share of 23% in Q2 2023 (60TWh). With the first LNG terminals having been commissioned in Germany, natural gas delivered by ship now also contributes 20TWh (or 8% of the total in the second quarter of 2023).

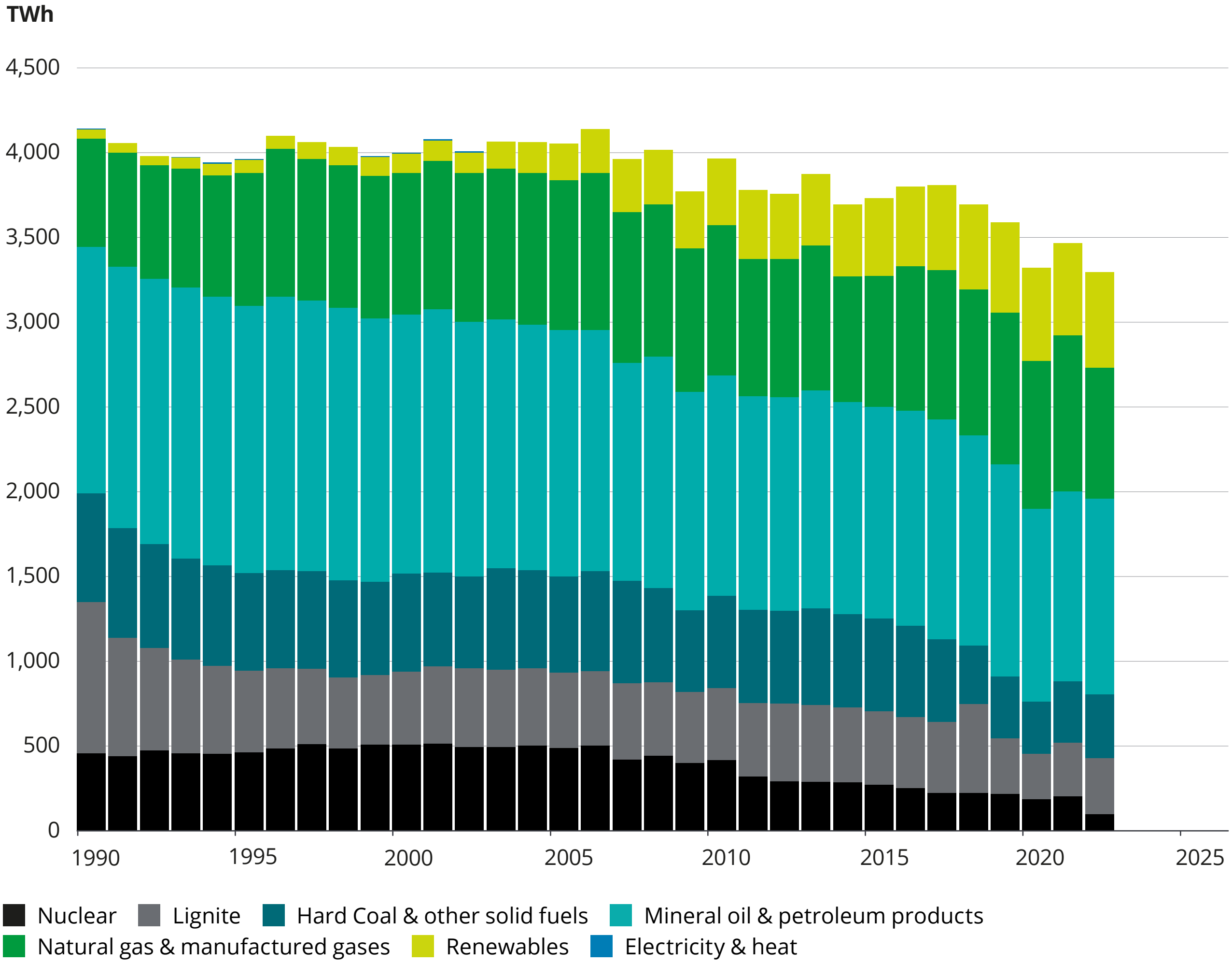
Fig. 2-2 – Natural gas supply for Germany, 2021–2023



Source: Oeko-Institut analysis based on BDEW (2023a).

With primary energy consumption[4] remaining largely constant from 1990 to 2005 and then declining by around 20% to 2022, the share of natural gas in primary energy consumption increased from around 15% in 1990 to just over 20% at the turn of the millennium, reaching a pinnacle of 27% in 2021, before falling back to 24% in 2022 (see Figure 2-3). The significant decline in the share of coal, oil, and nuclear energy in total primary energy supply between 1990 and 2022 (23% in total) is thus offset by the increase in the share of natural gas (one-third) and the increase in the share of renewables (two-thirds).

Fig. 2-3 – Primary energy consumption for Germany, 1990–2022



Source: Oeko-Institut analysis based on AG Energiebilanzen (2023b).

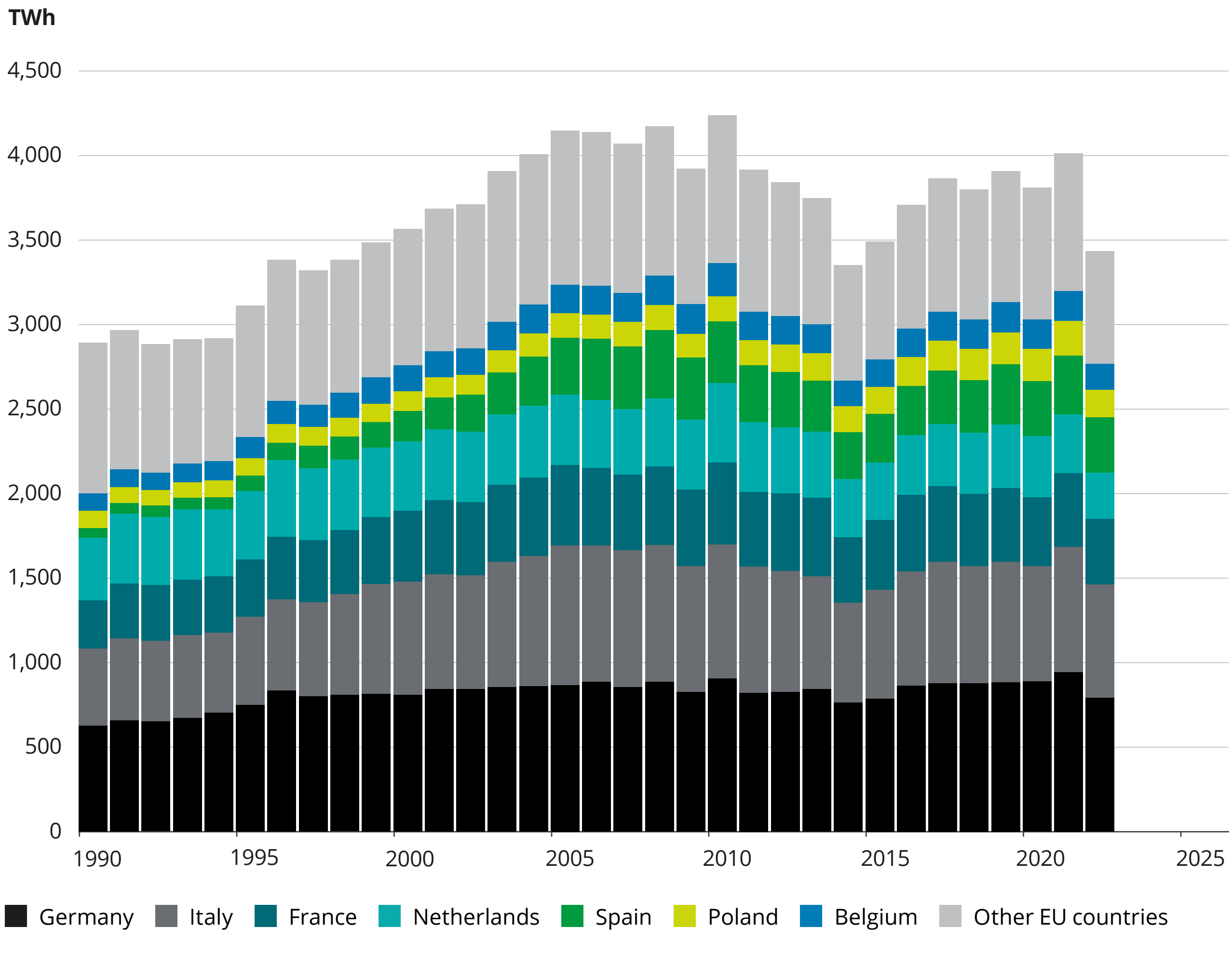
[4] It should be noted, however, that the energy-statistical evaluation of the contributions of wind and solar energy to the primary energy supply leads to distortions, and that part of the decline is not due to increased energy efficiency of the overall system, but to energy-statistical artefacts.

2.2 Natural gas consumption and supply in the EU

Figure 2-4 shows the evolution of natural gas consumption in the 27 countries that currently make up the EU.

- Total natural gas consumption in the EU increased by just over 20% between 1990 and 2000, with varying trends between the member states. While natural gas consumption in Spain increased threefold and growth in Belgium (+63%), France (+45%), Italy (+48%), and Germany (+29%) was well above average, increases in countries such as Poland (+13%), the Netherlands (+11%) and the sum of all other countries (-10%) remained below the average growth in consumption in the EU.
- The two decades after 2000 were characterized by a slight increase in natural gas consumption, which varied between 16% and 47% (when compared with 1990, with an average of 34%). The already relatively high levels of consumption in France, Italy, Belgium, and Germany increased only slightly. Gas consumption increased significantly in Spain (up to 500% compared with 1990) and now also in Poland (by 100%) after the turn of the millennium. There is a slight decrease in the Netherlands (returning to 1990 levels), although very little change in the other member states.
- In 2022, there was a significant reduction in natural gas consumption in most countries, ranging from 10% to 20% compared with 2021. Among the large gas-consuming countries, only Spain is an exception with a decrease of only 4%. For the EU, demand falls by just under 15%.
- Ultimately, the last three decades of natural gas use in the EU have been the result of very different consumption trends in the large member states, with the development in the Central and Eastern European countries being of particular importance. In Central and Eastern European member states, which were heavily dependent on coal at the beginning of the transition, gas consumption increased significantly (Czechia +49%, Poland +100%), while in countries with relatively high gas consumption before 1990, gas demand fell sharply as a result of economic adjustment processes (Lithuania -59%, Bulgaria -49%).

Fig. 2-4 – Natural gas demand trends in the EU by country, 1990–2022

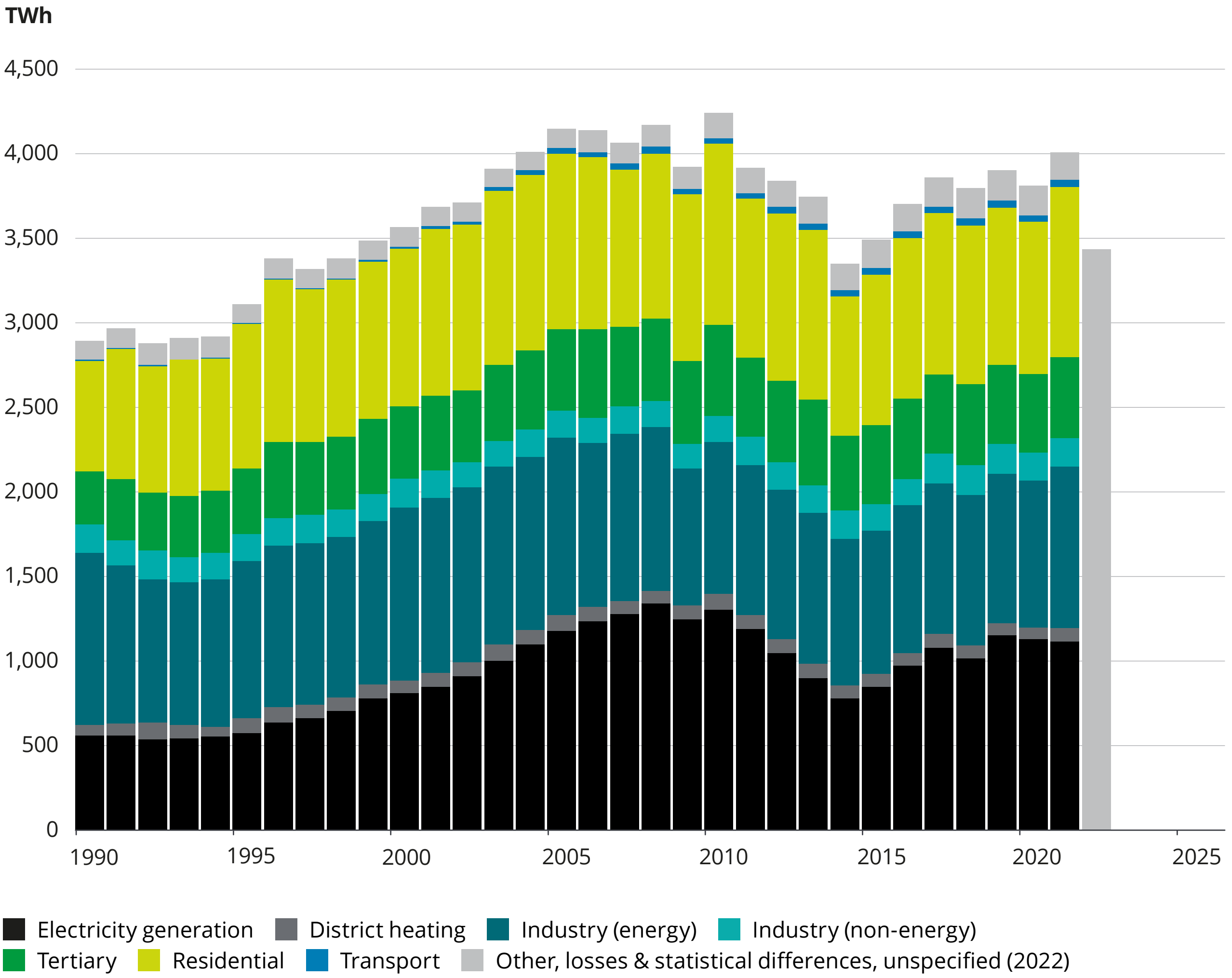


Source: Oeko-Institut analysis based on Eurostat (2023a) and Energy Institute (2023).

In terms of sectoral consumption structures, the EU shows much more dynamic development than Germany (see Figure 2-5):

- The share of power generation in total natural gas consumption increased only slightly from the early 1990s to 2000, but in absolute terms, it increased by well over 40%. Until 2010, the demand for natural gas in the power sector increased by 130% compared with 1990, before decreasing slightly. At the beginning of the 2020s, power generation accounted for approx. 30% of EU consumption.
- Natural gas consumption in industry has slightly decreased by about 10% in the EU since 1990, but it is still the second largest consumption sector (28%), with non-energy uses also accounting for approx. 16% of total industrial gas consumption.
- A quarter of total natural gas consumption is used in the residential sector; i.e., mainly to heat buildings. This share has remained almost constant since the beginning of the 1990s, resulting in an increase in consumption of about 40% compared with 1990, with fluctuations due to temperature. A similar trend can be seen in the tertiary sectors, where the share of natural gas in total consumption is approx. 12%, while all other sectors, including district heating and transport, play a marginal role in the EU.

Fig. 2-5 – Natural gas demand trends in the EU by sector, 1990–2022



Source: Öeko-Institut analysis based on Eurostat (2023a) and Energy Institute (2023).

Imports of natural gas to the EU have changed significantly over time, both in terms of levels and countries of origin (see Figure 2-6):

- Between 2000 and 2005, natural gas imports to EU member states increased by about 27%, remaining stable until 2010 before declining slightly. From 2018 to 2021, they increased to 50% above the 2000 level. In 2022, EU natural gas imports fall by around 10 percentage points, to 40% of the 2000 baseline.

- In 2021, imports from Russia constitute by far the largest share for all EU member states. This share was more than 50% at the beginning of the 1990s, falling to just over 40% by 2010 before rising again to approx. 50%. In 2021 and 2022, the share imported from Russia fell to 43% and 25% respectively.

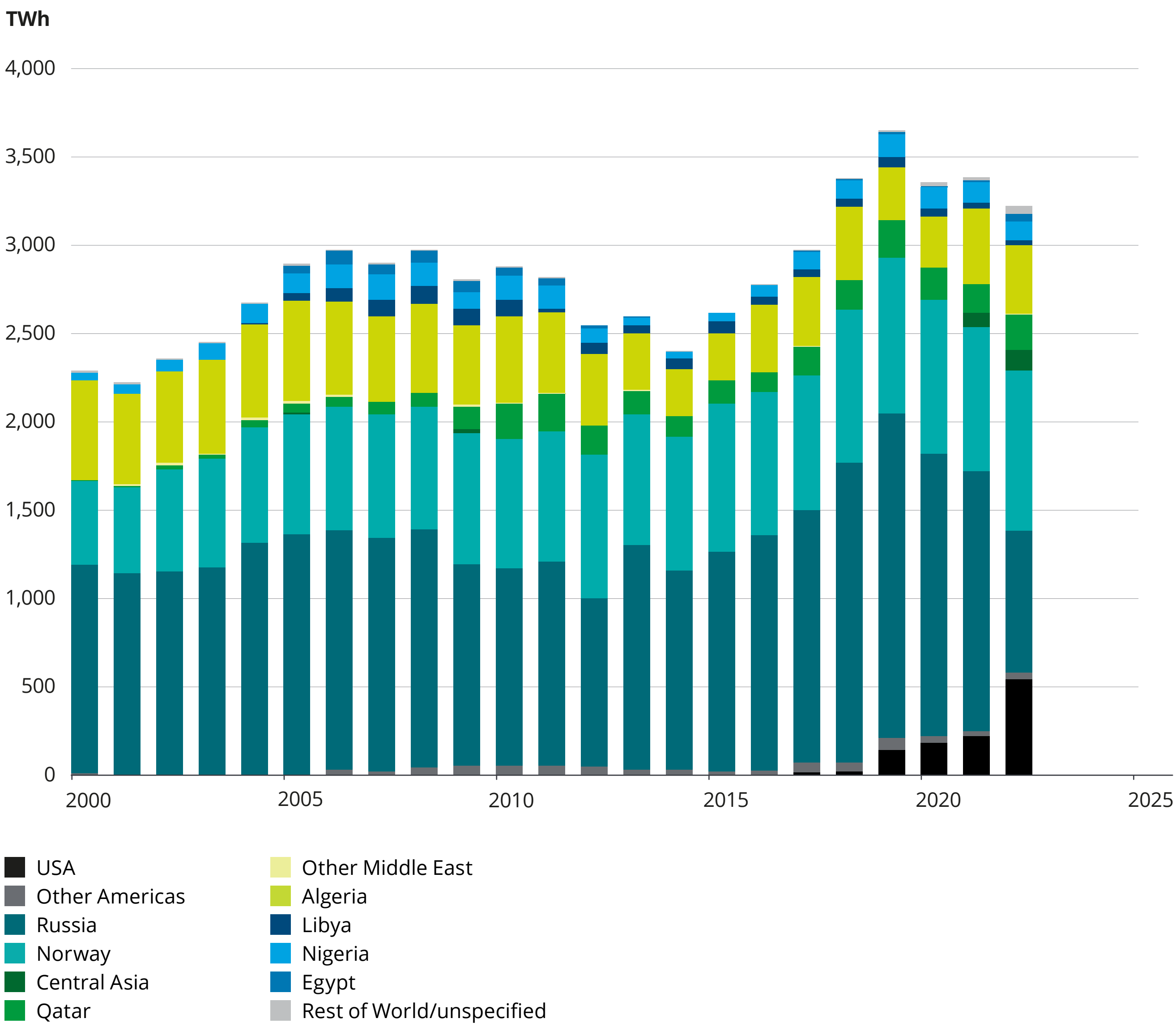
- Since 2002, natural gas imports from Norway have constituted the second largest import share. It increased from 21% in 2000 to approx. 25% from 2005 to 2011, before rising further to a level of approx. 30% in the five subsequent years. After a slight decline (it averaged 25% from 2017 to 2021), it rose significantly to 28% in 2022.

- Algeria accounts for the third largest share of imports in the years since 2000. However, its share in total EU imports has steadily decreased from 25% in 2000 to approx. 12% currently.

- Until 2016, there were no LNG supplies from the US to the EU. In the following years, however, the share of US imports increased relatively quickly, from 7% in 2016 to 17% in 2022, at which point it overtook the contribution of Algerian imports.

- All other import regions (in particular Libya and Nigeria) represent only small shares of natural gas imports.

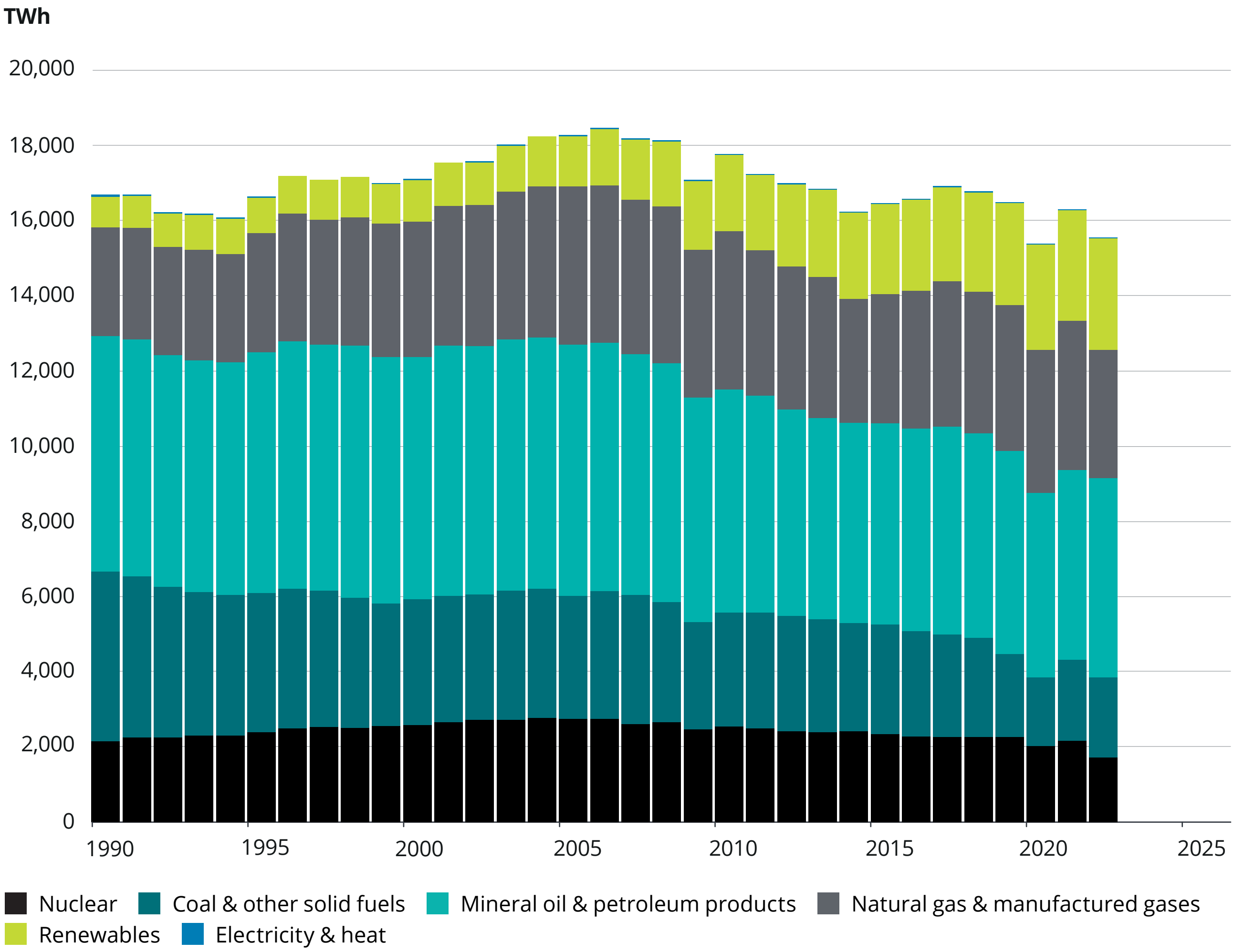
Fig. 2-6 – Imports of natural gas to the EU, 2000–2022



Source: Oeko-Institut analysis based on BP (2022) and Energy Institute (2023).

In the EU, total primary energy consumption remained at about the same level between 1990 and 2000 (see Figure 2-7). After a slight increase of approx. 10% until 2007, it falls back to the 1990 level by 2019. In the crisis years 2020 (global pandemic) and 2022 (Russian attack of Ukraine), primary energy demand is 8% and 7% below the comparable 1990 level, respectively. The share of natural gas in total primary energy consumption rises from just under 20% in the 1990s to 25% in 2020 and then declines slightly (about 22% in 2022). The significant decline in the primary energy shares of coal and oil (amounting to approx. 17% overall) is offset to one-quarter by the increasing share of natural gas, and to three-quarters by the significant increase in the share of renewables.

Fig. 2-7 – Primary energy consumption trends in the EU, 1990–2022



Source: Oeko-Institut analysis based on Eurostat (2023a) and Energy Institute (2023).

2.3 Global natural gas trends
Global natural gas consumption has roughly doubled since 1990. This is the result of very different trends in different world regions (see Figure 2-8):

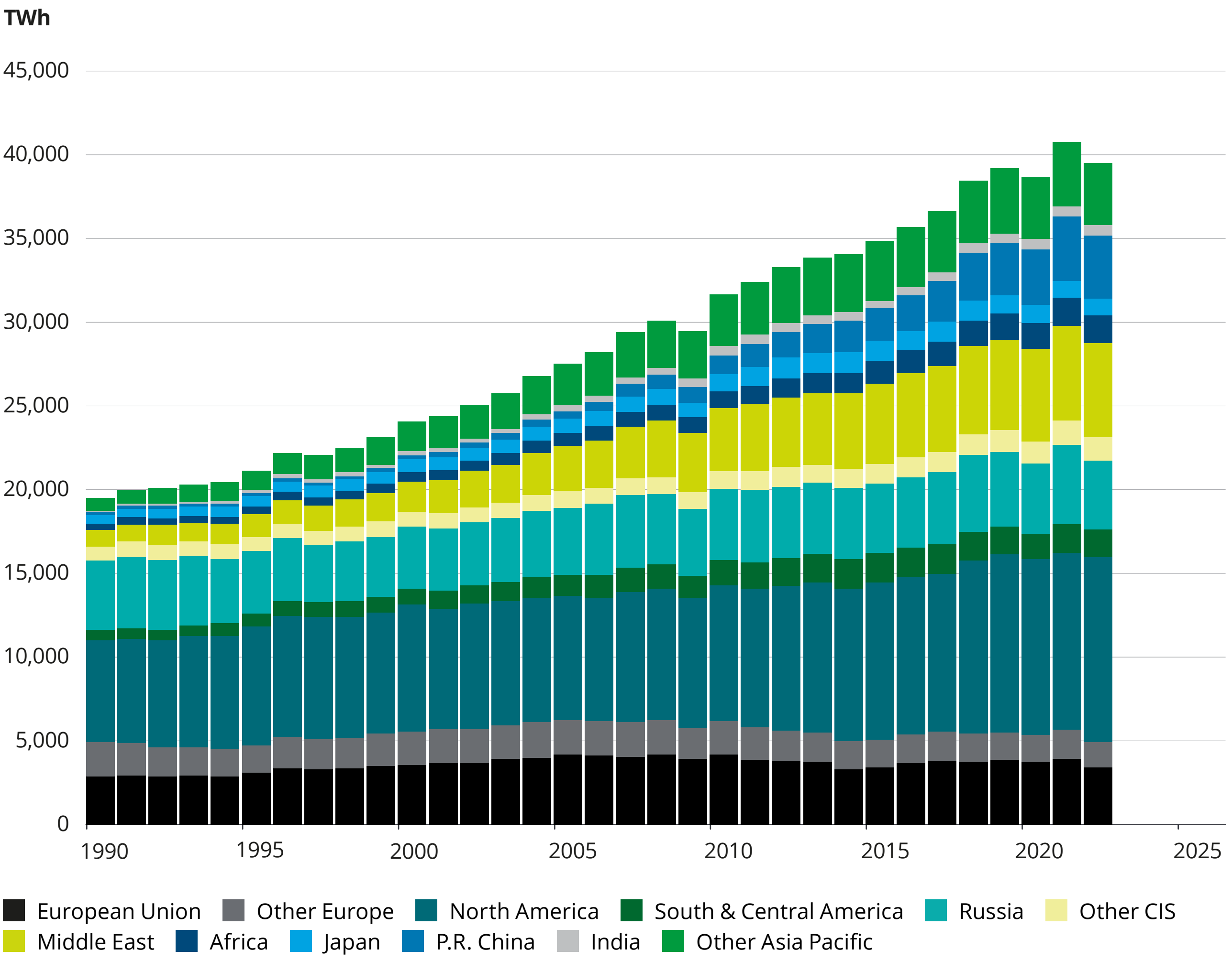
- Comparatively low demand growth during the period 1990 to 2021, with some variations, is seen in the EU (just over 30%) and Russia (+15%). At the start of the 1990s, Russia was the second largest consumer of natural gas (20%) and the EU was the third largest consumer (15%). Both regions saw their shares decrease over the decades, falling to 12% and 10% respectively in 2021.

- In North America, there is an increase of around 70% over the same period. North America thus accounts for more than a quarter of world natural gas consumption, a decline of about 5% compared with the early 1990s.

- In all other regions of the world, natural gas consumption has multiplied. Taking into consideration the low starting value, natural gas consumption increased by more than 100% in Japan, by 180% in Central and South America, by 320% in Africa, by 430% in India, by almost 500% in the Middle East and by 2,350% in China. Nevertheless, only the Middle East (14% in 2021) and China (9%) have shares in global gas consumption similar to those of the EU.

- However, the natural gas crisis in 2022 only resulted in Russia and the EU experiencing a significant decrease in consumption compared with 2021 (with -14% at similar levels). The decline in natural gas demand in the other regions was small (-1% in China, -3% in Africa and Japan, -4% in Central and South America, -7% in India). In the Middle East, natural gas consumption stagnated at 2021 levels, while increasing in North America by around 5%.

Fig. 2-8 – Global natural gas demand trends by region, 1990–2022

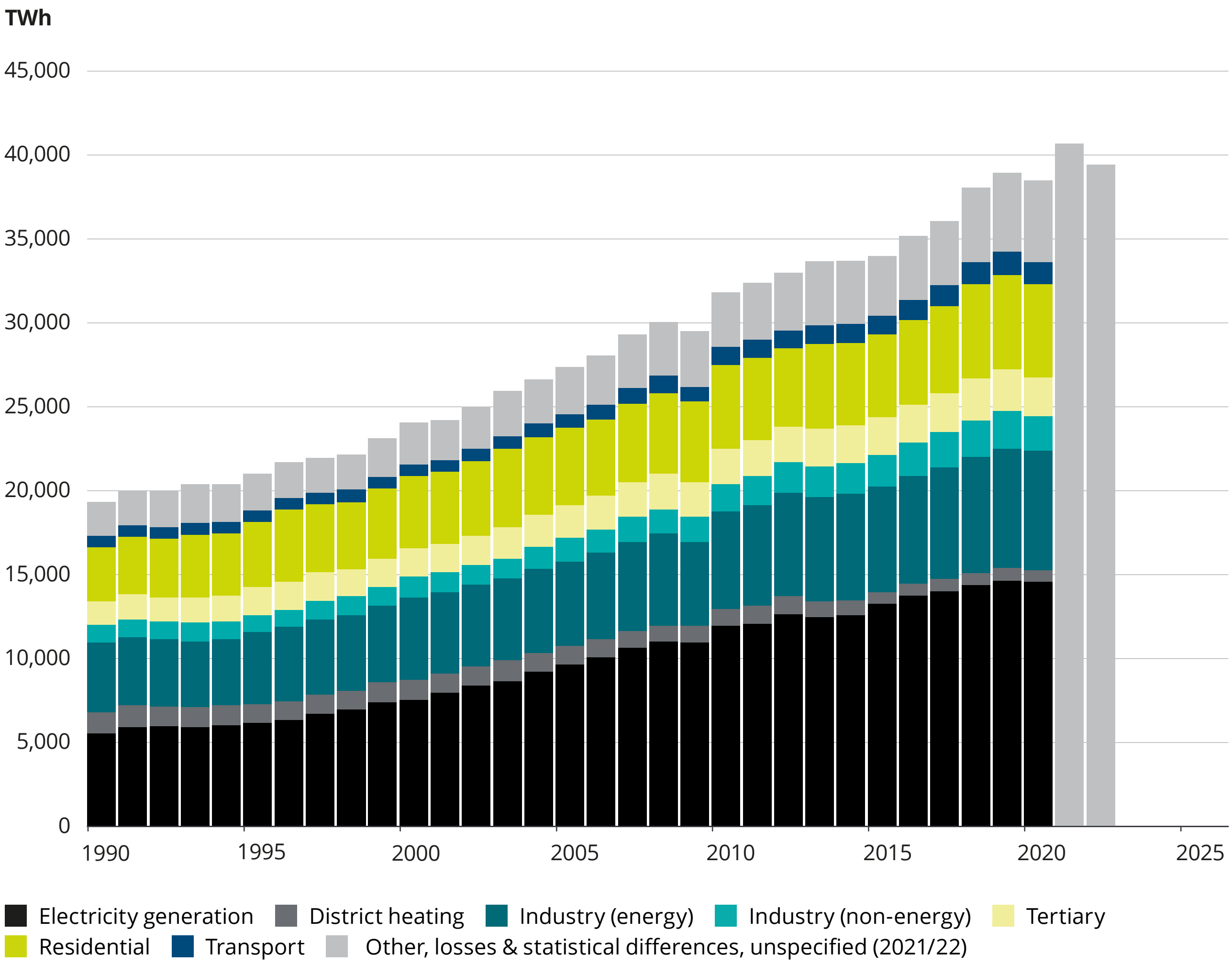


Source: Oeko-Institut analysis based on IEA (2019) and Energy Institute (2023).

Looking at the sectoral structures of natural gas demand (see Figure 2-9), a global perspective reveals the following patterns:

- From 1990 to 2000, the consumption share of electricity generation (with a significant overall increase in natural gas consumption) remained relatively constant at 30%, increasing to about 38% in 2010 and remaining at this level thereafter. Compared with 1990, the global use of natural gas for electricity generation has thus increased by approx. 160%. In contrast to Germany and the EU, the power sector clearly plays a dominant role in the total demand for natural gas at the global level.
- At the global level, industrial demand for natural gas is the second-largest demand segment in the period from 1990 to 2020 (about 25% of demand). However, the growth in demand of the industrial sectors (+75%) is slightly lower than the growth in total natural gas consumption which almost doubled in this period. Non-energy uses account for about one-fifth of global natural gas consumption.
- Household use of natural gas has increased by more than 70% since 1990, but its share of total consumption has fallen slightly (currently approx. 14%).
- Similar trends can be observed in the tertiary sectors, although their share of total gas consumption is less than half that of the residential sector (currently approx. 6%).
- All other sectors play only a minor role in terms of consumption shares and dynamics.

Fig. 2-9 – Global natural gas demand trends by sector, 1990–2022



Source: Oeko-Institut analysis based on IEA (2019) and Energy Institute (2023).

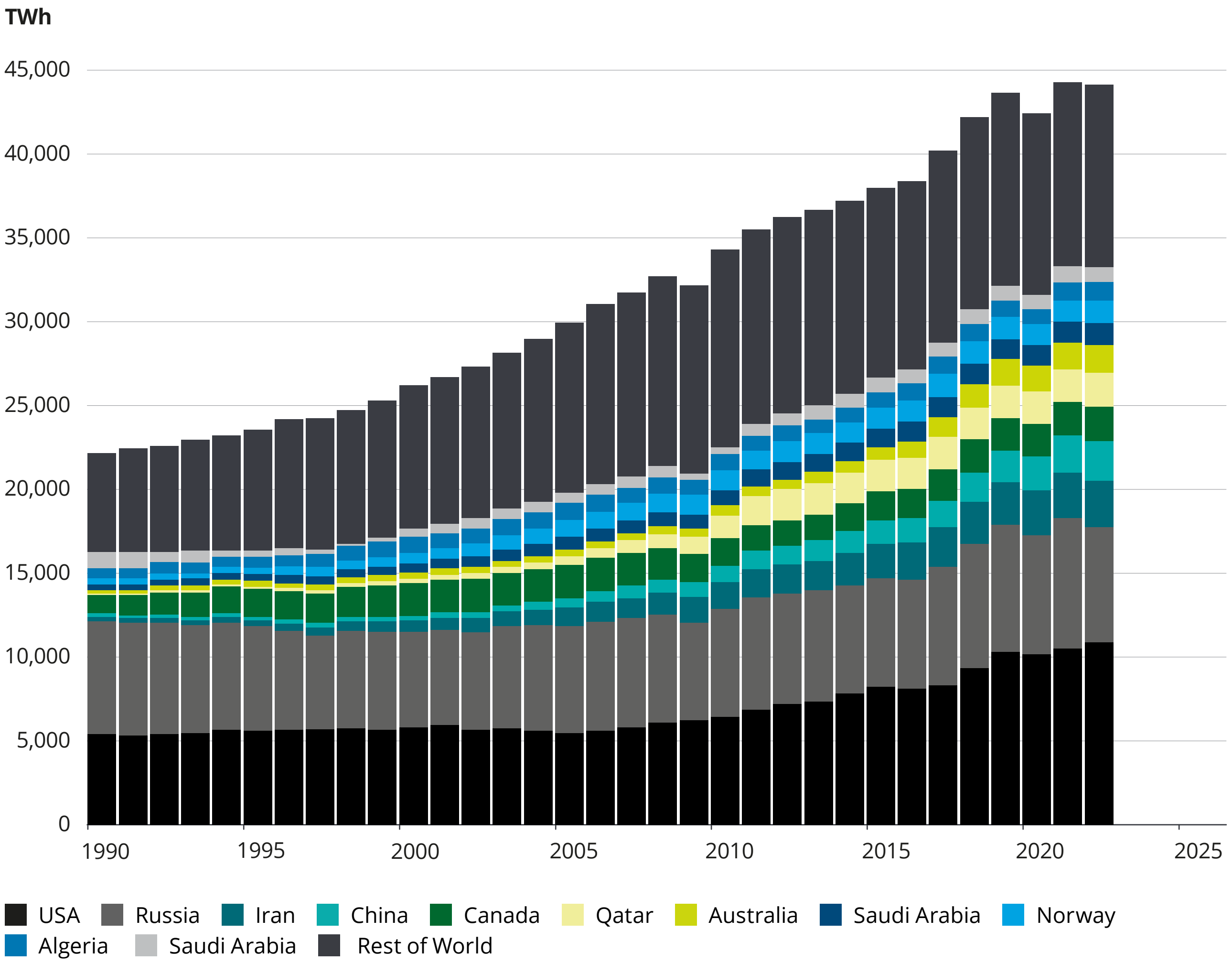
Global natural gas supply is dominated by a select few production countries and regions (see Figure 2-10 and Section 7).

- The US accounts for the largest share of production (20% to 25%) from 2000 to 2022. After a period of only small production increases (until about 2006), gas production in the US increases significantly, doubling to the base level of 1990 in 2022.

- From 1990 to 2000, Russia produced the most gas in the world. In the following decade, production was roughly on a par with the US, after which Russia fell to second place in world gas production. Its share of world gas production fell from 30% in 1990 to 17% in 2021. In 2022, Russian gas production fell by about 12% compared with the previous year.

- Natural gas production in Iran and China has grown tremendously in recent decades. The production shares of both countries, which amounted to 1% in 1990, increased to 6% and 5% respectively by 2022, corresponding to growth by a factor of 10 (Iran) and 14 (China). This puts them at about the same level as Canada, whose production has increased by approx. 70% over the same period. Qatar (+2,650%), Australia (+640%), Norway (+390%), Saudi Arabia (+280%), and Algeria (+90%) continue to show very strong production growth. These countries now account for between 2% and 4% of global gas production.

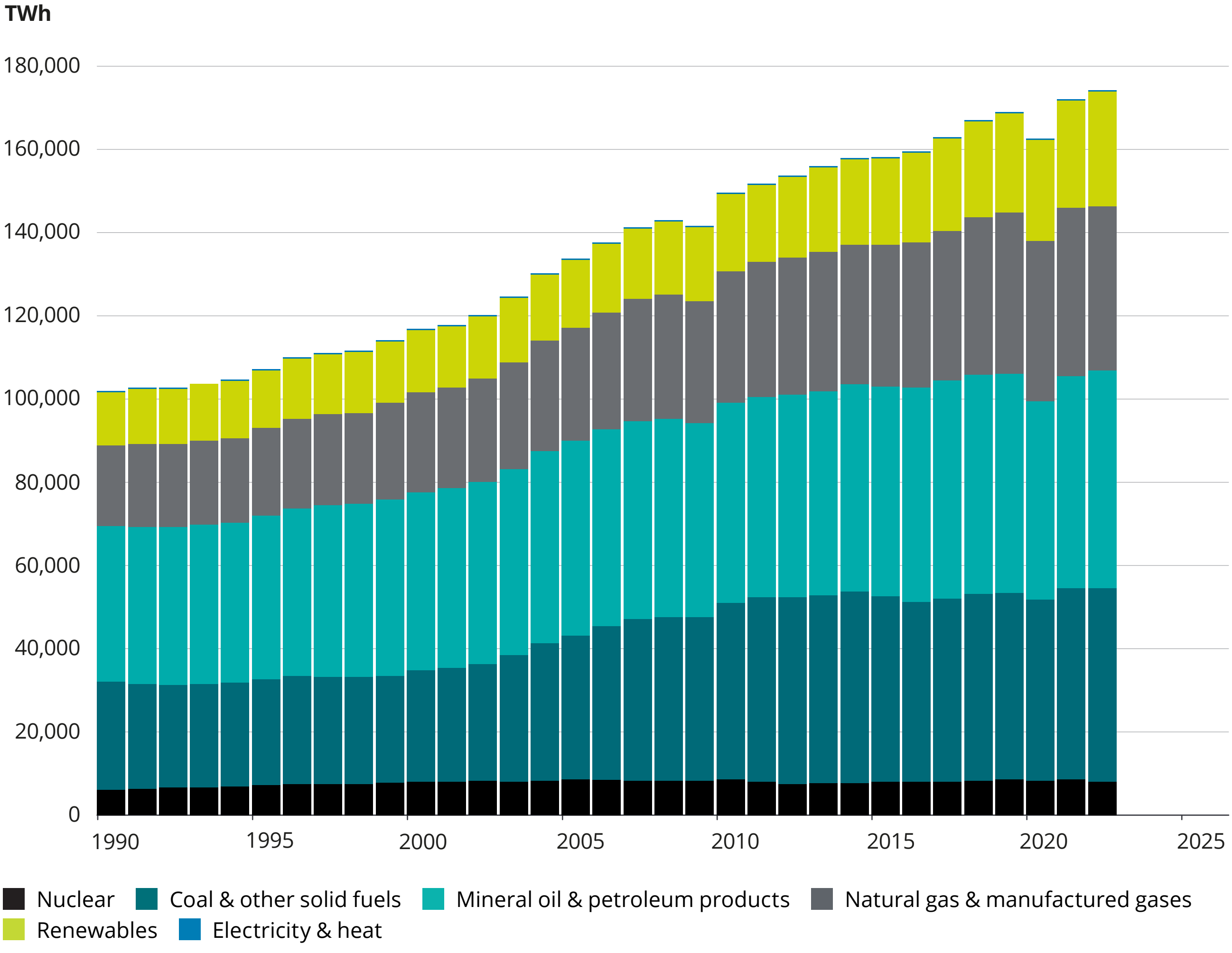
Fig. 2-10 – Global dry natural gas production, 1990–2022



Source: Oeko-Institut analysis based on IEA (2019) and Energy Institute (2023).

World primary energy supply (see Figure 2-11) increased by about 70% from 1990 to 2000. The strongest growth in primary energy supply occurred in the decade after the turn of the century, when consumption growth roughly doubled compared with 1990-2000. After 2010, the increase in total primary energy supply flattened out somewhat, but was only slightly lower than in the previous decade. The share of natural gas in total primary energy supply was approx. 20% from 1990-2010, with slight fluctuations, and then increased to 23%-24%. The significant decline in the global primary energy shares of coal and oil (by approx. 6% combined) was offset by the rising shares of natural gas and renewables, both of which increased by about half.

Fig. 2-11 – Global primary energy supply trends, 1990-2022



Source: Oeko-Institut analysis based on IEA (2019) and Energy Institute (2023).

Key results and takeaways

Natural gas consumption in Germany and the EU has followed a similar pattern since 1990. Demand for natural gas increased significantly until around 2005, followed by a period of considerable fluctuation with an overall slight downward trend.

The trends in both Germany and the EU are mainly driven by gas consumption in industry and buildings (residential and tertiary sectors). Electricity generation plays a much smaller role in gas consumption in Germany than in the EU as a whole.

In recent years, Germany's natural gas supply has become increasingly dependent on Russian imports. Before the Russian attack of Ukraine, import shares reached 60%, with part of the imports from Russia also being passed on to other countries. The EU's gas supply is much more diversified, but here too Russian import shares have reached 40%-50%. Since 2022, gas imports from Russia have plunged.

Shifts in the primary energy supply structures in Germany and the EU were also very similar. The declining shares of coal, oil, and nuclear energy in primary energy supply were offset by higher shares of renewable energy sources and natural gas, with the substitute contributions of renewables clearly dominating in both Germany and the EU.

On the other hand, the development of natural gas consumption at the global level shows growth that is interrupted only by a few (crisis) years, although there have been signs of a plateau forming in recent years. The highest growth rates occurred in China, India, and the Middle East, although these regions only represent the smaller part of global gas consumption, which is still dominated by OECD countries

The use of gas for power generation is the strongest driver worldwide and accounts for the largest share of natural gas consumption. Compared with Germany and Europe, demand from the industry, the tertiary sectors and households play a much smaller role.

Global natural gas is supplied by a relatively small number of major producing countries. These include the US, Russia, Norway, countries in the Middle East, Central Asia, North Africa, and Australia. However, China's gas production has also increased significantly in recent years.

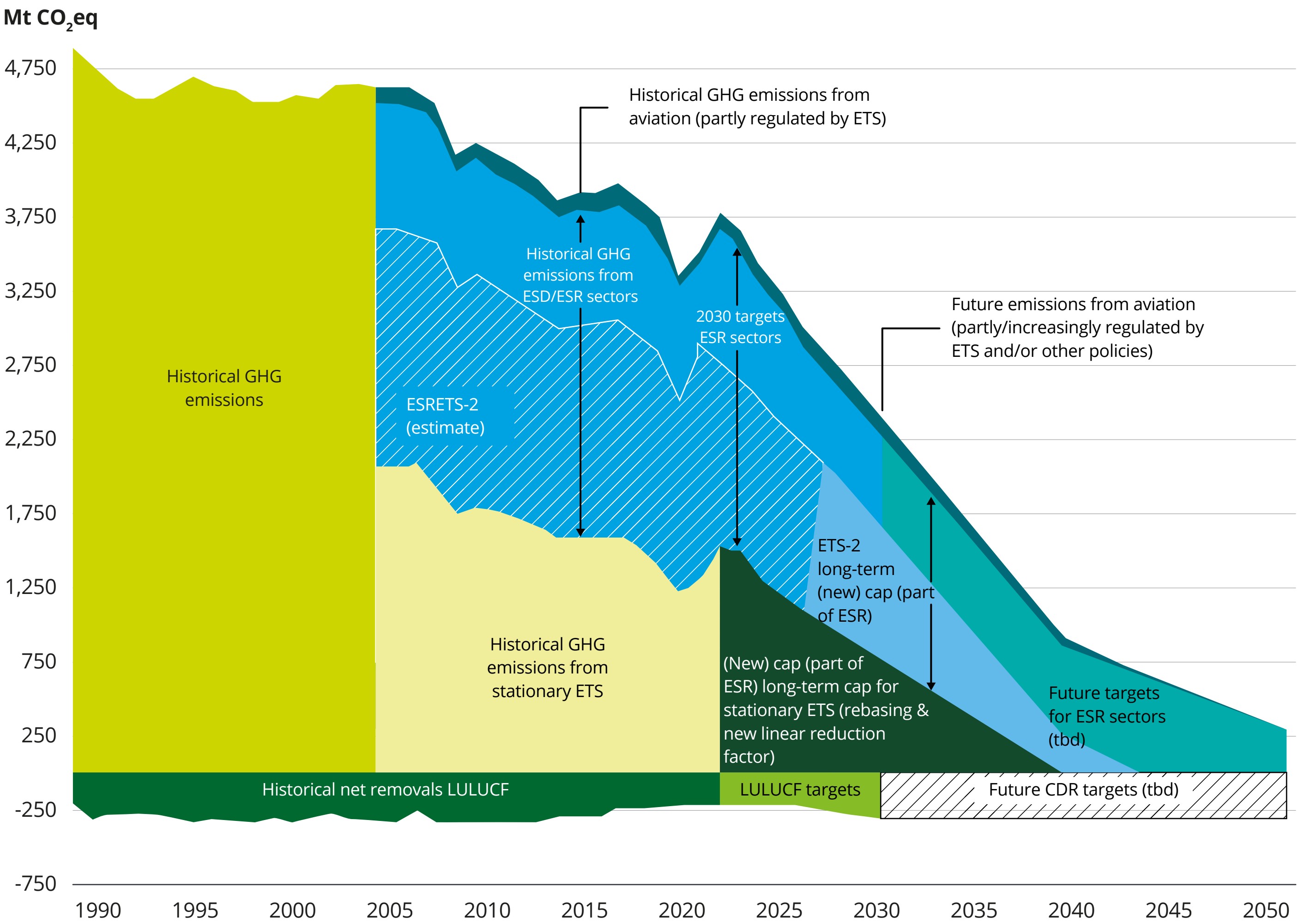
The declining share of coal and oil in world primary energy supply have been replaced by renewables and natural gas in roughly equal proportions since 1990.

3. The political context in the EU and Germany

In the EU and Germany, there is now a clear consensus on the need to phase out fossil fuels, including natural gas, to reduce greenhouse gas emissions and achieve climate neutrality in the long term. Ambitious targets have been implemented substantiated by national strategies, robust monitoring frameworks, and a comprehensive set of policies. Analyzing the policy environments in the EU and Germany allows to depict the speed and technological focus of the contemplated energy transition and, in particular, the future role of natural gas.

3.1. The EU's climate policy framework
In 2019, the EU endorsed a net-zero emissions objective by 2050 (Council of the European Union, 2019). In 2018, about 3.7GtCO_2-equivalent emissions (CO_2eq) of greenhouse gases were emitted in the EU, partly offset by 250MtCO_2eq carbon sink related to land use, land-use change and forestry (LULUCF). Figure 3-1 shows the decarbonization trajectory contemplated by the EU to reach net-zero by 2050. To deliver on this target, the European Commission launched a new growth strategy, the EU Green Deal. Contrary to previous approaches, which were based on isolated measures, the EU Green Deal is a first-of-its-kind holistic strategy to foster the green transition. In 2020, the Fit-for-55 package was initiated to deliver 55% emission reduction by 2030 compared to 1990. Since 2021, these goals have been enshrined in the European Climate Law (Regulation EU 2021/1119).

Fig. 3-1 – Climate policy architecture of the EU



Source: Oeko-Institut analysis based on UNFCCC (2023), EEA (2023a), Official Journal of the European Union (2021), Official Journal of the European Union (2023a).

To curb CO_2 emissions, the EU mainly relies on EU-wide carbon pricing instruments, which are set to expand further. By putting a price on greenhouse gas emissions, carbon pricing plays a fundamental role in the energy transition by weakening the business case for fossil fuels compared to low-carbon alternatives.

- The core historical instrument is the EU ETS, a cap-and-trade mechanism, which includes energy-intensive activities that covered 38% of carbon emissions in 2021 (see Figure 3-1). Introduced in 2005, the EU ETS covers mainly carbon dioxide emissions (and in some cases, nitrous oxide, and perfluorocarbons) from electricity and heat generation and heavy industries, such as iron and steel, cement, chemicals and oil refineries. Since 2012, this mechanism also includes aviation and will be extended to maritime transport activities from 2024 onwards. Under EU ETS, the total amount of greenhouse gas emissions is capped and decreases over time. Within the cap, operators can buy, receive, and trade EU allowances (EUA). Emissions from EU ETS covered activities must be reduced by 62% by 2030, as compared to 2005 (Official Journal of the European Union, 2023a), a more ambitious trajectory compared to the EU's overall 2030 target. Considering the annual reduction rate of available EUAs determined by the regulation currently in force, 2038 may be the last year for issuing EUAs (see Figure 3-1).

- A separate market (EU ETS-2) will be created to cover fuel combustion in road transport, buildings, and small industrial installations as of 2027 (Official Journal of the European Union, 2023a). This introduction may be delayed until 2028 if oil or gas prices are exceptionally high. The ETS-2 cap will be set to achieve 42% emission reductions by 2030 compared to 2005 levels. The regulation provides for several measures in the event of exceptionally high price of certificates. For instance, if the average price of allowances exceeds 45€/tCO_2 for a period of two consecutive months, the Market Stability Reserve shall release up to 20 million additional allowances to alleviate social impacts in terms of energy affordability. By 2030, the EU ETS and ETS-2 could cover approx. 70% of the EU's greenhouse gas emissions (see Figure 3-1).

- As part of the EU Green Deal, the EU ETS will be complemented by a Carbon Border Adjustment Mechanism (CBAM) as of 2026. From this year, this mechanism will set a CO_2 price on imported energy-intensive goods (Official Journal of the European Union, 2023c). It will target specific industrial products such as iron and steel, cement, aluminum, fertilizers, and clean hydrogen produced outside the EU. The CBAM price will mirror the EU ETS price to ensure a level playing field and reduce the risk of relocation of industry (carbon leakage). As a counterpart, the free allocation of ETS allowances will be phased out gradually until reaching zero by 2034.

The EU ETS is complemented by the EU Effort Sharing Regulation (ESR), which stipulates national targets for emission reductions in non-ETS sectors. Road transport, heating of buildings, small industrial installations, agriculture, and waste are currently covered by this framework (about 55% of emissions in 2022, see Figure 3-1), which seeks to reduce emissions by 40% by 2030 (Official Journal of the European Union, 2023b). The ESR provides for a more equitable distribution of climate action: member states with a higher gross domestic product (hereafter GDP) per capita, such as Germany, have stricter emission reduction targets. As described above, by 2030, the current ESR scope will also be partially covered by the ETS-2 market, covering less than a quarter of the EU's emissions by that date.

The EU has adopted a target for net greenhouse gas removals from natural sinks (land use, land use change and forestry sector, LULUCF), amounting to 310MtCO_2eq by 2030 (Official Journal of the European Union, 2023b). To ensure that sufficient mitigation efforts are undertaken, the contribution of net removals from natural sinks to the 2030 climate target is limited to 225MtCO_2eq, approx. 9.4% of EU's emissions by then. The removal of residual emissions from hard-to-abate activities will become increasingly important in the long term, and it is possible that the European Commission will place a greater focus on this in future target-setting (see Figure 3-1). To prepare, the European Commission proposed a draft regulation in December 2022 to establish a Carbon Removals Certification (CDR) framework (2022b). Through this voluntary scheme, CO_2 can be removed and stored in three forms: permanent storage (such as through Direct-Air-Capture and Carbon Capture and Storage); carbon farming (for instance increased capture in soils and forests) and embedment in products (for instance wood-based construction materials).

A series of sectoral measures completes this blueprint and has been bolstered by the REPowerEU plan, with a key impact on natural gas demand:

- Energy efficiency and savings: To sever reliance on Russian gas, REPowerEU relies on demand-side measures (such as the Save Gas for a Safe Winter plan) and bolstered targets, including a recast of the Energy Efficiency Directive (EED) approved in July 2023 (European Parliament and Council auf the European Union, 2023a), setting a 11.7% reduction target in final energy consumption by 2030 compared to 2020. In the residential sector, about 80% of final energy consumption is used for space and water heating, which mostly relies on natural gas. The proposed recast of the Energy Performance of Buildings

Directive (EPBD) aims to improve the energy performance of public buildings, aspiring to zero emissions by 2027, and for new buildings to be zero emission as of 2030, as well as improving the energy performance of the building stock (European Parliament, 2023). The REPowerEU plan also includes a €56 billion investment for energy efficiency measures and heat pumps, aiming to install a further 30 million units by the late 2020s (European Commission, 2022c). This would save 37bcm (approx. 361TWh) of natural gas demand by 2030. With regards to industry, the EU supports the onset of a circular economy. Key regulation drafts include the recast of the Ecodesign for Sustainable Products Regulation (European Commission, 2022d), and the Packaging and Packaging Waste Regulation (European Commission, 2022e), which seeks to decrease the need for fossil feedstock by extending the life of existing materials.

- Clean energy supply: The draft recast of the Renewable Energy Directive (RED) intends to raise the binding share of renewables in gross final energy consumption by 2030 from the current 32% to 42.5%, with the goal of reaching 45% (Council of the European Union, 2023a). This means doubling the existing renewable energy generation capacities, partly to replace fossil-based power plants. The development of clean hydrogen is identified as a key priority. The REPowerEU plan targets the consumption of 20Mt of renewable hydrogen by 2030, while aiming to produce 10Mt domestically (European Commission, 2022a). Moreover, the EU aims to partially replace Russian gas[5] with a notable increase in biomethane production to about 370TWh by 2030, compared to less than 40TWh biomethane and 158TWh biogas produced in 2021 (European Biogas Association, 2022). In a similar vein, the recast of the Urban Wastewater Treatment Directive (European Commission, 2022f) aims to untap potential to produce biogas via sludge digestion, with a preliminary estimate of approx. 16TWh within the EU (European Commission, 2022g).

- Mitigating upstream methane emissions: The proposed Methane Emissions Reduction Regulation (European Commission, 2021a) encourages transparency by imposing mandatory reporting obligations on oil, gas, and coal companies. Rules are established for detecting and repairing methane leakages and sets limits on venting and flaring. It also introduces a global monitoring tool for methane emissions arising from fossil fuel imports to the EU. The EU ETS market will also cover methane emissions from maritime shipping from 2026 onwards. The EU and the US have also supported the Global Methane Pledge, a collective framework in which participating countries voluntarily commit to reducing methane emissions by at least 30% by 2030 over 2020 levels.[6]

[5] More broadly, the REPower EU plan intends to replace Russian imports with the increase of LNG imports from more reliable trade partners (such as US and Norway), a joint gas purchase mechanism and the expansion of electricity and gas interconnections (for instance the Mediterranean Gas Hub and the Southern Gas Corridor).

[6] These measures are consistent with a transitional use of natural gas in a limited number of circumstances and under strict conditions in the EU to achieve the 2030 climate targets, as reflected in the EU taxonomy which is focused on renewable energies.

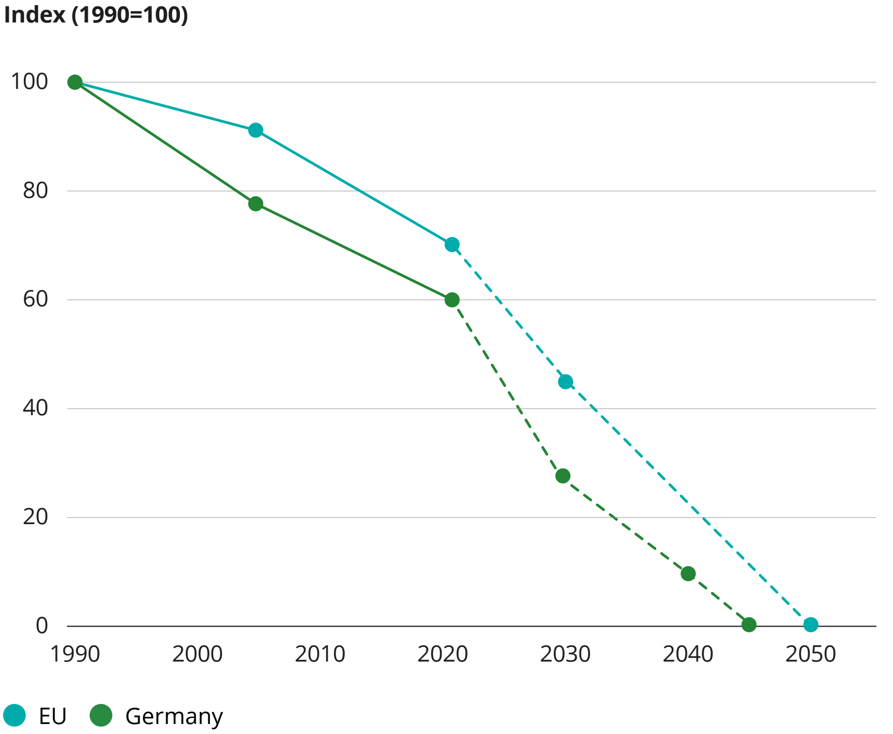
3.2. Germany's climate policy framework

In line with the EU Effort Sharing Regulation, Germany has more ambitious climate targets than the EU (see Figure 3-2). Climate action and awareness have been increasingly prioritized in Germany in recent years, both on a political and societal level. A strengthening of the 2019 German Climate Law was adopted in 2021 (German Federal Government, 2021), targeting 65% (previously 55%) greenhouse gas emission reduction by 2030 compared to 1990, and achievement of climate neutrality by 2045 (previously 2050). It also sets explicit emission pathways to 2030 at a sectoral level (see Table 3-1).[7]

The energy transition in Germany was initiated in the 1990s, with a focus on phasing in solar and wind power to gradually replace coal and nuclear power. Although coal continues to be the single largest source of Germany's electricity mix (approx. one third in 2022, BMWK, 2023a), the Act to Reduce and End Coal-fired Power Generation (German Federal Government, 2020), passed in 2020, stipulates that Germany must phase out hard coal and lignite power by 2038 at the latest. The Coalition Agreement of the current German Government envisages an earlier phase-out by 2030.[8] Meanwhile, the last three nuclear power plants were shut down in April 2023 (BMWK, 2023b).

Germany set a binding target of 80% of renewable energy sources in electricity generation to be achieved by 2030 (German Federal Government, 2023a) and carbon neutrality to be reached by 2035 in the power sector. In 2022, renewable energy sources constituted 44% (254TWh) of the power mix according to provisional data (AG Energiebilanzen, 2023c). By 2030, approx. 600TWh of renewable electricity should be produced to satisfy expected demand (German Federal Government, 2023a), more than twice the current volume. The ambitious rate of renewable energy deployment as foreseen by the German Government will be a key driver for electrification across sectors, mainly transport and heating. Success in meeting these targets will prove instrumental if Germany is to reach climate targets.

Fig. 3-2 – Historical greenhouse gas emissions and targets including LULUCF and international aviation



Source: Deloitte analysis based on historical data from EEA (2023a). The graph illustrates an index of actual emissions including LULUCF for the years 1990, 2005, and 2021 (solid lines) as well as emission reduction pathways based on climate targets (dotted lines). Emissions are indexed to the year 1990 (EU: 4,712tCO_2eq, Germany: 1,299tCO_2eq).

To achieve the targets set by the law, an explicit pathway has been established for the build-up of renewable energy production capacity (see Table 3-2) to reach 8.4GW biomass capacity by 2030, 400GW solar power and 160GW onshore wind capacities by 2040 (German Federal Government, 2023a) and 70GW offshore wind by 2045 (German Federal Government, 2023b).

In line with the revision of the EU Energy Efficiency Regulation, Germany intends to enshrine energy efficiency targets into law. The draft law (German Federal Government, 2023c) approved by Cabinet in April 2023, proposes an upper limit for final energy consumption of some 1,900TWh. This represents a reduction of about a third compared to the 2021 level (AG Energiebilanzen, 2023a). The draft version further sets a binding target for primary energy consumption of about 2,250TWh in 2030, requiring a reduction of 35% over 2021 levels (AG Energiebilanzen, 2023b).

[7] A revision of the Climate Law is currently underway. The draft amendment (German Federal Government, 2023d) still includes annual sectoral emission pathways; however, these are no longer binding. Instead, the law sets binding overall emission targets that can be reached by transferring emissions across sectors and years.

[8] To achieve the accelerated coal phase-out, an agreement with local plant operators has already been established in the Federal State of North Rhine Westphalia, although it is still outstanding with operators located in several former Eastern German States.

Tab. 3-1 – Annual emission budgets by sector

Annual emission budgets in $MtCO_2$ equivalent	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Energy	280		257								108
Industry	186	182	177	172	165	157	149	140	132	125	118
Buildings	118	113	108	102	97	92	87	82	77	72	67
Transport	150	145	139	134	128	123	117	112	105	96	85
Agriculture	70	68	67	66	65	63	62	61	59	57	56
Waste and Other	9	9	8	8	7	7	6	6	5	5	4

Source: Federal Climate Change Law Annex 2, permissible annual emission budgets for the years 2020 to 2030 (German Federal Government, 2021). This represents the annual emissions budget for each sector in yearly intervals, given in $MtCO_2eq$.

Tab. 3-2 – Capacity targets for renewable energy sources in Germany

Year	2022	2024	2026	2028	2030	2040	2045
Installed capacities (GW)	134				360	600	630
Including solar (GW)	67	88	128	172	215	400	400
Including wind onshore (GW)	58	69	84	99	115	160	160
Including wind offshore (GW)	8				30	40	70
Gross electricity generation (TWh)	254	310	388	479	600		

Source: BMWK (2023d), German Federal Government (2023a; 2023b).

In addition to the EU legislation, Germany has implemented a series of ambitious sectoral policies. While core EU climate instruments – such as EU ETS, EU ETS-2, CBAM – form the backbone of energy and climate policies, these sector-specific measures have the potential to radically change the German economy.

- Carbon pricing on fossil fuels: A carbon tax on fuels for road transport and heating was introduced in 2021 (German Federal Government, 2019). The level is set at 30€/tCO_2 in 2023 and is set to increase to 55–65€/tCO_2 by 2026 under the current legislation. This instrument could be replaced by the EU ETS-2, once the latter becomes operational. In line with the EU Eurovignette Directive (European Parliament, Council of the European Union, 2022), a carbon price component (200€/tCO_2) will be introduced into the toll system by the end of 2023 for commercial vehicles with a gross weight over 3.5 tons, while fully exempting zero emission vehicles from the toll until 2025 (BMDV, 2023a).
- Electrification and energy performance of buildings: Natural gas is used in 49% of non-commercial buildings in Germany today (BDEW, 2023b), and legislation to phase-out fossil-fuel powered heating systems by 2045 was adopted in Parliament on September, 8 2023. (German Federal Parliament, 2023). The proposal would also require that, as of 1 January 2024, heating systems of new buildings use at least 65% renewable energy, such as from electric heat pumps. To meet these targets, the German government announced a goal of installing 500,000 heat pumps a year by 2030 (BMWK, 2022a).
- Decarbonization of industry: The transformation of industry, a major natural-gas-consuming sector in Germany, is largely driven by increasing reporting and due diligence constraints,[9] as well as stakeholder and shareholder expectations. Several subsidy schemes exist to support the greening of the transformation process: of high relevance here is the Carbon Contract for Difference (CCFD) scheme deployed by the BMWK (2023c), for which the preparatory phase of the first round of submissions started in June 2023. This mechanism will provide subsidies for energy-intensive activities (such as cement, steel and paper manufacturing), and bridge the cost gap between low-carbon technologies (such as the use of renewable energy) and their fossil-based counterparts during the contractual period of 15 years. The use of blue hydrogen as a low-carbon fuel is only eligible for the scheme under specific conditions. This is in line with the recast of German Hydrogen Strategy, another cornerstone of the German industrial policy, which places a clear emphasis on green hydrogen capacity build-up[10] (German Federal Government, 2023e). By 2030, the strategy aims for a national electrolysis capacity of 10GW, to be complemented by green hydrogen imports to cover up to 70% of total demand, estimated at between 95 and 130TWh. The revision of the National Port Strategy (BMDV, 2023b) positions Germany as a green hydrogen hub.

[9] See, for example, the German Act on Corporate Due Diligence Obligations in Supply Chains that came into force on 1 January 2023.
[10] If the cost differential were to be reversed during the life of the contract, the beneficiary would have to pay it back to the Federal State.

Key results and takeaways

The European Commission has launched the EU Green Deal to foster the green transition, amidst a wave of legislative and policy action. This includes the 2020 Fit-for-55 package and the 2021 European Climate Law, which aim to achieve a 55% reduction in greenhouse gas emissions by 2030 and climate neutrality by 2050.

The energy crisis triggered by the Russian attack of Ukraine prompted an EU policy response that accelerated the ongoing energy transition. To alleviate the sharp drop in natural gas supply and severe dependency on Russian energy exports, the REPowerEU plan aims to achieve a faster ramp-up of renewable energy sources, including hydrogen and biomethane, and improve energy efficiency alongside measures to diversify imports.

Reducing greenhouse gas emissions will increasingly ascribe a pivotal role to carbon pricing mechanisms, particularly in weakening the business case of fossil fuels. Current mechanisms that are in place or proposed are the EU ETS, EU ETS-2, and the CBAM.

Germany’s climate targets are more ambitious than those set at EU level. The phase-out of nuclear power plants, the legislated phase-out dates for coal, and the expansive renewable energy targets will enable cross-sectoral electrification, especially of the buildings and transport sectors. This is bolstered by measures such as carbon pricing on fuels, overhauls of building heating requirements, and the transformation of industry.

4. The future of natural gas in the EU and Germany

Against the backdrop of the Russian invasion of Ukraine, this scenario-based outlook explores the role of natural gas on a pathway consistent with the most recent German and EU climate policies. The outlook is built on the core assumption that EU member states, including Germany, succeed in delivering their climate commitments by 2050 (and in the case of Germany, by 2045).

This outlook relies on a scenario-based approach in which EU member states deliver on their climate commitments. We do not impose phase-down constraints for naural gas. Instead, we adopt consensus assumptions on core demand drivers such as the market price of fossil fuels, the availability of Carbon Capture and Storage (hereafter, CCS), and methane-emission factors (see details in Section 4.4). We then obtain natural gas consumption pathways using Deloitte's detailed energy system model, DARE. This chapter presents our results at the German and EU levels.

Our scenario-based modeling of final energy demand at the EU scale, including Germany, is based on two pillars: Firstly, we adopt a consensus-based real GDP growth forecast with a constant annual rate of about 1.7% until 2030, and 1.4% thereafter.[11] Secondly, we preclude any demand destruction or behavioral change, in assuming for instance that the industry will maintain a constant share in GDP, foregoing any relocation. In other words, we assume sustained development in German and EU industry,[12] in line with political ambitions. We also assume a building stock trajectory in line with the EU Renovation Wave Strategy (European Commission, 2020).

We account for climate policy targets, including an increasing carbon price,[13] and then rely on cost-optimization, leveraging the DARE model to assess natural gas demand by 2050. In line with EU commitments restated in REPowerEU, we assume a 55% emission reduction by 2030 with regards to 1990 levels, with net zero emissions reached no later than 2050. We additionally consider national political targets within the power sector, such as the phase-out timelines for coal.

Our scenario-based approach then allows us to select a mix of cost-efficient technologies to satisfy demand, giving rise to a pathway for natural gas demand.

4.1.Primary energy supply

Modeling results show that primary energy demand in the EU and Germany stands at similar levels in 2050 as in 2018 (see Figure 4-1). In the years between, two countervailing trends explain this evolution:

- By 2030, emissions reduction efforts are underpinned by efficiency gains and the ramp up of electrification. The latter occurs in sectors where fossil fuel alternatives are less efficient (for instance through energy retrofits and heat pump deployment in buildings, and electric engines in light duty vehicles), which reduces energy demand. The share natural gas use in total primary energy supply moderately decreases in both EU and Germany, from over 20% in 2018 to about 17% in 2030. Indeed, the focus is initially on phasing out of the most carbon-intensive fossil fuels, including coal and oil.

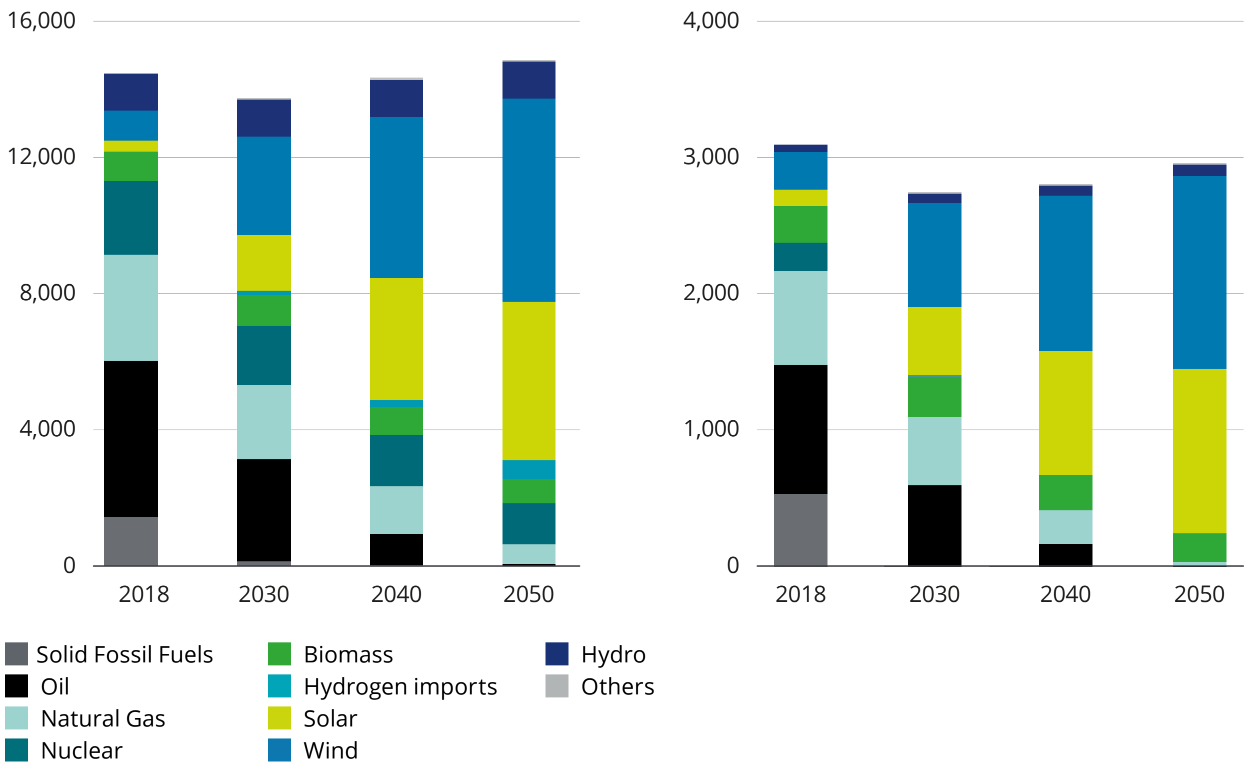
- In the longer term, energy needs increase in line with economic growth and the associated higher energy demand for industry and transport activities, while holding the technology mix constant. The deeper decarbonization of hard-to-abate sectors (such as high temperature industrial heat, shipping and aviation) requires solutions involving more energy conversion steps than current fossil-based alternatives, which lowers energy efficiency. For instance, producing e-fuels[14] requires a substantial amount of energy both to produce the clean hydrogen and to capture the CO_2 used as feedstock in the production process.

[11] These trends are in line with the recent forecasts from EU Institutions (European Commission, 2023b; European Strategy and Policy Analysis System, 2019; European Central Bank, 2023), the Economist Intelligence Unit (Economist Intelligence Unit, 2023), and the International Energy Agency (IEA, 2022d).
[12] Limited industrial relocation may occur between member states, but the industrial supply within the EU as a whole is expected to rise consistently with real GDP.
[13] We rely on the recent analysis from Umweltbundesamt (2022) until 2030, after which we assume a convergence towards the 2050 level adopted for the advanced economies in the Announced Pledges and Net Zero Emission scenarios of the World Energy Outlook (IEA, 2022d).
[14] E-fuels (such as e-methane, e-kerosene, e-methanol) are produced from renewable or decarbonized electricity.

Fig. 4-1 – Primary energy supply per energy source, 2018-2050

a) EU **b) Germany**

in TWh **in TWh**



Source: Deloitte analysis based on the DARE model. This graph shows the evolution of primary energy consumption which covers about 90% of total consumption. Reference year 2018 is based on data from Eurostat (2023a) and AG Energiebilanzen (2023a).

By 2040, natural gas use has continued to decrease, constituting around 10% of the total primary energy supply in both EU and Germany, while renewable energy sources make up 70% and 85% respectively.

- Wind- and solar-energy shares increase in line with political aspirations. Wind energy reaches about a third of overall EU primary energy supply by 2040, while solar energy constitutes about a quarter (respectively more than 40% and 30% in Germany). Nevertheless, oil continues to contribute up to 6% of the EU and German energy mix, primarily due to its continued use in the maritime and aviation sectors, during the transition out of long-life assets and the development of new solutions such as e-fuels.
- Natural gas, meanwhile, continues to find use in the building and industry sectors, as well as for electricity generation. This too can be attributed to the long operational lifetime of certain appliances, such as gas-run heating systems, and to the time necessary for heat pumps to be installed.

By 2050, natural gas is the only remaining fossil fuel in use and plays a minor role in the EU primary energy supply.

- Wind and solar power together become the largest source of primary energy by 2050. Their share in the EU primary energy mix grows steadily from 8% in 2018 to more than 70% by 2050. Their importance is even greater in Germany, where they account for almost 90% of the primary energy supply in 2050. Wind power dominates by 2050, providing about 40% of EU primary energy supply (almost half in Germany), compared to 6% in 2018. However, solar power experiences the fastest growth, growing respectively 13-fold and 9-fold over the outlook period in net electricity generation in the EU and Germany, respectively.
- Natural gas consumption falls dramatically. This trend is common to all fossil energy sources; however, the rate of decline is driven by the carbon footprint of each energy carrier and depends upon the existence of cost-efficient alternatives. In the EU and Germany, natural gas provides 4% and 1% respectively of the energy supply by 2050. This remnant use can be explained by the fact that natural gas emits less carbon dioxide compared to other fossil fuels, as well as its compatibility with

CCS (such as for power generation and industrial heat). By way of contrast, the most carbon-intensive fuels, such as coal and lignite are the first to be phased out, dropping by more than 90% between 2018 and 2030, and a full phase-out reached well before 2040 in both the EU and Germany. The consumption of oil products follows, with a more moderate decrease of 35% between 2018 and 2030 in the EU (almost 40% in Germany), but a sharp decrease thereafter, ultimately constituting less than 1% of the 2050 EU and German primary energy mix.

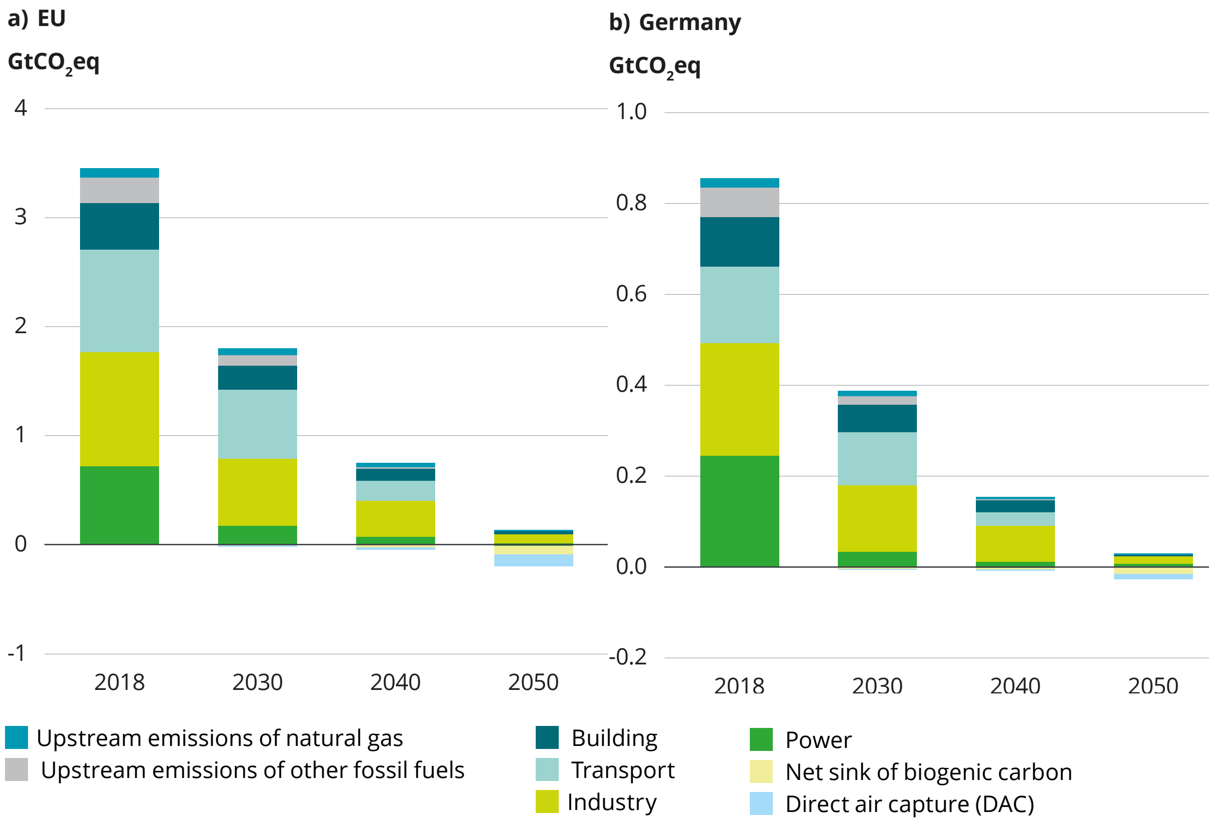
4.2. Greenhouse gas emissions

In compliance with EU pledges, climate neutrality is achieved by 2050 (see Figure 4-2). Total net greenhouse gas (GHG) emissions fall from 3.7GtCO_2eq in 2018 (including upstream emissions) to zero in 2050. This is due to the combined effects of a decrease in direct emissions (efficiency improvements), the phase-out of fossil fuel imports (overall decrease in demand and scale-up of clean alternatives such as biomethane), and the ramp-up of carbon removal solutions. The latter processes include the sequestration of biogenic carbon through bioenergy with CCS (hereafter BECCS), long-term integration into chemicals products, and Direct Air Capture (hereafter DAC) with underground CO_2 storage. By 2030, the net emissions level (about 1.9GtCO_2eq) complies with EU Fit-for-55 objective to achieve a 55% decrease over 1990 levels.

Direct emissions are decreasing in all sectors, albeit at a different pace. Decarbonization is fastest in the power sector, where coal phase-out and renewables deployment targets (Section 4.5.1) result in a more than 75% decrease of emissions from 2018 to 2030. Electrification and reduced energy demand lead to emission reduction of around half and one-third in the building and transport sectors, respectively. These trends continue beyond 2030. By way of contrast, after a 41% emissions reduction between 2018 and 2030, the industry sector becomes increasingly difficult to decarbonize due to the lack of cost-efficient carbon-free alternative technologies (such as for cement). By 2050, more than 90MtCO_2eq of industrial emissions cannot be economically abated, adding to residual direct emissions in buildings, transport and power generation, as well as upstream emissions. As a result, more than 190MtCO_2eq of carbon removal will be needed to comply with net-zero targets.

Driven by a more ambitious political agenda, CO_2 emissions are falling faster in Germany than in the rest of the EU. In the power sector, the roll-out of renewables and almost complete elimination of coal lead to a more than 85% decrease in power emissions from 2018 to 2030. Relative emissions reduction by 2030 in the industry, buildings and transport sectors are roughly on par with the EU average. As a result, Germany cuts its emissions by 83% by 2040 over 2018, compared to 79% for the whole of EU. This rate of emission reduction would enable Germany to achieve climate neutrality by 2045.

Fig. 4-2 – Greenhouse gas emissions, 2018–2050



Source: Deloitte analysis based on the DARE model. Reference year 2018 is based on data from European Energy Agency (2023a; 2023b) and Eurostat (2023b).

4.3. Natural gas consumption

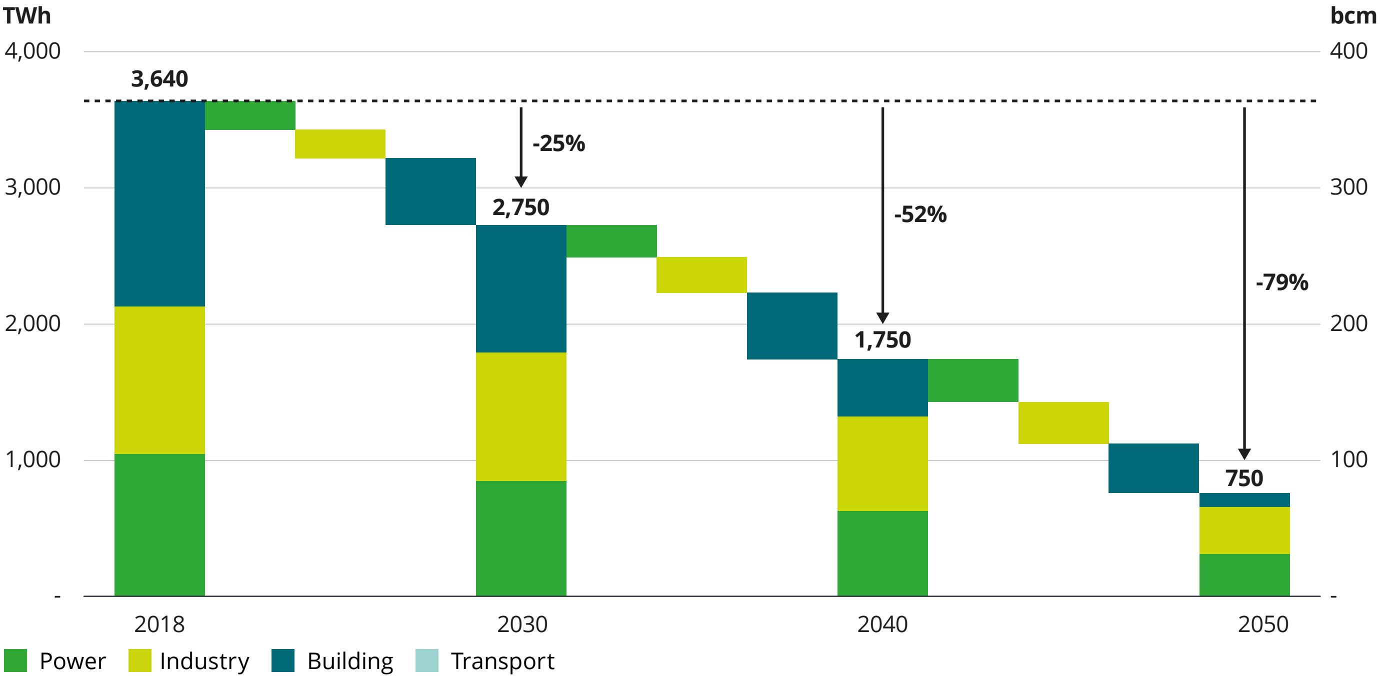
This outlook shows a steady decline in natural gas use over the next three decades, with a faster phase-out in Germany compared to the rest of the EU.

- In the EU, the building sector (residential, tertiary, and district heating) was the largest consumer of natural gas in 2018, while presenting cost-efficient decarbonization options (see Figure 4-3). This tendency is observed throughout the outlook. By 2030, the buildings sector accounts for more than half of the drop in natural gas demand (a drop of 15% relative to total European natural gas use in 2018). Leveraging thermal retrofits and heat pump deployment, consumption declines even further, reaching -70% by 2040 and almost -95% by 2050 over 2018. From 2030 onwards, decarbonization efforts gain momentum in industry and power generation. Natural gas is replaced by electricity and hydrogen-based solutions for industrial heat, and all fossil-based electricity generation capacities are replaced by renewable energy sources. By 2040, the demand for natural gas in the EU has halved and decreases even more by 2050, when it reaches about 20% of its 2018 level.

- In Germany, the largest natural gas-consuming sector in 2018 was buildings (46%), followed by industry (nearly a third) and power (nearly a quarter, see Figure 4-4). The buildings sector is the main contributor to the initial decline of natural gas consumption. It results in a 70% drop in natural gas consumption in the sector by 2040 over 2018 levels. Natural gas use in the power sector decreases at a steadier pace. Meanwhile, the intensified decarbonization of hard-to-abate activities accelerates natural gas decrease by 2050. This results in a 91% and 95% reduction of natural gas since 2018 in the power and industry sector respectively. Overall, German natural gas consumption decreases from 900TWh in 2018 to 650TWh in 2030, dropping down to 50TWh in 2050. This represents a 94% reduction between 2018-2050. This impressive decline, greater than that at EU level, is indicative of the stricter targets imposed on Germany through the Effort Sharing Regulation (European Commission, 2021b).[15]

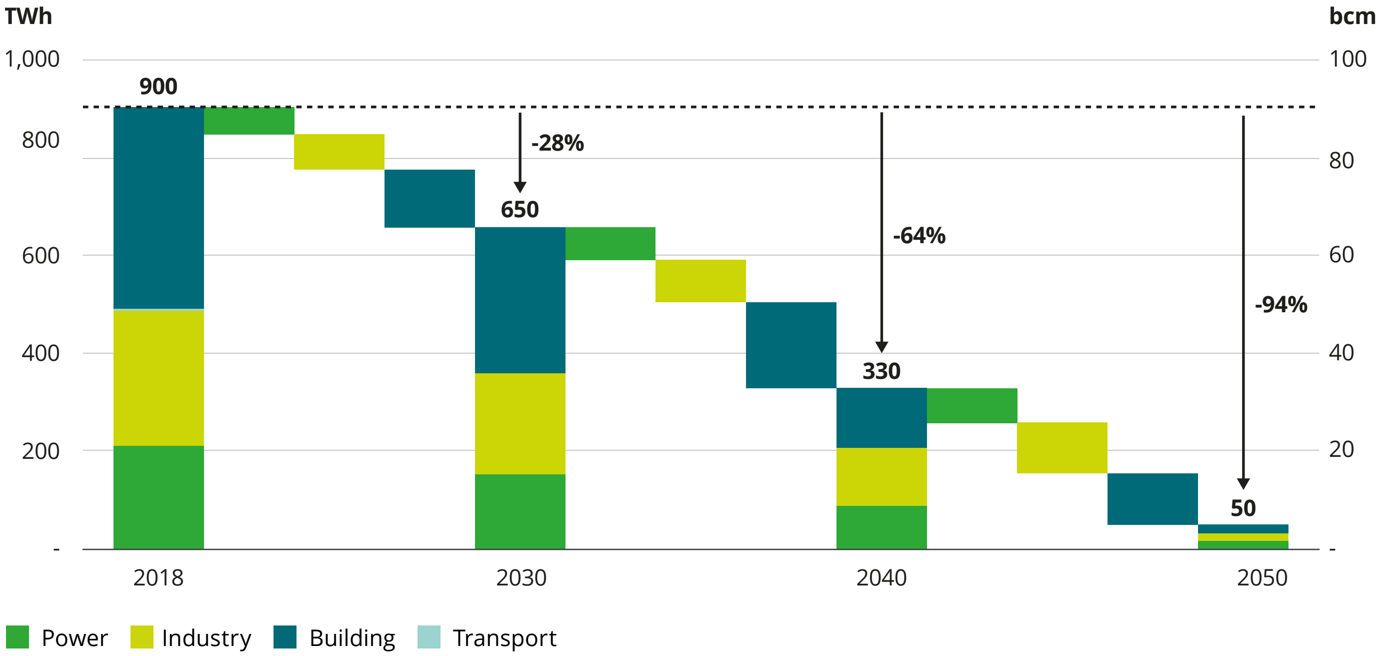
[15] See Section 3.1, the Effort Sharing Regulation sets differentiated emission reduction targets compared to 2005 levels for each Member State, depending on income levels and capabilities. The German objectives are among the most ambitious, with a -50% target.

Fig. 4-3 – Natural gas consumption in the EU, 2018–2050



Source: Deloitte analysis based on the DARE model. Reference year 2018 is based on data from Eurostat (2023a).

Fig. 4-4 – Natural gas consumption in Germany, 2018–2050



Source: Deloitte analysis based on the DARE model. Reference year 2018 is based on data from Eurostat (2023a) and AG Energiebilanzen (2023a).

Residual natural gas demand by 2050 is dedicated to critical uses. In the power sector, natural gas power plants are used as a backup to ensure the security of supply during peak hours. These power plants could technically run on clean hydrogen, provided there is political support to bear the additional costs compared to natural gas (or introduce regulatory constraints such as co-blending). In industry, natural gas is used as feedstock for chemical manufacturing and to produce a small share of high temperature heat combined with CCS technologies. To a marginal extent, it is also used in district heating systems for buildings. Deployment of biomethane further reduces residual natural gas consumption.

4.4. Core drivers of natural gas outlook

Natural gas demand is the outcome of a variety of technical, regulatory, economic, and environmental factors among which availability, CCS deployment, upstream methane emission trajectories, and the breakthrough of alternative energies play a key role. The price of natural gas incorporates the tightness of supply, exacerbated in the short run by the energy crisis sparked by the Russian attack of Ukraine. The speed of CCS deployment and the reduction of methane emissions shape the environmental footprint of natural gas use and, ultimately, its environmental burden as compared to other energy sources. Lastly, the availability of biomass and the speed at which the energy system transitions to electrification and hydrogen determine the role of natural gas in the future energy system.

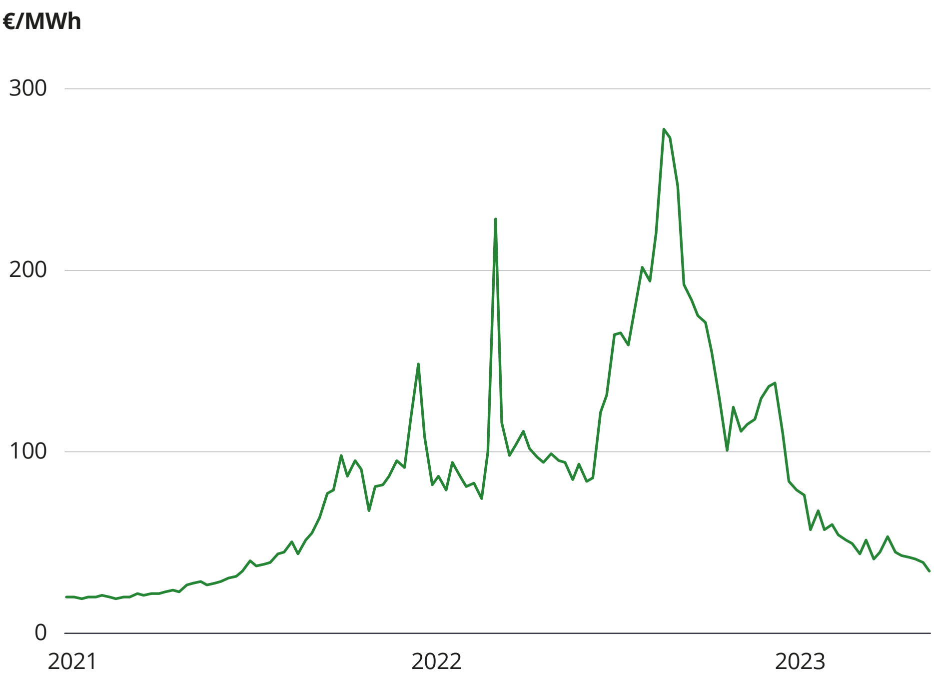
4.4.1. Availability and price

Imbalances between natural gas availability and demand exert upward or downward pressure on its price. Where the price of natural gas is high, incentives are placed on consumers to lower demand and on producers to expand supply. The price of natural gas also determines its attractiveness compared to other energy sources. As such, high prices may trigger technological shifts towards competing alternatives which exist for most applications (such as for industrial processes or for heating air and water in buildings). Carbon pricing has a similar effect and is intended to specifically foster the use of low carbon energy sources (see Section 3.1)

The future evolution of natural gas availability and price remains uncertain. Overall, natural gas prices are influenced by factors that remain hard to predict, such as economic conditions, geopolitical developments, environmental regulations, the evolution of import infrastructure and expansion of the LNG market (see details in Section 7). Moreover, the Russian attack of Ukraine sparked major market disruptions (see Figure 4-5), as Russia has weaponized its natural gas exports to Europe (in 2021, Russia accounted for 50% of EU imports).

As a result, natural gas forward prices, such as the Dutch Title Transfer Facility (TTF) futures, increased more than 15-fold between 2021 and 2022. In response, the EU engaged in significant actions to reduce dependency on Russia (see Section 3.1). Tightness in the natural gas market has been alleviated since mid-2022, with prices returning close to pre-conflict levels at the time of writing. However, periods of supply tension and increased price volatility may persist throughout the medium term.

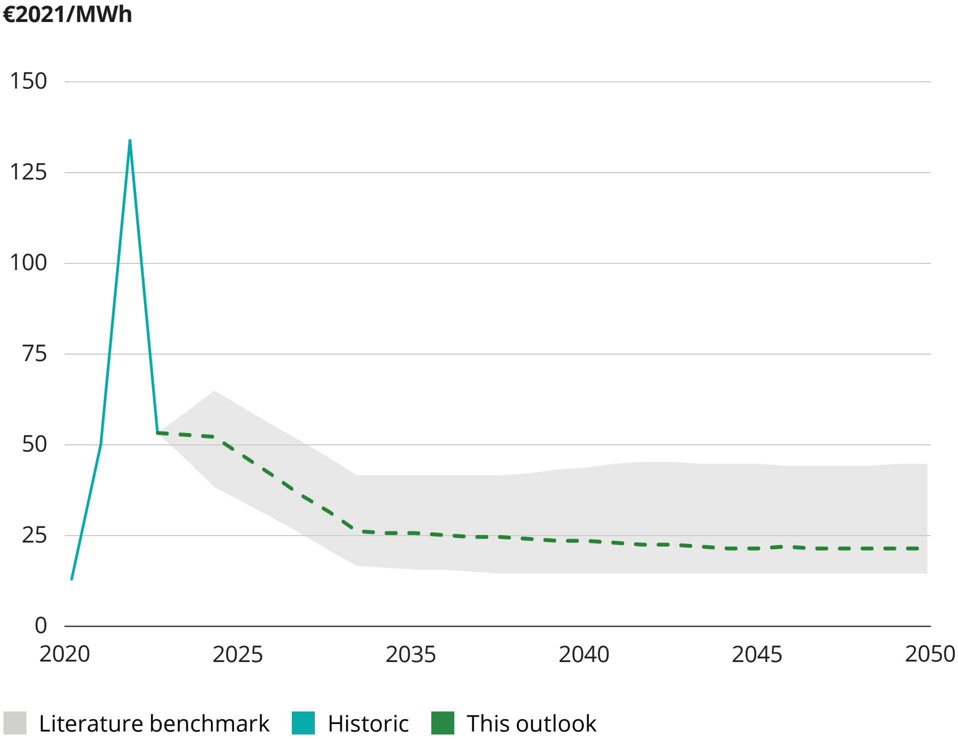
Fig. 4-5 – Historical price of the front-month Dutch Title Transfer Facility (TTF) gas futures, 01/2021–05/2023



Source: Intercontinental Exchange (2023).

In this outlook, we assume a natural gas price trajectory which falls in the medium to low part of the benchmark range established by existing literature (see Figure 4-6). We rely on the recent market analysis from Umweltbundesamt (2022) until 2030, after which we relied on the long-term trajectory from the Announced Pledges scenario of the World Energy Outlook (IEA, 2022d). The resulting trajectory follows a significant decrease in prices at the start, dropping to around 25€/MWh by 2030. This is still around twice the pre-Covid price levels (average 2019 TTF prices were around 13€/MWh[16]), which reflects a lasting shift in the supply mix in Europe with a higher share of LNG, whose transport is more expensive. Between 2030 and 2050, prices slightly decrease due to falling demand, allowing investment in exploration and production to be scaled back.

Fig. 4-6 – Scenarios of future natural gas price in Europe, 2020–2050



Source: The literature benchmark includes scenarios from (Agora Energiewende et al. 2021; BMWK, 2022b; IEA, 2022d; Deutsche Energie-Agentur, 2021; Ariadne-Kopernikus, 2021; Umweltbundesamt, 2022). Note that historic values are borrowed from the intercontinental exchanges and have been yearly averaged.

4.4.2. Carbon Capture and Storage (CCS)

CCS technologies are an essential component of many net-zero pathways (IPCC, 2022; IEA, 2022d), despite major uncertainties around the timing and extent of its deployment (see details in Section 6.5). CCS can contribute to the energy transition in several ways. By capturing and storing CO_2, these technologies can reduce the environmental footprint of carbon-intensive sectors such as heavy industry. Furthermore, the recycling of CO_2 provides the carbon feedstock that is necessary to produce clean products for hard-to-abate activities such as transport (synthetic fuels for aviation and shipping) and the chemical industry (for instance clean methanol). In some applications, CCS technologies could provide for negative emissions via BECCS (Bioenergy Carbon Capture and Storage) and DACS (Direct Air Capture and Storage), essential to offset residual emissions in net zero pathways.

Nevertheless, the magnitude and pace of CCS development in Europe remains uncertain. Existing studies support significant offshore storage potential in Europe, with CO_2 injection capacity estimated at between 500 and 1,400Mt per year (European Commission, 2021c; Ringrose & Meckel, 2019). However, the industrial roll-out is highly uncertain, as CCS has not yet been developed on a large scale – in 2022 only 2.4Mt of CO_2 were captured in Europe (IEA, 2022b) and most technologies (particularly DACS) are still at the demonstration or prototype stage (IEA, 2020a). CCS can only witness large-scale development if accompanied by the roll-out of CO_2 transport infrastructure connecting industrial hubs to CO_2 storage and utilization sites.

Greater deployment of CCS can reduce the environmental impact of fossil fuels. Even if CCS does not capture all CO_2 emissions,[17] it significantly reduces the environmental impact of fossil fuels, especially from existing assets and during the early phases of the energy transition. Depending on applications, the levelized cost of capturing CO_2 ranges from 13USD/tCO_2 to 120USD/tCO_2. For some activities such as cement manufacturing, it is clearly the lowest cost abatement option (IEA, 2021).

In this outlook, nearly 350Mt of CO_2 are captured each year by 2050, assuming a 15% annual growth rate of CCS capacities. This is broadly in line with the European Commission's modeling exercises; capture levels in their two climate-neutral scenarios amount to 320 and 530MtCO_2 (European Commission, 2022h). However, uncertainties remain as to the feasibility of these deployment rates. Despite efforts over the past ten years, the achievement of the industry in terms of making CCS technology viable has been limited to date.

[16] See IEA (2020).

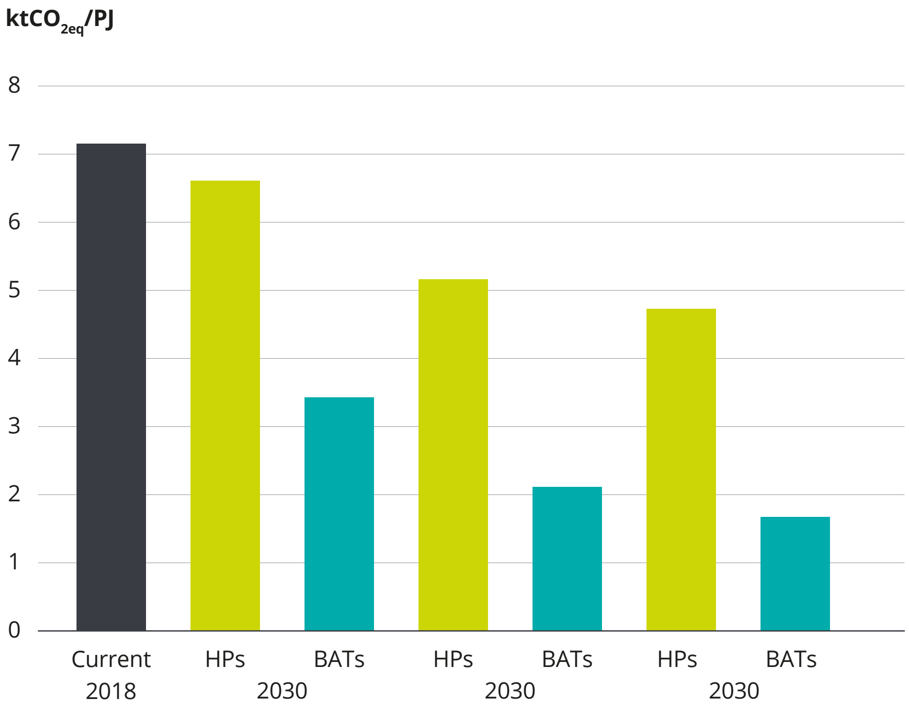
[17] CCS facilities could capture between 90 and 95% of direct emissions related to fossil fuel combustion. However, upstream emissions are not covered by CCS and add up to residual direct emissions.

4.4.3. Methane emissions

Indirect emissions from natural gas carry a significant carbon footprint. These emissions[18] mainly result from leakage along the natural gas value chain.[19] While downstream and some midstream emissions depend on the consuming country's standards as well as the chosen transport mode, upstream emissions remain the responsibility of producing and exporting countries and account for the bulk of total methane emissions. Upstream methane emissions thus vary significantly among producing countries. For instance, methane emissions per unit of gas produced are more than 500 times higher in Libya and Iraq compared to Norway and the UK, which rank among the pioneers in methane emission abatement.[20]

Upstream methane emissions can dramatically reduce the window of opportunity for natural gas in the EU energy transition. The global warming potential of methane is significantly higher than that of CO_2. The reduction of upstream methane emissions are expected to play an important role in curbing the EU's greenhouse gas emissions, but they remain largely outside the control of national policies. The pace of deployment of best available technologies (BAT) to reduce upstream emissions will therefore significantly shape natural gas demand in the EU. Key pledges on the reduction of methane emissions include the World Bank's 'Zero Routine Flaring by 2030' initiative, the EU and US-led 'Global Methane Pledge' initiative, and the 'Global Methane Alliance' launched by the United Nations and Climate and Clean Air Coalition. Yet, the current national strategies and international pledges fail to deliver the conditions for the full roll-out of best available methane abatement technologies. As shown in Figure 4-7, this is already a significant improvement compared to the current situation (by 2050, a 30% reduction over 2018), yet still below a global adoption of the best available technologies (which could deliver more than a 75% drop by 2050).

Fig. 4-7 – Upstream methane emission factors in Europe



Source: Shirizadeh, B, Villavicencio, M, Douguet, S, et al. (2023).

[18] Indirect emissions are usually classified according to the stage in the value chain they are associated with, that isupstream (extraction and processing), midstream (transmission, liquefaction and regasification of LNG) and downstream (distribution and consumption) activities.

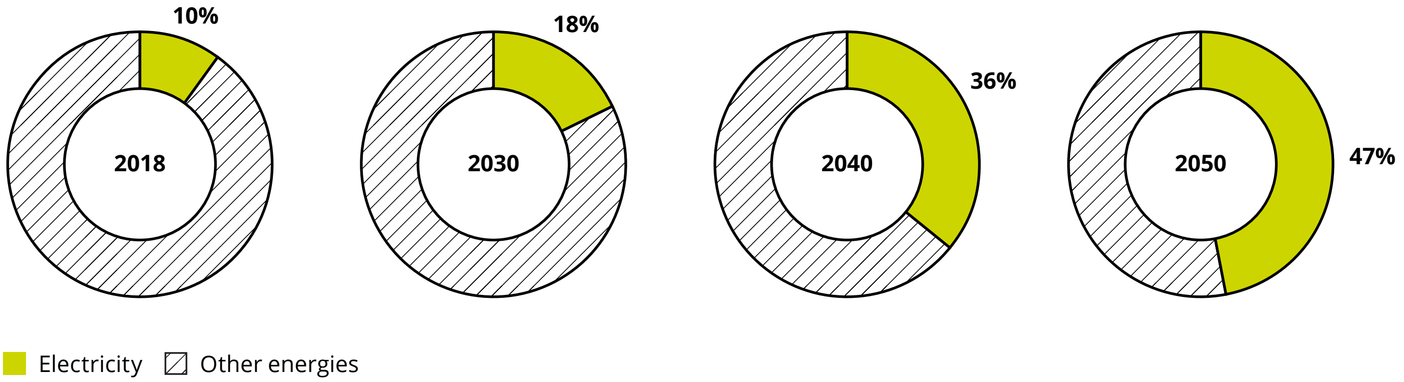
[19] In the late 2010s, methane emissions in Europe caused an additional climate burden of 13% to 35%, depending on the timeframe in which methane's climate warming potential is calculated, in addition to the direct CO_2 emissions at combustion point. The range depends on the GWP100 or GWP20 norm (described by the IPCC working group one (IPCC, 2018a) considered for the computation, where the greenhouse potential of methane is amortized respectively over 100 or 20 years. Using GWP100, each ton of methane emitted has the same global warming effect as 29.8 tons of CO_2 a figure that increases to 82.5 if GWP20 is used.

[20] Computations based on 2019 methane emission data from BP (2022).

4.4.4. Alternative energy sources

Electrification is a key lever to achieve decarbonization and reduce reliance on fossil fuels (IPCC, 2022). In many end-uses – including road transport, low-temperature industrial heat, and buildings – electric devices can replace carbon-intensive fossil fuel equipment. With renewable energy deployment 'greening' electricity production and lowering production costs, electricity gradually plays a more prominent role in final energy demand. This outlook sees a surge in electrification in Europe (see Figure 4-8) as the share of electricity in total final energy demand grows from 10% in 2018, to almost 50% in 2050. This reduces the need for natural gas and other fossil fuels within the energy mix.

Fig. 4-8 – Share of electricity in EU final energy supply, 2018–2050



Source: Deloitte analysis based on the DARE model.

Bioenergy[21] is a renewable substitute to fossil fuels in a variety of contexts. It is currently the largest source of renewable energy worldwide, used in buildings, industry, power generation and transport.[22] It can be burned to release its embedded energy (such as heat supply), but also as a feedstock for the chemical industry (such as plastics) and to produce biofuels, which can be used as direct substitutes for fossil fuels given their similar chemical characteristics. For instance, biogas – produced from agricultural waste, solid waste, or woody biomass – can replace natural gas in existing gas appliances. The carbon footprint of bio-products is much smaller than that of their fossil-based counterparts. The CO_2 released into the atmosphere during combustion of biomass was indeed previously absorbed by the bio-feedstock.

Nonetheless, bioenergy deployment faces several challenges. The European Commission has established criteria to characterize the sustainable use of biomass in the Renewable Energy Directive (RED) II (Official Journal of the European Union, 2018). For instance, bioenergy cultures should neither compete with food supply, nor entail deforestation and Indirect Land Use Change emissions. The use of biomass in the EU energy system is expected to grow up to 2030. However, the scale of developments beyond 2030 will depend on the availability of sustainable feedstocks, which may be binding (European Commission, 2019).

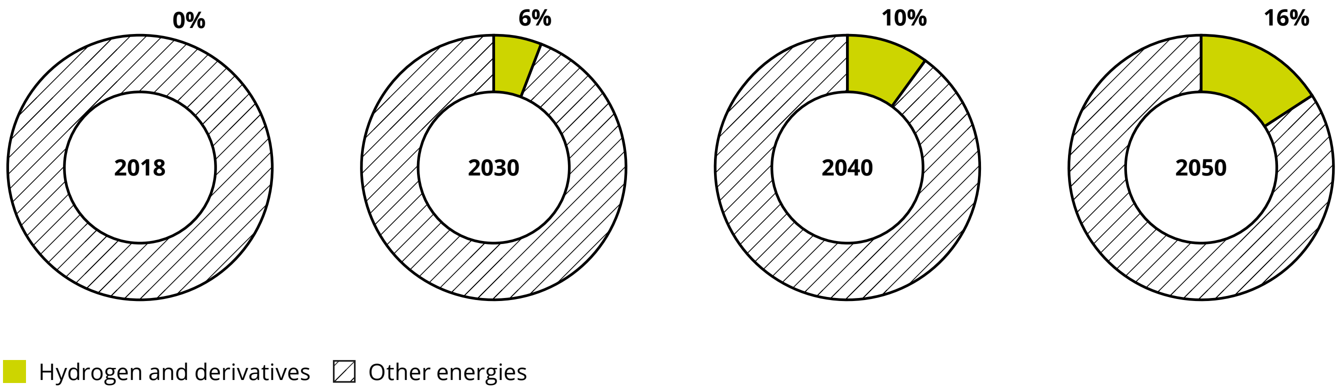
This outlook shows a moderate use of biogenic material, in line with the low availability scenario of the European Commission's ENSPRESO database (JRC, 2019). Bioenergy adoption depends on competition from alternative clean technology, leading to differences between sectors. Biofuels account for more than 30% of final energy demand in the aviation and maritime sectors by 2050. During this time, bioenergy use increases by more than 2.3 times in the power sector, with lesser contributions to the heat supply of industrial and building sectors, having been outcompeted by increasing electrification. However, biomass replaces many fossil feedstocks in chemicals processes.

[21] Bioenergy refers to all energy carriers produced from biomass.
[22] We refer here to 'modern' bioenergy, as opposed to 'traditional' wood-burning for cooking and heating. See for instance the IEA web page on bioenergy, retrieved from https://www.iea.org/energy-system/renewables/bioenergy.

Hydrogen and its derivatives (ammonia, methanol, SAF) now clearly appear as a low carbon alternative technology for hard-to-abate activities that cannot easily be electrified (IEA, 2022d).

- Clean hydrogen is a versatile energy carrier used for carbon-free combustion (such as high-temperature industrial heat), converted into electricity via fuel cells or turbines providing power grid stabilization services and combined as a feedstock with captured CO_2 to produce e-fuels for road transport, shipping, and aviation. As climate policies become more ambitious, clean hydrogen – produced from natural gas (through steam methane reforming with CCS or pyrolysis, hereafter blue hydrogen), or water electrolysis powered by renewable energy sources (hereafter green hydrogen) – can gradually replace fossil fuels in industrial processes.
- This outlook sees significant growth in the EU market dominated by green hydrogen. In 2030, clean hydrogen demand reaches about 20MtH_2eq, in line with REPowerEU targets. It is dominated by green hydrogen, with a share of the supply mix already reaching 50% by 2030 and soaring to more than 90% by 2050. During this time, the use of clean hydrogen almost triples, steadily increasing from 6% of final energy demand by 2030 to 16% at the end of this outlook (see Figure 4-9). Blue hydrogen appears to be a useful transition technology during the ramp-up phase. As green hydrogen becomes increasingly competitive, leveraging economies of scale from mass deployment, the business case for blue hydrogen weakens (Deloitte, 2023). Meanwhile, the tightening environmental standards (related to unabated CO_2 emissions and upstream methane leakage) on the road to carbon neutrality diminish its environmental case.

Fig. 4-9 – Share of clean hydrogen and derivatives in EU final energy supply, 2018–2050



Source: Deloitte analysis based on the DARE model.

4.5. Sectoral drivers of natural gas demand

4.5.1. Power

The rise in electrification combined with the need to decarbonize the energy mix puts increasing pressure on the power sector. As the use of fossil fuels gradually declines in transport, industry, and buildings by 2050, final electricity demand more than doubles compared to 2018. It reaches about 5,700TWh in the EU and more than 1,200TWh in Germany. In the same time-frame, the decarbonization of the power sector (20% of the EU's GHG emissions in 2018, see Figure 4-2) requires a fast-paced retirement of fossil-based assets. This has consequences for the use of natural gas, which accounted for about 9% and 18% of the German and EU's net electricity generation in 2022 (ENTSOE).

Against this background, the European Green Deal has set highly ambitious targets for the deployment of renewables, with the potential to radically change the EU energy landscape. Within the EU, the recast of the Renewable Energy Directive, or RED III (Council of the European Union, 2023a), attained provisional agreement raises the binding share of renewables in gross final energy demand to a minimum of 42.5% in 2030. In Germany exists a binding target of 80% of renewable energy sources in the power mix by 2030 (German Federal Government, 2023a) and carbon neutrality to be reached by 2035 in the power sector. In addition, an EU decarbonized gas market package has been proposed, which fosters the use of renewable and low-carbon gases with a target share of 66% in 2050, and setting 2049 as the sunset date for long-term fossil gas contracts (Council of the European Union (2023b).

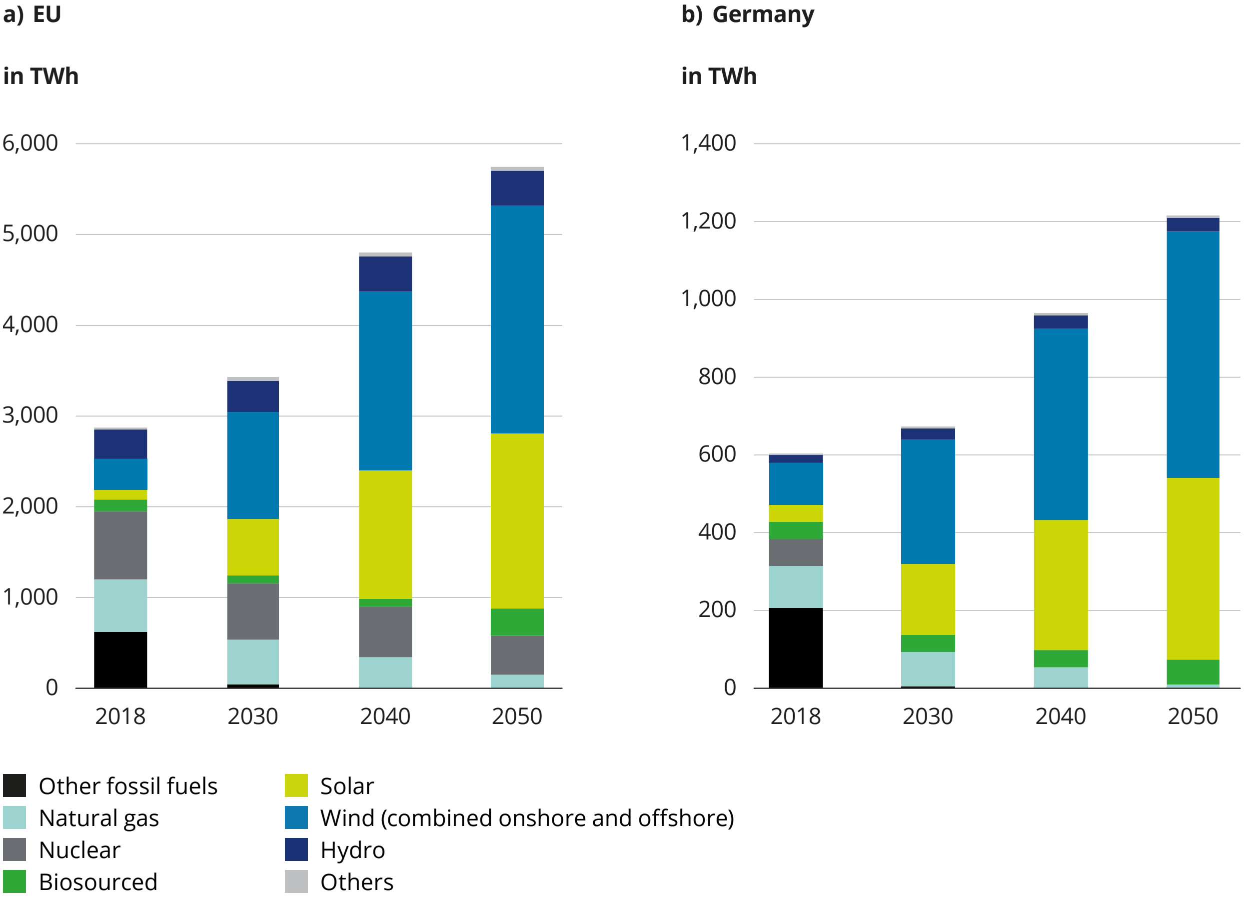
By 2030, this outlook sees the use of natural gas in the power sector decline by about 15% in the EU, as abatement efforts prioritize the phase-out of the most carbon-intensive fossil fuels (see Figure 4-10). In Germany and throughout the EU, coal- and lignite-fired power generation declines by more than 90% (by more than 560TWh and 200TWh respectively) over 2018. Within this timespan, oil, which already played a marginal role in 2018, is almost entirely phased out. In several countries, the decommissioning of nuclear power plants leads to a further reduction of about 150TWh of net electricity supply, including 70TWh in Germany alone. This evolution limits the ability to reduce gas-fired generation. Hence, by 2030, our pathway sees a moderate approx. 70TWh decline in the EU compared to 2018, including about 25TWh in Germany. To bridge the gap with increasing demand, renewable energy generation more than doubles and reaches about 2,250TWh in the EU and 590TWh in Germany. The pace of solar and wind capacity installation reaches 50GW and 30GW per year respectively from 2022[23] to 2030 (see Figure 4-11), globally in line with the REPowerEU targets (48GW and 36GW per year).

By 2040, this outlook shows a continued decrease of natural gas use, both in the EU and in Germany. Between 2030 and 2040, the use of natural gas almost halves, contributing to 7.5% (about 350TWh) of net electricity generation in the EU and 6% (about 55TWh) in Germany (from 13% in 2030) by 2040. In line with the increased electrification across sectors, net electricity generation has increased to 970TWh in Germany, and approx. 4,730TWh in the EU, with solar and wind power acting as the dominant energy carrier (providing approx. 830TWh and 3,340TWh in Germany and the EU, respectively). Other fossil fuels, such as coal and lignite, have been phased out by 2040 at both EU and German levels, meeting and indeed exceeding targets as decreed by, for example, the German 'Act to Reduce and End Coal-Fired Power Generation' (which stipulates an exit by 2038 at the latest). Any remaining natural gas use by 2040 thereby helps meet residual demand which cannot yet be covered through renewables.

By 2050, renewables dominate electricity generation, while natural gas' use in the power sector falls by more than 70% at EU level and 90% in Germany compared to 2018. From 2030 onwards, wind and solar power alone represent more than 50% of net electricity generation in the EU, a share growing to almost 80% by 2050 (more than 70% and about 90% in Germany). Overall, the share of renewable energies in net electricity generation is greater than 65% in the EU and 80% in Germany by 2030. Solar power accounts for the bulk of the growth, with over 1,300GW installed in the EU between 2030 and 2050, as opposed to about 680GW for wind power (including about 330GW and 170GW in Germany). This massive scale-up, combined with the increasing attractiveness of renewables and the tightening of climate policies (such as carbon pricing) pushes natural gas out of the power market, with other fossil fuels almost eliminated from 2030 onwards. From 2030 onwards, gas-fired power plants can operate on clean hydrogen to reduce reliance on natural gas – provided public support is made available (such as through the introduction of co-blending regulatory constraints) –, or equipped with CCS. Overall, gas-fired power plants in the EU supply about 170TWh by 2050 (including less than 10TWh in Germany), less than 3% of the generation mix (less than 1% in Germany).

[23] The 2022 data were retrieved from the ENTSOE Transparency platfrom.

Fig. 4-10 – Net electricity generation, 2018–2050



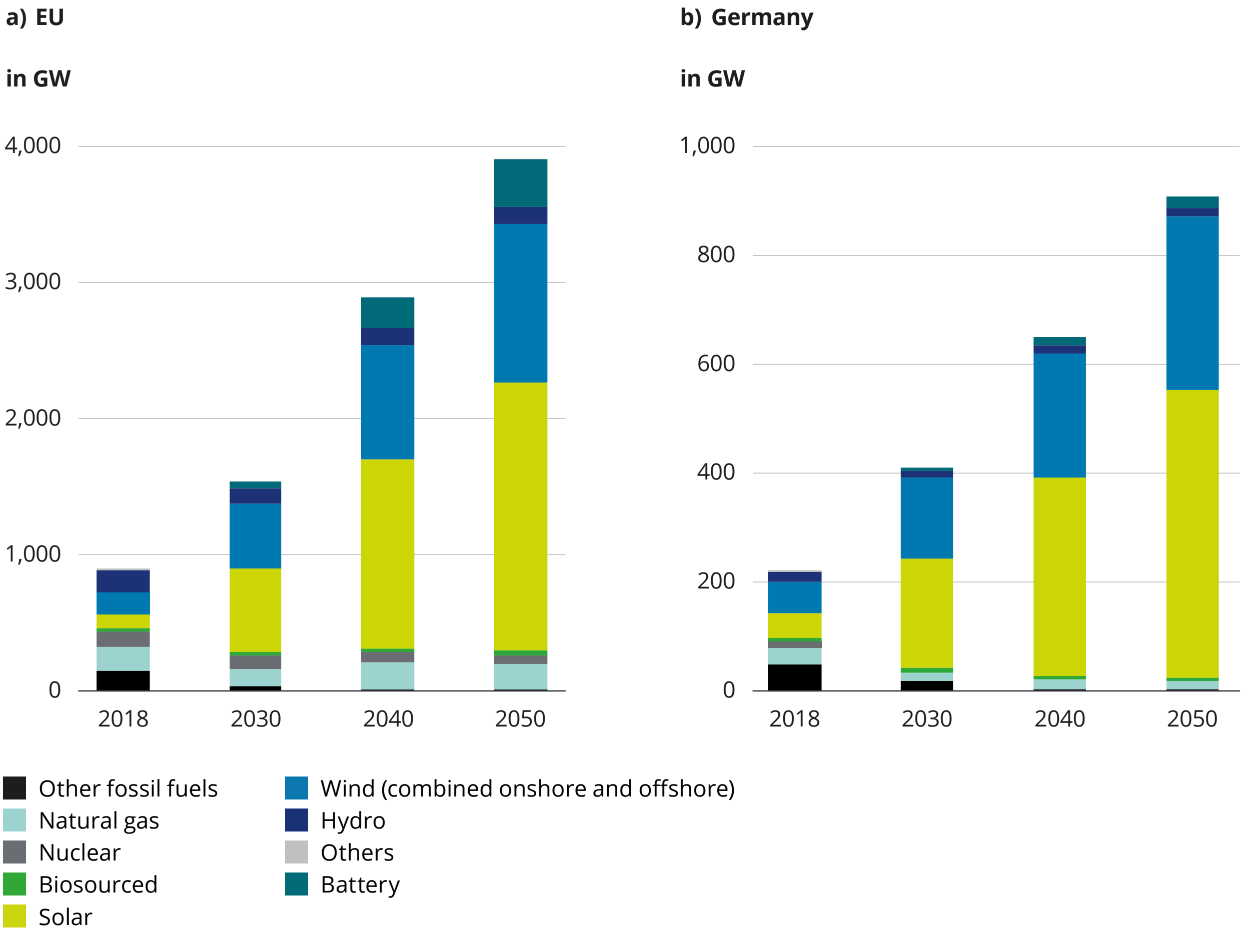
Source: Deloitte analysis based on the DARE model. Coal and lignite account for most of the 'Other fossil fuels' aggregate. From 2030 onwards, gas-fired power plants can be equipped with CCS and run on co-blended hydrogen (limited use, all corresponding electricity volumes are reported in the 'Natural gas' aggregate). Reference year 2018 is based on ENTSOE data.


HYDROGEN - TRANSPORT

In addition to the strong development of batteries, gas-fired backup capacities help ensure the adequacy and reliability of the power system. The growing share of variable wind and solar power entails a rising need for energy storage. By 2050, about 340GW of batteries are installed in the EU, including 25GW in Germany. During periods of net demand peak (such as due to low solar irradiation or weak wind), highly responsive gas-turbines can provide cost-efficient upward balancing service.

About 200GW of gas turbines (including those equipped with CCS or running on hydrogen) are operational in the EU up to the end of this outlook. In 2050, these capacities primarily serve as back-up, with a utilization rate of less than 5% (operating for only a few hundred hours a year). However, system adequacy may require some additional back-up capacity, for instance to cope with seasonal variability, which goes beyond the scope of the modeling approach (see Appendix 1).

Fig. 4-11 – Power capacities installed, 2018–2050



Source: Deloitte analysis based on the DARE model. Coal and lignite account for most of the 'Other fossil fuels' aggregate. Gas-turbines can be equipped with CCS and run on natural gas and/or clean hydrogen. Reference year 2018 is based on ENTSOE data.

Potential delays in deploying renewable energies do not change the overall story on the natural gas phase-down

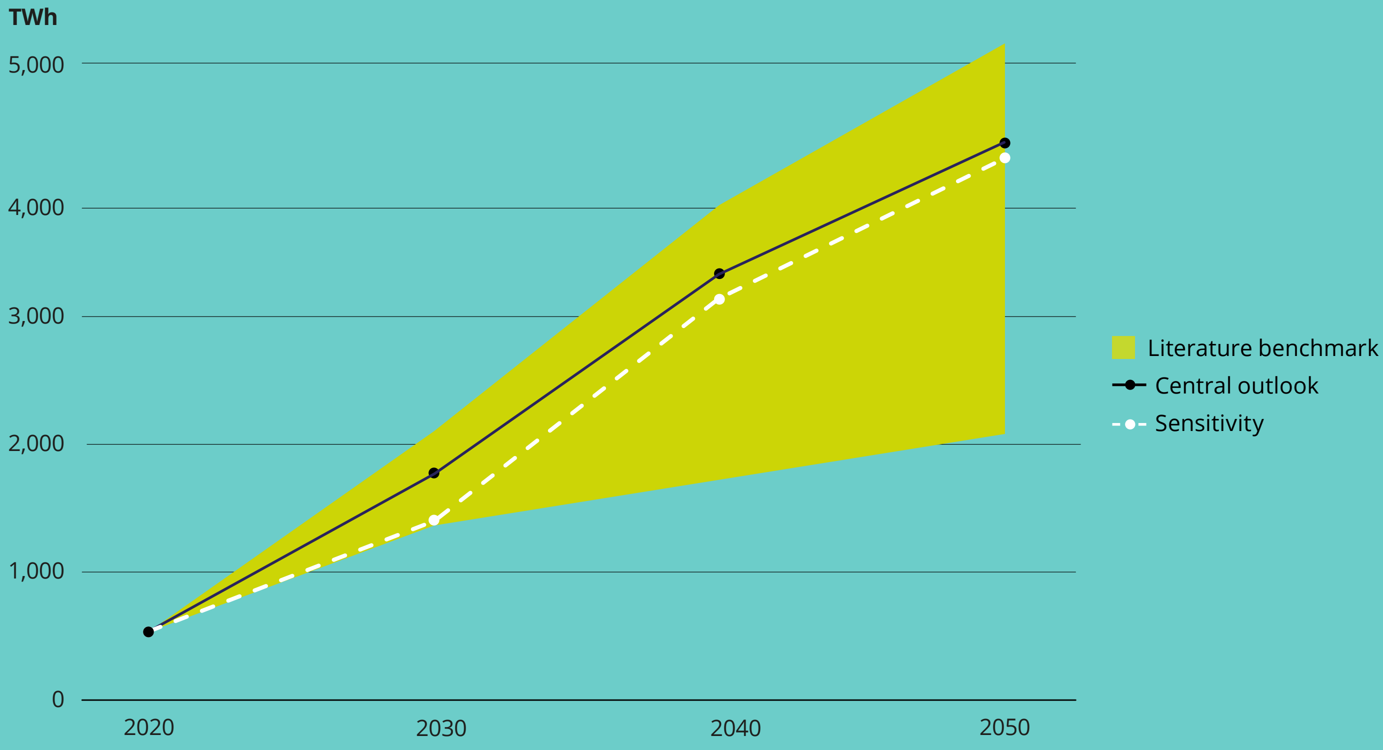
The substantial need for solar and wind power deployment raises political and industrial challenges. In line with the REPowerEU targets, this outlook sees installed wind power capacities almost double in the EU from 2018 to 2030, while solar power increases by more than five-fold. However, limited manufacturing capacities, insufficient policy support and permit constraints, and delays in grid adaptation could jeopardize achievement of these targets (IEA, 2022c). This would result in continued reliance on fossil fuels for power generation, and potentially delay electrification until these bottlenecks are resolved.

Nevertheless, were the EU to miss the REPowerEU targets, natural gas demand would still decline at both German and EU levels. Our central outlook is contrasted with an alternative scenario which includes a delay in renewable energy deployment. By 2030, only 450GW of solar and 345GW of wind power are installed, respectively about 25% and 30% below the REPowerEU targets, respectively. This trajectory is in line with the Stated Policies scenario from IEA (2022d), a rather conservative benchmark (see Figure 4-12). In Germany, this amounts to 140GW of installed solar and 100GW of installed wind capacities by 2030, that is 30% and 35% lower than in the central scenario respectively.

- By 2030, total natural gas consumption reaches about 3,150TWh in the EU and 820TWh in Germany, which is about 15% and 10% lower than in 2018 respectively (see Figure 4-13). Delayed solar and wind deployment slows down the electrification of end-uses – EU net electricity generation is 6% lower than in the central outlook – and leads to a greater need for fossil fuels in power production. In particular, natural gas consumption in the German power sector increases by 14% in the 2020s. As a result, total German and EU gas consumption by 2030 is about 25% and 15% higher than their counterparts in the central outlook respectively.

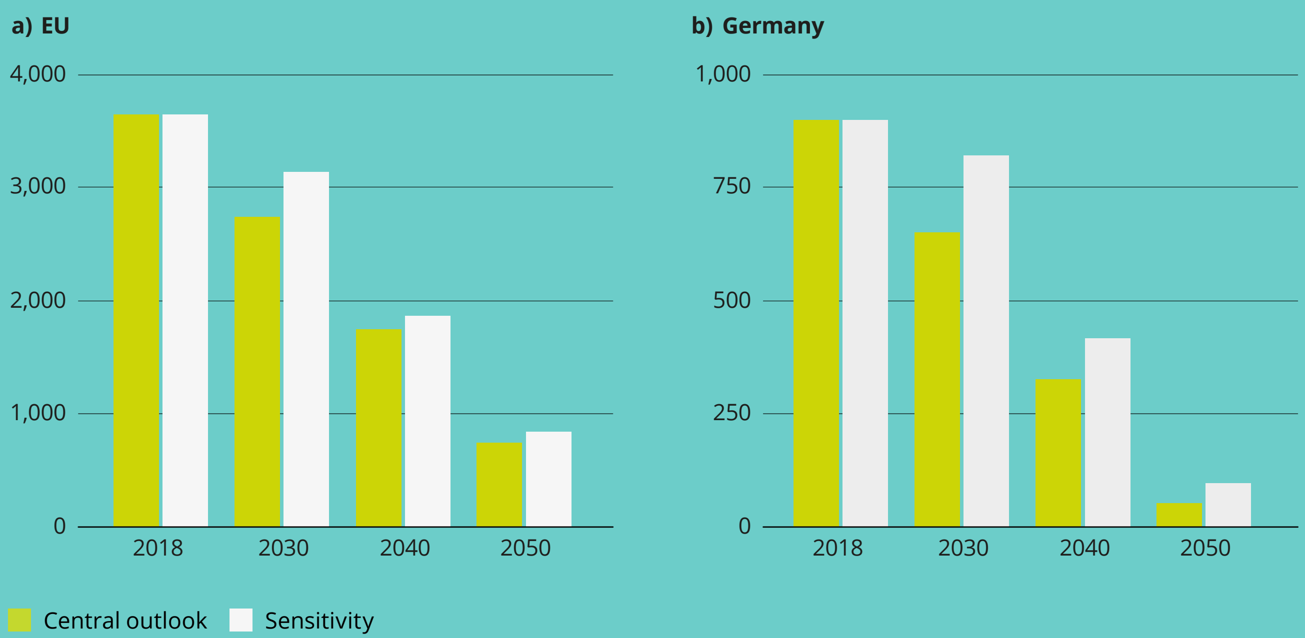
- By 2050, natural gas significantly declines to 840TWh in the EU and 96TWh in Germany, about 85TWh and 40TWh above the level observed in the central outlook respectively. Wind and solar power clearly emerge as the most competitive technologies, with installed renewable capacities catching up as of 2030. By 2050, the resulting net electricity generation is only 2% lower in the EU than in the central outlook, however at 20% use of natural gas. For some activities (such as in industry), delay in electrification in the 2020s leads to greater deployment of fossil-based technologies than in the central outlook. Due to the long operational life of these assets, total natural gas demand is 11% higher in the EU. However, total natural gas demand remains comparable to the central outlook and appears marginal by 2050 at both EU and German level.

Fig. 4-12 – Wind and solar net electricity generation in the EU, 2018–2050



Source: Deloitte analysis based on the DARE model. The benchmarked literature includes scenarios from IEA (2022d), ENTSOE-ENTSOG (2022) and Agora Energiewende (2023).

Fig. 4-13 – Natural gas consumption, 2018–2050



Source: Deloitte analysis based on the DARE model. Reference year 2018 is based on data from Eurostat (2023a) and AG Energiebilanzen (2023a).

4.5.2. Industry

Cutting carbon emissions in 'hard-to-abate' industrial activity is challenging yet crucial to reach climate neutrality. Industry accounted for 22% (757MtCO_2eq) and 24% (176MtCO_2eq) respectively of overall greenhouse gas emissions in 2021 in the EU (EEA, 2023a) and in 2020 in Germany (Umweltbundesamt, 2023), driven by high emission processes in the chemical, iron and steel and cement industries. These are all hard-to-abate sectors in which full electrification is difficult, and where other complementary technologies are needed. The challenge is further exacerbated by the long operational lifetime of industrial assets and the significant investment required to change production processes. Natural gas has historically played an important role in industry, primarily by providing low-cost energy and feedstock, constituting 27% of total natural gas consumption in EU in 2021 (Eurostat, 2023a) and 26% in Germany.

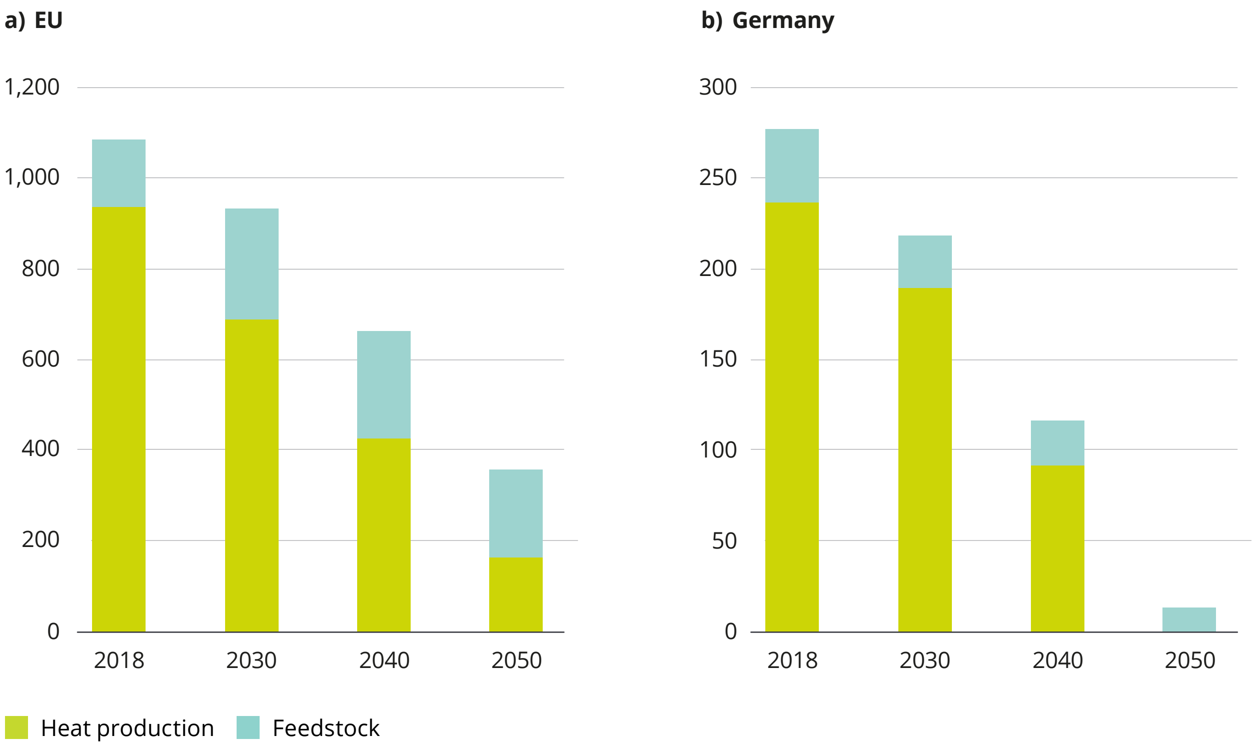
The Fit-for-55 package envisages the transition towards a green industry. This includes a tightening of the EU ETS and introduction of the CBAM, together with the Industry Act to be implemented in member states. In Germany, the Climate Change Act 2021 (German Federal Government, 2021) stipulates that German industry must reduce its emissions to 118MtCO_2eq by 2030, an almost 60% decline over 1990 levels. To promote industry transition, the Federal Government has put in place several instruments (see Section 3.2), including a Carbon Contracts for Difference (CCfD) support scheme.

Natural gas-intensive industries have been hard hit by the energy market crisis triggered by the Russian attack of Ukraine. Industrial output of these industries dropped by an average of 8% in 2022 in the EU (IEA, 2023b). To alleviate the impact of the energy crisis on consumers, the EU introduced a correction mechanism to cap natural gas price spikes while the German government introduced price breaks on industrial tariffs for natural gas and electricity (German Federal Government, 2022).

In the longer term, these recent events have given political traction to accelerating the transition away from fossil fuels in the industry, as exemplified by the REPowerEU plan.

The bulk of natural gas consumption in German and EU industries is for heat production, which falls by more than 80% at EU level and dwindles to zero in Germany by 2050 (see Figure 4-14). More than 85% of the approx. 1,100TWh of natural gas consumed by EU industry in 2018 (almost 280TWh for Germany) used to generate heat. Natural gas is also a key feedstock for chemicals manufacturing (such as clean hydrogen and its derivatives like ammonia, methanol and e-fuels) and will play a possible role in coming decades in steel production via Direct-Reduced-Iron (DRI) routes or blue hydrogen. While most process heat can be replaced by low-carbon technologies by 2050, the decline in the use of natural gas as a feedstock appears slower (not least due to growing industrial activity in this outlook).

Fig. 4-14 – Natural gas consumption in industry, 2018–2050

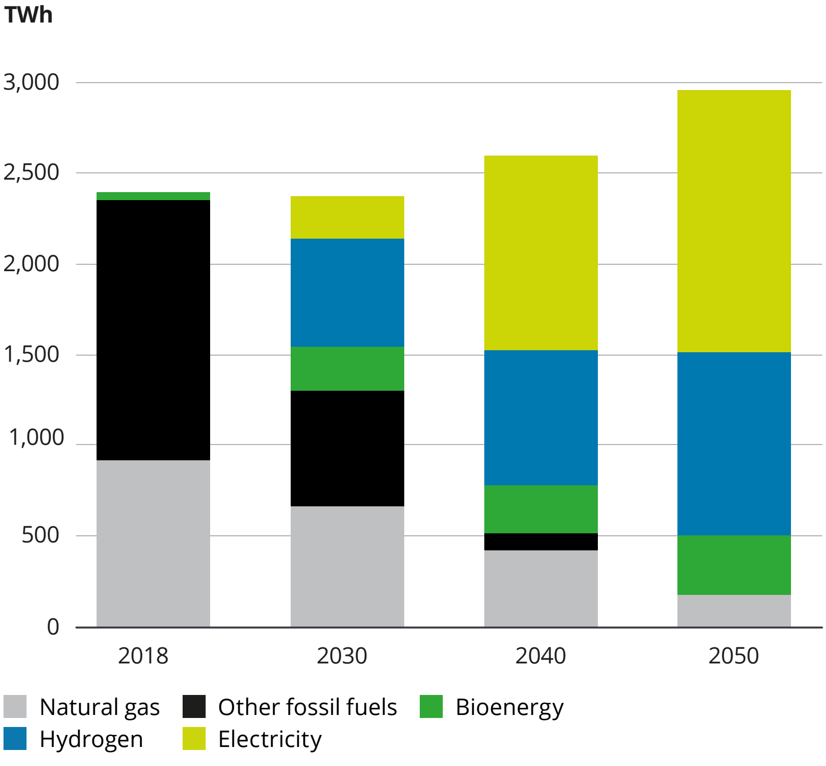


Source: Deloitte analysis based on the DARE model. Reference year 2018 is based on data from Eurostat (2023a) and AG Energiebilanzen (2023a).

- Direct electrification of low-temperature heat production in industrial processes is a cornerstone of industrial decarbonization (see Figure 4-15). The roll-out of electric boilers starts in the mid-2020s, first replacing oil-based systems, then natural gas-based systems. Rapid decarbonization of the power sector is crucial to ensure sufficient low carbon electricity is available for industrial electrification. Medium-to-high temperature processes are less suitable for electrification. The associated emissions are therefore abated, but at a slower pace, through the deployment of biomass-based heat production and the roll out of clean hydrogen burners. Overall, in 2050, only a few natural gas furnaces equipped with CCS remain. Yet heat produced from natural gas constitutes only 6% of total industrial heat production at the end of the outlook period.

- The use of natural gas as an industrial feedstock peaks in 2030 in the EU and then slowly declines. Due to its chemical composition, natural gas is difficult to replace in complex chemical reactions. For example, the main alternatives to natural gas in methanol production are based on biomethane, whose availability is limited, or clean hydrogen and captured CO_2, a prohibitively expensive process.[24] Moreover, in some processes, the carbon contained in natural gas is embedded into the final product, significantly limiting direct emissions, and reducing the incentive to replace natural gas for these specific processes (such as in methanol). Natural gas can also be used to produce blue hydrogen and clean steel.[25] The use of natural gas as a feedstock increases in the EU between 2018 and 2030 to meet the growing industrial activity. However, a peak in natural gas use is reached around 2030 as alternative solutions such as green hydrogen ramp-up (such as in steel and methanol production). Yet, the operational lifetime of industrial assets leads to a residual demand for natural gas as a feedstock in 2050, above the level observed in 2018. In Germany, greater availability of biomethane and high political ambition in electrification and green hydrogen use lead to a decreasing trajectory over the entire period. Nevertheless, consumption of natural gas as an industrial input remains substantial by 2050 when compared to 2018 levels.

Fig. 4-15 – Industrial heat production in the EU, 2018–2050



Source: Deloitte analysis based on the DARE model. Reference year 2018 is based on DARE scope and has been calibrated based on Eurostat (2023a).

[24] Moreover, the availability of captured CO_2 is largely determined by the scale-up of the DAC process, which is not expected to reach industrial readiness prior to the 2030s.
[25] In steel manufacturing, coal-based blast oxygen furnaces can be replaced by less-emissive DRI processes. In the latter, natural gas can be used as a reductant until sufficient amounts of clean hydrogen are available to replace it.

4.5.3. Buildings

With about 85% of its buildings constructed in the past century, rapid improvement the energy performance of residential and tertiary buildings is a major challenge for the EU (European Commission, 2020). In 2018, the final energy consumption of the building sector (residential, tertiary, and district heating) reached 4,300TWh in the EU, including about 1500TWh of natural gas. In Germany, natural gas consumption in buildings was above 400TWh. Given the longevity of many building components, a long-term strategic approach is mandatory both at EU and national levels. Renovation of building shells and accelerated electrification through heat pump deployment are seen as vital elements for the decarbonization and improvement of energy security.

The EU has implemented bold political ambitions and regulatory targets to trigger the decarbonization of buildings. The 'Fit-for-55' package set the pace, stipulating that all buildings should be zero-emission by 2050. Considering the poor energy performance of 75% of the existing buildings in the EU, this target requires reaching ambitious milestones. The Energy Performance of Buildings Directive (EPBD) legislates mandatory energy certificates for all new constructions by 2030. The 2020 EU Renovation Wave paves the way for an ambitious reduction of energy consumption and intends to double the renovation rate to reach 35 million renovated dwellings by 2030 (European Commission, 2020). The REPowerEU Plan also sets targets to reduce final energy consumption in buildings by 6.5% by 2030 via the deployment of heat pumps, a more efficient and low-carbon heating technology than fossil-based alternatives.

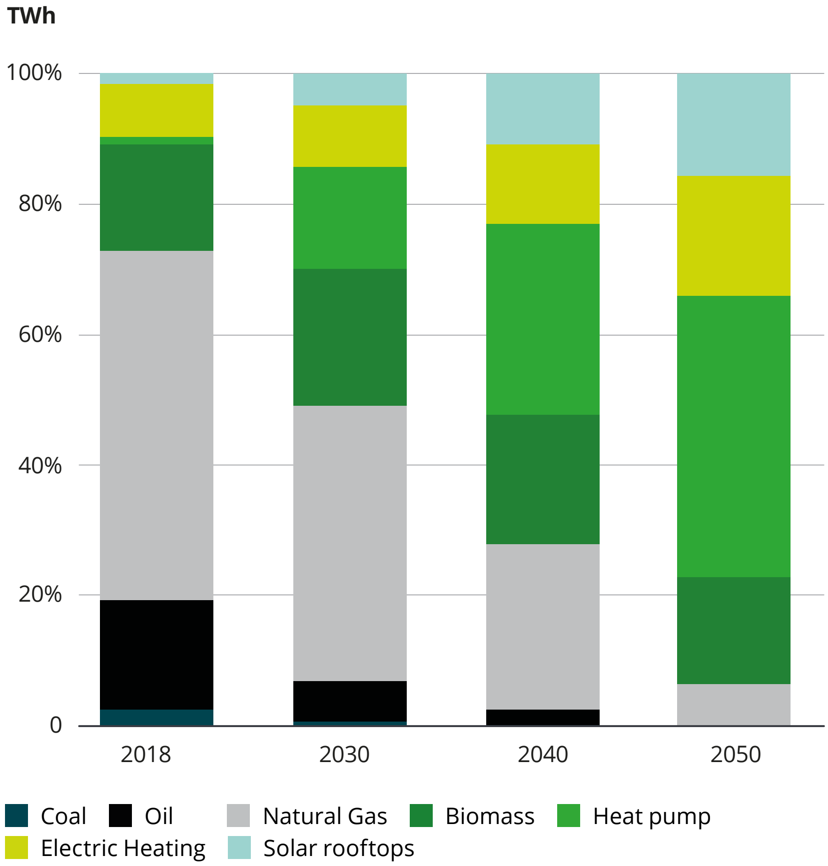
Our outlook shows a marked reduction of natural gas consumption in buildings (residential, tertiary, and district heating), both in Germany and in the EU, driven by a reduction of heat demand and a switch to alternative energies (see Figure 4-16).[26]

- Throughout the 2020s, natural gas remains a pillar in the energy mix of buildings during the prioritized phase out of other fossil fuels. Accelerated renovation efforts, focusing initially on thermal sleeves, enable some 20% reduction of the final energy consumption in the building sector by 2030 over 2018 in Germany and the EU. This reduction is broadly consistent with the decrease described in the IEA's World Energy Outlook (2022d). Throughout the 2020s, decisive policy support for heat-pumps increases their share in heat generation. By 2030, up to 80% of 2018 coal-based heating and more than 70% oil-based heating are phased out. This results in a decrease in natural gas consumption from more than 400TWh in 2018 to less than 300TWh in 2030 in Germany, and from about 1,500TWh to 950TWh in the EU.

- From 2030 onwards, the EU is increasingly able to accelerate the switch away from natural gas for heating and cooling purposes. By 2050, the reduction of the final energy demand in the German and EU building sectors is halved compared to 2018. Leveraging strong policy support, heat-pumps, rooftop, and domestic solar panels dominate the mix of heat production at the end of this outlook period. By 2050, heat pumps produce 50% of the useful heat in Germany and about 45% in the EU, followed by solar thermal (approx. 25% and 15% respectively) and biomass (more than 15%). As a result, natural gas consumption is marginal in the building sector (mainly for district heating), contributing less than 5% of final energy demand in buildings in Germany and the EU (18TWh and 85TWh respectively).

[26] In this modeling exercise, the building sector encompasses residential buildings, commercial buildings, and district heating. Heat demand also refers to both heat and cooling demand.

Fig. 4-16 – Useful heat supply mix in EU buildings, 2018–2050



Source: Deloitte analysis based on the DARE model. The reference year is built upon the POTEnCIA model (JRC - European Comission, 2016) and DARE results.

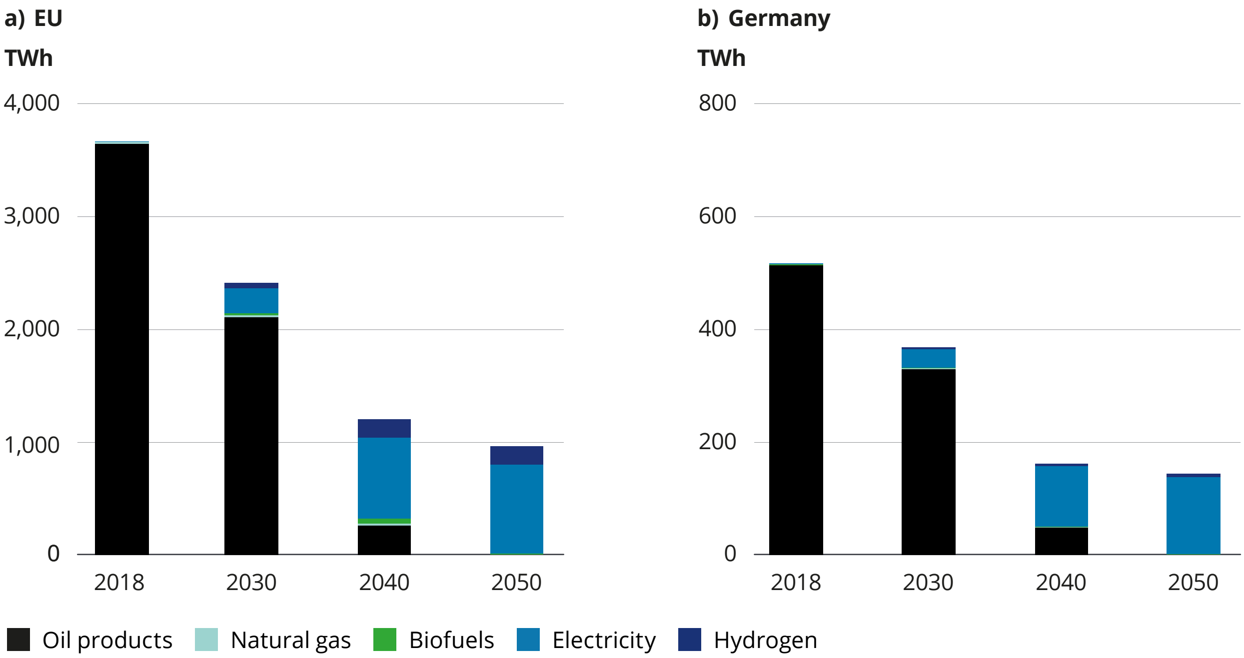
4.5.4. Transport

The use of natural gas for transport in the EU and Germany is historically negligible, representing less than 1% of total consumption in 2021 (Eurostat, 2023). Natural gas demand in transport is entirely driven by the road sector, in particular Compressed Natural Gas (CNG) engines and, to a much smaller extent, trucks powered by LNG. Only a tiny share of the EU vehicle fleet is concerned: in 2021, 0.6% of cars, 0.6% of light commercial vehicles and 0.7% of trucks were gas-powered (ACEA, 2023).

The role of natural gas as a transition fuel is particularly questionable in transport due to a variety of viable alternatives such as electrification biofuels. Compared to gasoline and diesel vehicles, vehicles running on natural gas emit less CO_2[27] and air pollutants.[28] This favorable comparison fueled expectations that the number of gas-powered vehicles would increase, particularly during the transition to zero-emission vehicles.[29] However, recent EU regulatory changes[30] have imposed stringent caps on CO_2 and air pollutant emissions from new vehicles over the next few years. These tightening standards are likely to drastically narrow the business case of natural gas for road transport. LNG has also been considered an attractive option for reducing emissions of the maritime sector (ITF, 2018), but the required technological development could be hampered by the inclusion of shipping in EU ETS as of 2024, which will also include upstream methane emissions.

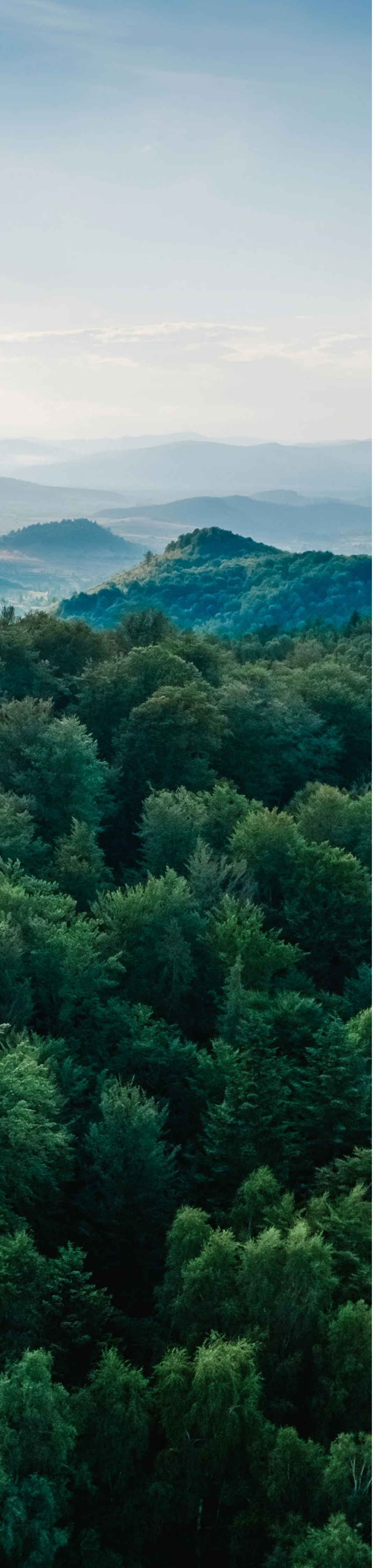
This outlook sees natural gas play a marginal role in all transport segments. Electric vehicles rapidly emerge as the dominant option for passenger cars and light-duty vehicles, leaving little, if any, room for natural gas-powered vehicles. The latter constitute 0.5% of the passenger car fleet in 2030 and are phased out in both the EU and Germany before 2050. CNG engine sales grow moderately for buses, coaches, and heavy-duty trucks. However, these vehicles never constitute more than 4% of the fleet and are 80% fueled by biogas. Overall, natural gas consumption in road transport remains stable around its 2018 level until 2040, before this technology is entirely phased out in 2050 (see Figure 4-17). Nor is natural gas gaining ground in the maritime sector, superseded by more environmentally-friendly options such as renewable ammonia, methanol, and biofuel propulsion.

Fig. 4-17 – Final energy consumption per carrier in road transport, 2018–2050



Note that the decrease in total energy consumption results from improvements in vehicle design (including improved aerodynamics, lower rolling-resistance tires) and efficiency gaps between electric and internal combustion engines (electric engines consume less than half the energy per kilometer).
Source: Deloitte analysis based on the DARE model. This graph shows the evolution of final energy consumption in the scope of the DARE model, which covers passengers cars, light commercial vehicles, heavy duty vehicles, buses and coaches. In the EU, natural gas represented less than 20TWh in 2018, and less than 15TWh from 2030 onwards. In Germany, natural gas represents less than 3TWh from 2018 onwards.

[27] Using a Well-to-Wheel (WTW) approach, the Joint Research Centre (Prussi, Yugo, De Prada, Padella, & Edwards, 2020) estimates that CNG cars emit 20% less CO_2 per km than petrol cars (126 vs 157 g CO_2/km).
[28] Aosaf, Wang, & Du (2022) finds that CNG emits significantly less CO and NOx than gasoline, diesel or LPG cars at idle speed.
[29] Zero-emission vehicles are defined by the Clean Vehicles Directive of the European Commission as vehicles without an internal combustion engine, or with an internal combustion engine that emits less than 1gCO_2/kWh or less than 1gCO_2/km.
[30] See for instance the CO_2 emissions performance standards for cars and light commercial vehicles (European Parliament and Council of the European Union, 2023b) and the EURO 7 norms (European Commision, 2022i).



4.6. Benchmarking

Several studies assess the role of natural gas in the German and EU economy by 2050. As a benchmarking exercise of our outlook, we reviewed 13 studies provided by 11 institutions (think tanks, private actors, administrations, and international institutions).

- In Germany, the so-called "Big Five" of studies modelling climate neutrality scenarios – BMWK T45 Langfristszenarien (2022b), BDI-Klimapfade 2.0 (2021), Dena Aufbruch Klimaneutralität (2021), Agora et al. Klimaneutrales Deutschland 2045 (2021), and Ariadne-Kopernikus: Deutschland auf dem Weg zur Klimaneutralität 2045 (2021) – are the most comprehensive studies available to date. These represent the views of various stakeholders and incorporate some of the most recent German climate and energy policies such as in the Climate Protection Law. However, assumptions vary across scenarios, such as the speed of renewable energy expansion, the sectoral contributions towards emission reductions the ban on fossil heating. Furthermore, most of these studies were published prior to the Russian attack of Ukraine. Only BMWK (2022b) accounts for the policy reactions (such as the REPowerEU strategy) and explores a swift exit from natural gas in a dedicated scenario (labelled RedGas). Our review includes also the German Technical and Scientific Association for Gas and Water's outlook (DVGW, 2023) and the scenarios used by the European Commission (2021b) to evaluate the Fit-for-55 package.[31]

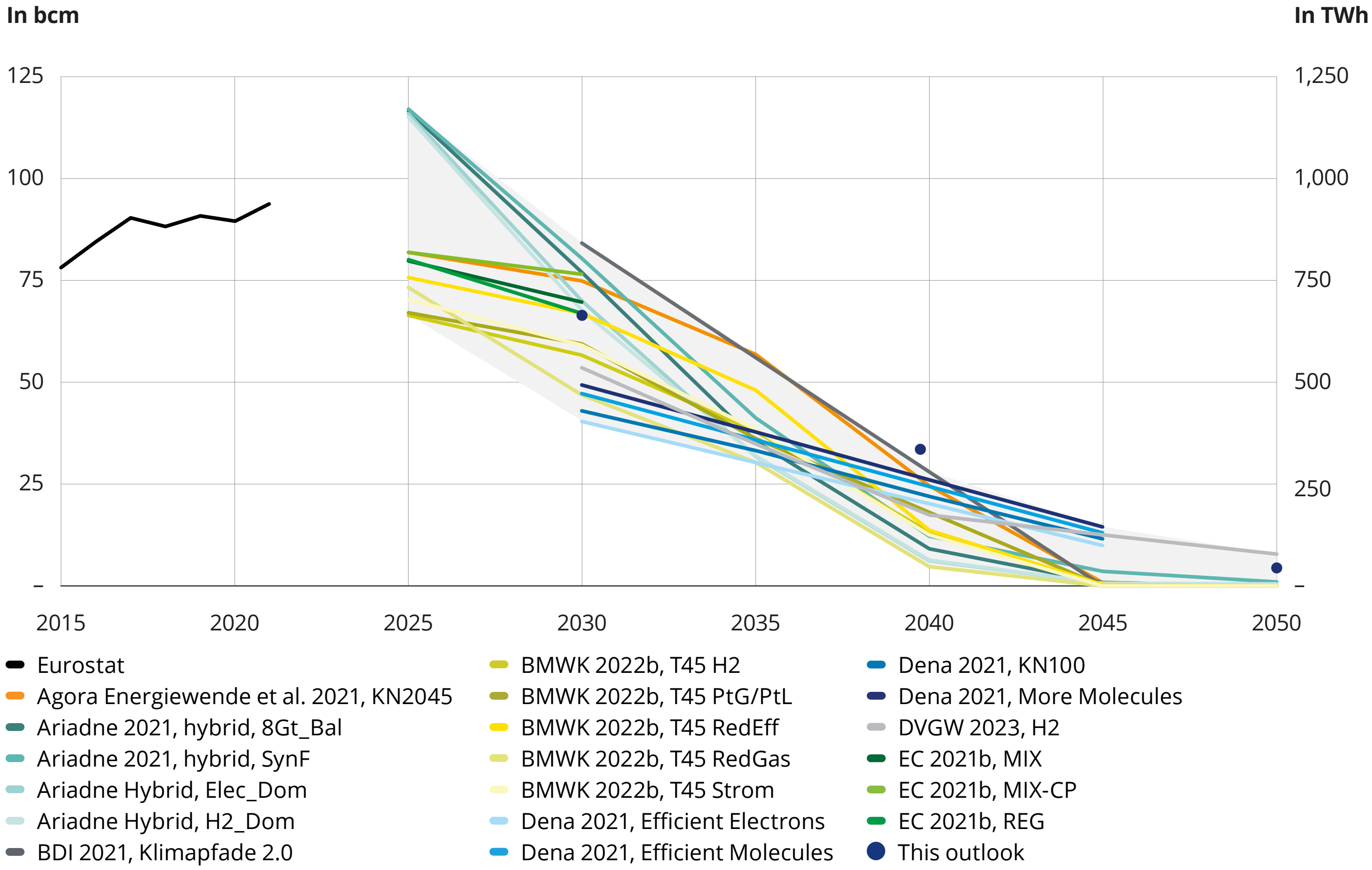
- For the EU, we examine the trajectories used by the European Commission (2021b), ENTSOE and ENTSOG[32] (2022) for their ten-year network development plan (hereafter, TYNDP scenarios), and Agora Energiewende (2023), which specifically addresses a fast and ambitious exit from natural gas following the Russian attack of Ukraine. These studies were carried out at EU level. We also survey the EU components of global studies from the World Energy Outlook (IEA, 2022d), BP (2023a), Shell (2023a) and interest groups such the Gas Exporting Countries Forum (GECF, 2022).[33]

The selected studies present a full range of views and technological scenarios on the future of energy systems. Where most of the studies rely on a cost-optimization approach, there is a strong heterogeneity in the scenario design, from the efficient response to current or announced climate policies (IEA; European Commission), the scale-up of technological solutions (such as hydrogen, Power to Gas/Power to Liquid, increased energy efficiency) and innovation (BMWK; Deutsche Energie-Agentur; Ariadne-Kopernikus), maintaining economic competitiveness (BDI), or macroeconomic and energy transition archetypes (ENTSOG ENTSO-E; Shell; BP).

Our benchmark confirms that there is consensus on declining natural gas demand in the future, in line with EU climate ambitions. Spurred on by the political reaction to the Russian attack of Ukraine, Germany, like other EU countries, has begun to undertake comprehensive measures accelerating the energy transition and reducing fossil fuel consumption, including natural gas (see Section 3). This trend is common to all recent outlooks, though with different paces between Germany and the EU.

[31] The outlook period ends in 2030 for these scenarios.
[32] European Network of Transmission System Operators for Electricity (ENTSOE) / Gas (ENTSOG).
[33] Gas Exporting Country Forum, an intergovernmental organization supporting its members to manage and plan the development of their natural gas resources.

Fig. 4-18 – Benchmarking of natural gas consumption in Germany, 2018–2050



Source: Literature review and Deloitte analysis based on the DARE model. Linear interpolations were performed for the missing years between data entries.

In Germany, the literature clearly shows a sharp decrease in natural gas consumption by 2045 (see Figure 4-18).

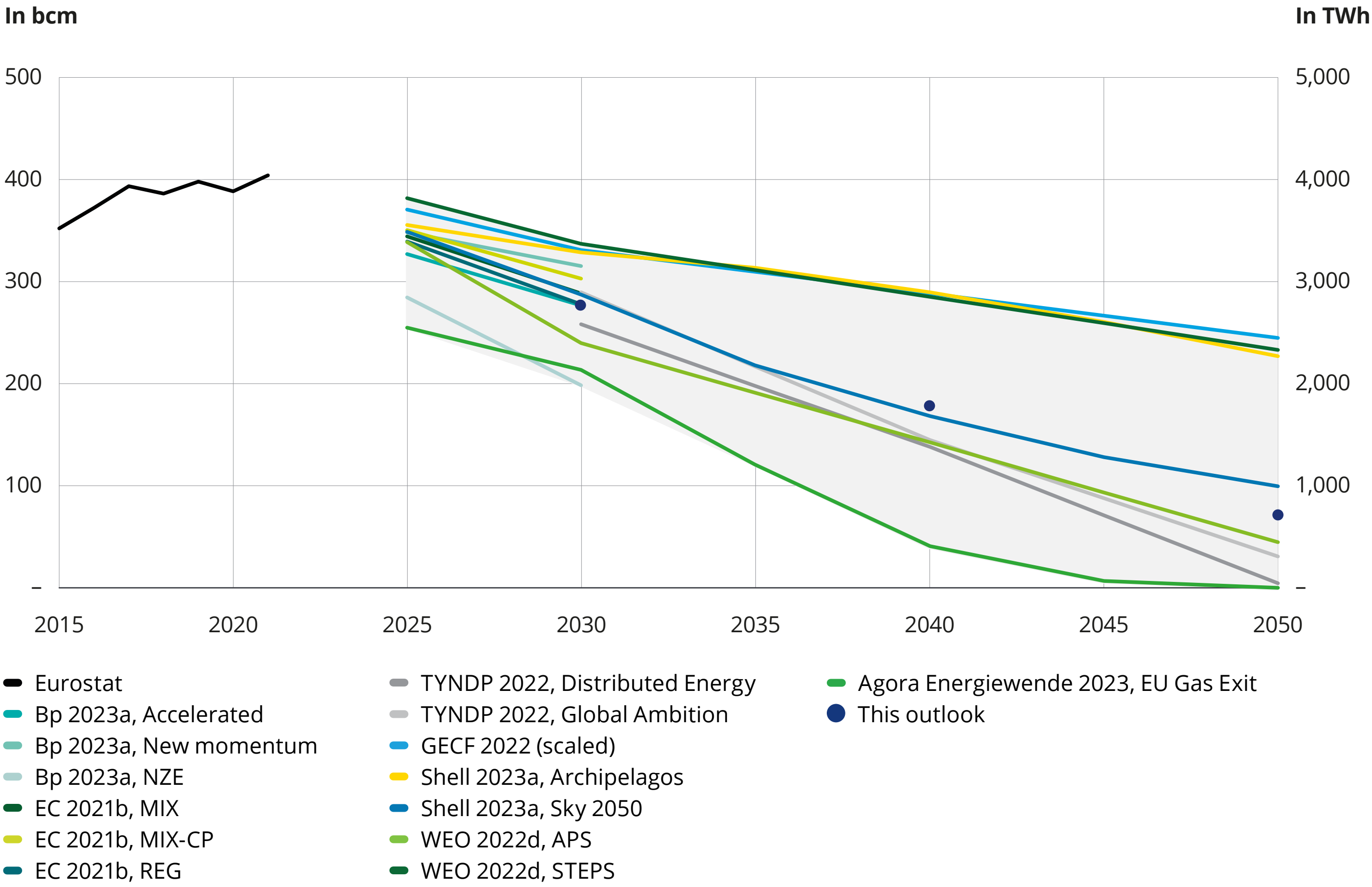
- Some uncertainty exists with regards to the trajectory to 2030. Compared to 2018, the benchmark shows an either relatively flat or falling demand for natural gas (for instance, the BMWK scenarios range from about 25% to 50% decrease). Overall, the surveyed outlook shows natural gas consumption declining slightly to almost halving by 2030 compared with 2020 levels, and declining steadily thereafter.

- The picture is clearer by 2050, with all outlooks showing a drastic decline of natural gas. The demand decrease ranges from 91% (DVGW[35]) to a complete phase-out (by 2045 for all BMWK scenarios). Factors facilitating a complete phase-out include assumptions surrounding industrial activity: for example, both Ariadne and Agora Energiewende et al. (2021) assume the chemical industry (e.g., ammonia production) to underperform. As the chemical industry is particularly difficult to decarbonize, a decrease in economic activity in this sector automatically reduces the need for natural gas. Other factors include an earlier switch to power generation from renewable energy sources, despite existing assets not having reached the end of their operational lifetime. While this accelerates the phase-out of natural gas, this approach will not prove cost-efficient and is likely to raise social acceptance issues due to the high associated costs. Particularly, fast natural gas exit scenarios – such as the dedicated BMWK RedGas theoretical exercise – raised practical issues. For example, substantial investments would be needed to cope with high electrification rates (renewable electricity generation and networks expansion) as well as a widespread use of green hydrogen to replace natural gas in hard to abate processes.

- Our outlook is aligned with these scenarios, demonstrating a steady decline in the use of natural gas. In the period to 2030, our pathway shows a decrease in natural gas consumption by more than a quarter, which then accelerates to reach a 95% reduction by 2050. There remains a residual 50TWh of natural gas used in Germany, mainly used to ensure the security of supply in the power sector, as a feedstock in the industry, and marginally for district heating.

[35] The DVGW pathways reports both fossil-based and clean gas (such as biomethane), while the other studies isolate natural gas.

Fig. 4-19 – Benchmarking of natural gas consumption in the EU, 2018–2050



Source: Literature review and Deloitte analysis based on the DARE model. Note that the GECF trajectory, whose scope is Europe, has been scaled to EU, for which we relied on the latter's GDP share. Linear interpolations were performed for the missing years between data entries.

In Europe, natural gas consumption also clearly decreases over the outlook period (see Figure 4-19). However, the range of uncertainty is larger, depending on the level of climate ambition and differing technological assumptions.

- There is a consensus for a decrease in natural gas by 2030. Compared to 2018 levels, the surveyed outlooks show a decrease ranging from -13% to almost -50% of natural gas consumption. The upper bound of this benchmark – the trajectories from the GECF (2022), the Stated Policies scenario from the IEA (2022d), and the Archipelagos scenario from Shell (2023a)[35] – is incompatible with COP 21 climate targets. On the opposite end of the spectrum, the ambitious Agora Energiewende EU Gas Exit Pathway[36] (presents a pathway explicitly dedicated to phase out from fossil gas use by 2050, which relies in particular on high electrification powered by the fast-paced deployment of renewable energy sources. This level of ambition is only met by the BP (2023a) Net Zero Emissions scenario, however, with data only available for 2030.

- In 2050, all climate-aligned scenarios show at least a broad 75% reduction in natural gas demand with regards to 2018, against a broad 40% decline in the other scenarios. The most balanced scenarios, but nevertheless ambitious, are the Shell Blue Sky (2023a) and the IEA Announced Pledges WEO (2022d) scenarios, with a 75% and 88% reduction by 2050 respectively.

- This outlook shows an 80% decline in natural gas demand in 2050, in line with the IEA's Announced Pledges and Shell's Sky 2050 scenarios from the benchmark. Our pathway offers a balanced view, taking advantage of consensus assumptions that do not seek to constrain the use of natural gas. This leads to a residual use of less than 750TWh of natural gas in 2050, in particular to fuel the sustained activity in the industry.

[35] The regional extract from the global outlooks were considered.
[36] Agora Energiewende (2023)

Key results and takeaways

Compared to the late 2010s, our outlook shows a significant decrease in natural gas demand, amounting to more than a quarter in both the EU and Germany by 2030 and in the range of half to two thirds by 2040. In 2050, the natural gas consumption only constitutes approx. 4% of total primary energy supply in the EU and approx. 1% in Germany.

A sensitivity analysis with delayed renewable energy deployment does not show a reversal in this pattern; with less than 75% of the REPowerEU's renewable capacity deployment targets achieved in 2030, the natural gas consumption is still almost 15% lower in the EU and 10% lower in Germany than in 2018.

The phase-out of natural gas is faster in Germany compared to the EU, in line with more ambitious national climate targets including the achievement of climate neutrality by 2045 complemented by strong climate and energy policies.

As the largest consumer of natural gas, the building sector significantly contributes to the decline in demand up to 2030, taking advantage of competitive abatement options (such as thermal retrofits, heat pump). From 2030 onwards, decarbonization gains momentum in the industry and power sectors as falling costs of abatement technologies, higher carbon pricing, and increasing penetration or renewables in the power system make it increasingly viable to move away from fossil fuels.

Our results are in line with recent energy outlooks, confirming a strong consensus on declining natural gas demand in Germany and the EU by 2050. In Germany, all trajectories reviewed show a drastic decline in natural gas demand from 2030 onwards prompted by the 2045 climate neutrality target. At the EU level, all climate-aligned scenarios show at least a broad 75% decrease in natural gas consumption by 2050.

5. The regulatory and economic context at the global level

Future trends in natural gas markets will be driven by the regulatory framework at the national and global level, primarily set by climate goals that are gaining momentum on political agendas, and the evolution of prices in different world regions, which are becoming increasingly interconnected due to LNG trade.

5.1 The climate policy framework
At the global level, the regulatory framework for the development of the energy system (as well as other areas of the national economy) is primarily limited to agreements within the international climate regime and resulting obligations for individual countries. As a result of the Paris Agreement to the United Nations Framework Convention on Climate Change (UNFCCC), which was adopted on 12 December 2015 and entered into force on 4 November 2016, political and regulatory frameworks for the development of greenhouse gas emissions have been established worldwide. The overarching goal of the Paris Agreement is "holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels" (Art. 2 paragraph 1 (a) Paris Agreement). With a view to this, it obliges the participating states to define Nationally Determined Contributions (NDCs) in a five-year cycle (for the first time in 2020) and to increase their ambitions over time on the basis of global stocktakes, which also take place regularly (for the first time in 2023). In addition to the medium-term goals of the NDCs, "all Parties should strive to formulate and communicate long-term low greenhouse gas emission development strategies" (Art. 4 para. 19 Paris Agreement).

These obligations, under international law, have led countries around the world to define long-term goals in addition to the medium-term goals of the NDCs. In some cases, countries have opted to integrate these goals into national law or incorporate them into national energy strategies.

Firstly, there is significant variation in how these long-term targets define their respective target values. For example, some countries have opted for climate neutrality and others for CO_2 neutrality. For the long-term perspective, many states are guided by net-zero emission targets.

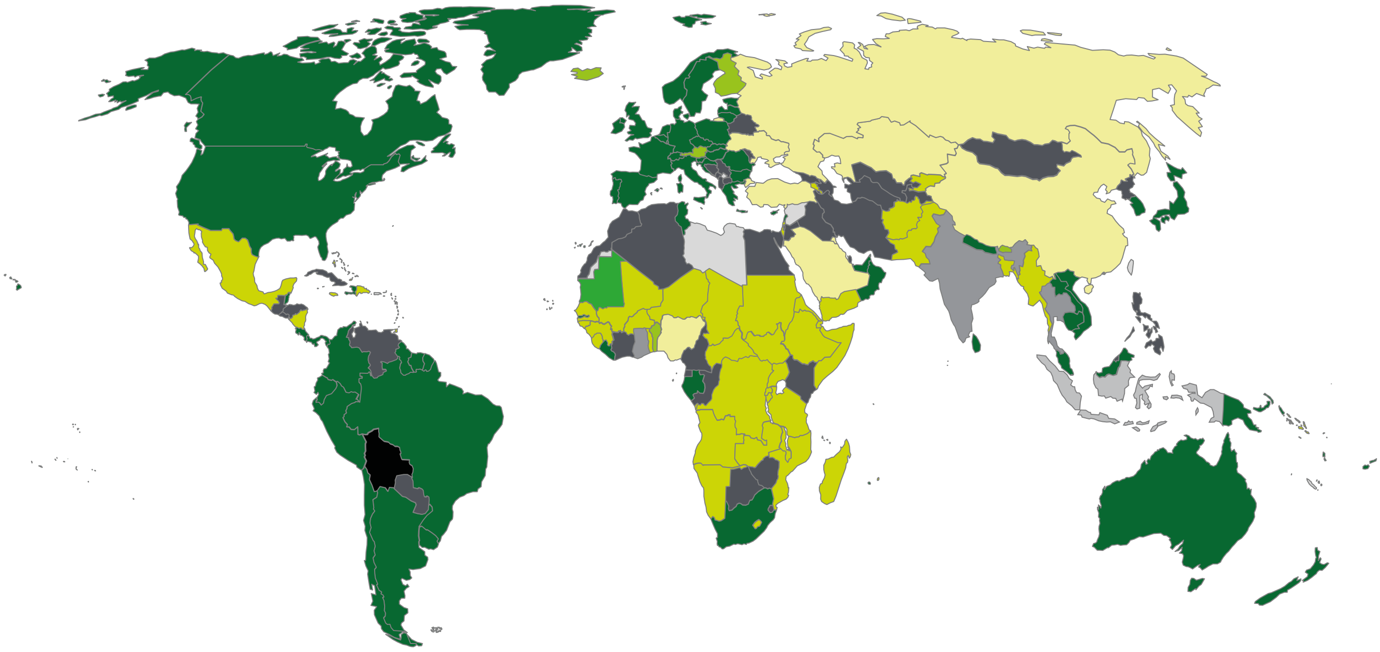
Secondly, the time horizons for the above-mentioned long-term goals differ considerably. While a minority of commitments refer to the period up to 2040, a majority of the countries have set long-term goals for the year 2050. However, some major countries have also defined their long-term goals for the time horizon up to 2060 or even beyond.

The legally and politically binding nature of the targets differs. While in some countries the climate targets are regulated by law, in others they are laid down in political strategy documents. In a number of countries, the long-term goals are still at the proposal stage or are subject to ongoing political and/or legal processes.

The decisions and proposals on the long-term goals also contain several different detailed provisions, such as the use of international flexibility mechanisms.

Figure 5-1 provides an overview of the geographical distribution of long-term climate policy goals. While climate neutrality (or similar commitments) is aimed for by 2050 in North and South America and in Europe, in the democratic industrialized countries of the Asia-Pacific region and in parts of Africa, the time horizons 2060 and partly 2070 dominate for Russia and the remaining Asian region.

Fig. 5-1 – Climate neutrality targets



Climate neutrality targets

- … by 2040 or before, binding
- … by 2040 or before, announced
- … by 2050 or before, binding
- … by 2050 or before, announced
- … by 2060 or before, binding
- … by 2060 or before, announced
- … by 2070 or before
- no climate neutrality etc. target
- no climate target

Source: Oeko-Institut analysis based on Net Zero Tracker (NZT) data: https://zerotracker.net/.

A more detailed analysis of the different commitments and objectives reveal structurally interesting aspects:

- The number of countries that aim for climate neutrality by 2040 or before, or claim to have already achieved climate neutrality, comes to approx. 5% of all countries. These countries account for 0.4% of the world's population and just under 1% of global GDP. The current share of global greenhouse gas emissions and of global consumption of coal, oil, and natural gas of these jurisdictions is far below 1%.

- Nearly 60% of the countries aim for climate neutrality between 2040 and 2050, well over half of them on a binding basis (fixed by law or in other policy documents). These countries are home to more than 40% of the world's population and account for just under 70% (measured in exchange rates) or slightly more than 55% (measured in purchasing power parities) of global value added. Their share of current greenhouse gas emissions is just over 40% and their share of global coal consumption is just under 20%. With regard to the global use of oil and natural gas, these countries' share comes to about 55%.

- Just under 5% of the analyzed countries are pursuing the goal of climate neutrality between 2050 and 2060 (above all China and Russia), mostly on a binding basis. However, these countries are home to almost 30% of the world's population and account for just over 20% or just under 30% (GDP at exchange rates or purchasing power parities) of global value added. This group of countries also comprises slightly more than 40% of the global greenhouse gas emissions in which coal combustion plays a prominent role. Two-thirds of global coal consumption is accounted for by this group. Correspondingly, the shares of global oil and natural gas consumption are relatively low, at just under 30% each.

- For the remaining three countries with long-term goals for climate neutrality, the target dates are 2065 and 2070 respectively, with India an outlier with its goal of climate neutrality by 2070. The share in the global population is correspondingly significant (20%). The shares in global economic power are relatively low, at approx. 4% and 8% (valuation with exchange rates or purchasing power parities). The contribution to global greenhouse gas emissions is also comparatively low, at just under 8%. At approx. 11%, the share of global coal consumption is significantly higher than that of oil (7%) and natural gas (3%).

The climate policy frameworks form a decisive framework for the development of future energy, particularly for natural gas demand. For countries with climate neutrality targets set from 2060-2070, the question arises as to whether the disproportionately high share of coal in both primary energy consumption and greenhouse gas emissions should or can be achieved via an interim switch to lower-CO_2 fossil energy sources or predominantly via a direct switch to CO_2-free energy sources.

The level of, and the global differences in, natural gas prices and the price differences between the various (fossil) energy sources, in addition to the diverse regulatory frameworks at national and global level, are a significant determinant of the future development of natural gas demand and the corresponding exploration projects.

5.2 The economic framework

The global differences in natural gas prices between various (fossil) energy sources, and the diverse regulatory frameworks at national and global level, are a significant determinant of the future development of natural gas demand.

The development of wholesale prices for natural gas since 1990 can be divided into 6 phases, each with different characteristics (see Figure 5-2):

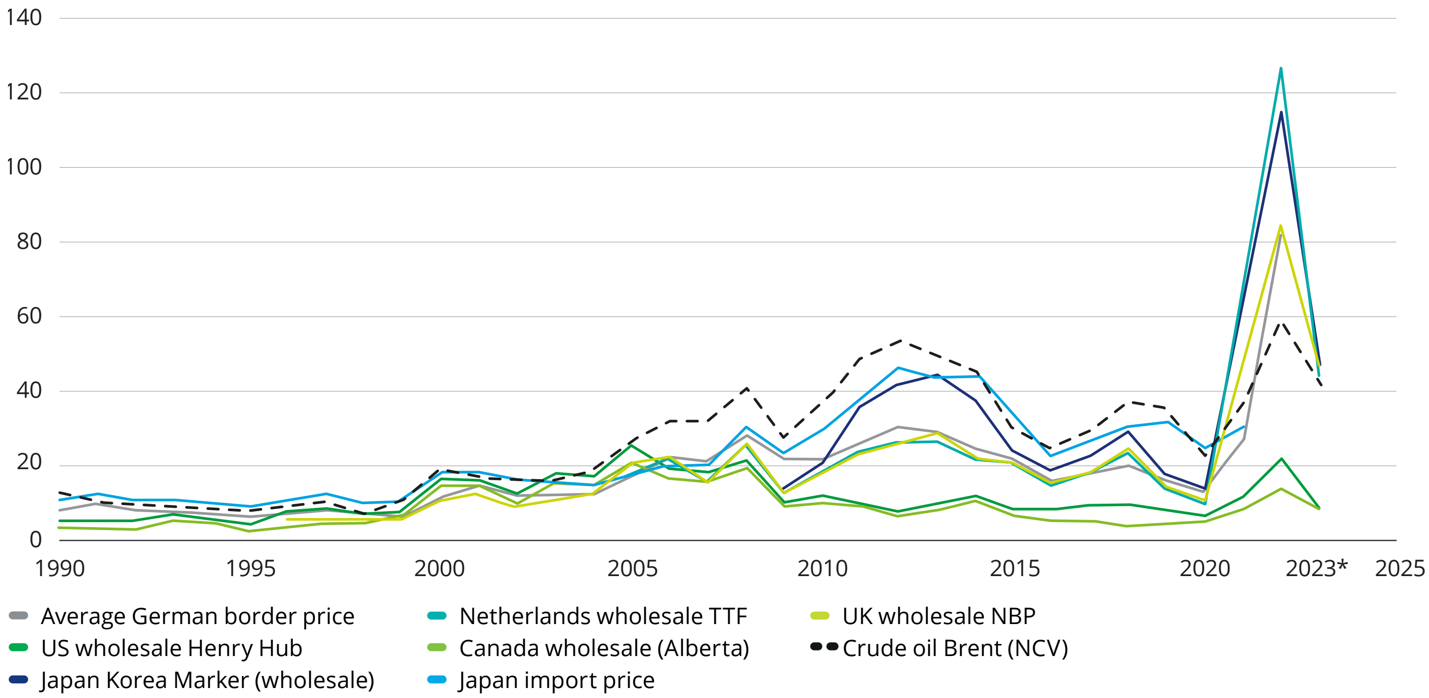
- Until the energy price turbulence in 2008, gas prices followed a relatively stable pattern. They were largely aligned with the price of crude oil, with wholesale prices in northwest Europe as well as in the UK slightly above or below prices in the US (±2 EUR/MWh) in most years. Natural gas prices in Japan were, with few exceptions, typically 2 to 3 EUR/MWh higher than prices in Europe.
- From 2006 onwards, gas and oil prices decoupled significantly, but remained similar in their dynamics. In 2008, however, the price differences between Europe and the US, and especially between the natural gas market in the Far East and Europe and the US, hugely increased. The highest price differences to date were reached in 2012 and were approx. 20 EUR/MWh (Europe-US) and over 30 EUR/MWh (Japan-US).
- Around 2015, prices between Europe and Japan/Korea converged again, with prices in East Asia mostly up to 5 EUR/MWh higher than in Europe. Price differences between Europe and the US remained significant and were mostly in the order of 10 EUR/MWh.
- In the crisis years of the Covid-19 pandemic, natural gas prices in Europe and Japan/Korea declined significantly; the differences to North American prices fell to around 5 EUR/MWh, with the values for Europe remaining significantly below those in Asia.
- With the start of the Russian attack of Ukraine, prices in Europe and East Asia skyrocketed, reaching previously unprecedented levels. In North America, prices (in nominal terms) reached the peaks of the years 2005 to 2008.
- Over the course of 2023, prices in all regions of the world fell again significantly and reached values of just over 40 EUR/MWh in Europe and for deliveries to Japan and Korea. In North America, wholesale prices were below 10 EUR/MWh.

For long-term forward deliveries in northwest Europe (annual futures for 2027 and subsequent years), future deliveries are currently traded on energy exchanges at prices of 30 EUR/MWh.

Fig. 5-2 – Natural gas prices, 1990–2023

EUR/MWh(GCV)

*data for 2023 based on monthly futures as of June 2023



Source: Oeko-Institut analysis based on Energy Institute (EI) Statistical Review of World Energy. European Energy Exchange (EEX): TTF Natural Gas Spot Prices, Intercontinental Exchange (ICE): LNG Japan/Korea Marker (JKM) prices, UK National Balancing Point (NBP) prices, U.S. Energy Information Administration (EIA): Henry Hub Natural Gas Spot Price, Europe Brent Spot Price FOB, Alberta Energy and Minerals: Alberta natural gas reference prices.

Price developments for the next few years will be shaped primarily by two uncertainties: the level of exports of natural gas from Russia and China's natural gas import needs. The development of the last year suggests far-reaching changes for Russia (see Table 5-1). The use of natural gas exports as an economic weapon against the EU caused pipeline imports from Russia to the EU to fall by over 100 bcm by the end of 2022 compared with the previous peak in 2019. Furthermore, the IEA expects a further decline of 35bcm for 2023 (IEA, 2023c). This decline contrasts with an expected expansion of Russia's exports to China via the Power of Siberia pipeline by about 7bcm. Hence, the medium-term price development of gas is subject to a varying degree of uncertainty. For one, it is unclear whether Russian export pipeline quantities of approx. 140bcm will be unavailable to the global market in the long term. Equally, it is uncertain to what extent and for what time horizon Russian exports will find their way onto the world market by other means (new construction of export pipelines to China, massive expansion of LNG liquefaction infrastructure), and whether the resolution of the Russian attack of Ukraine could result in a partial resumption of exports from Russia to the EU.

Tab. 5-1 – Russia natural gas production, consumption, imports and exports, 2015–2022

	2015	2016	2017	2018	2019	2020	2021	2022
					bcm			
Gas production	**584.4**	**589.3**	**635.6**	**669.1**	**679.0**	**638.4**	**702.1**	**618.4**
Domestic consumption	**408.7**	**420.6**	**431.1**	**454.5**	**444.3**	**423.5**	**474.6**	**408.0**
Pipeline imports	26.5	24.3	28.6	24.6	30.3	10.7	14.8	8.1
Pipeline exports	**194.2**	**202.0**	**219.7**	**222.4**	**220.7**	**197.4**	**201.3**	**125.3**
European Union (27)	123.4	132.6	155.0	164.1	166.0	146.4	132.3	61.5
Rest of Europe*	43.4	33.5	34.3	29.7	22.0	21.2	34.7	23.9
CIS**	26.2	24.7	26.2	29.2	28.9	26.1	27.1	25.3
China	0.0	0.0	0.0	0.0	0.3	3.9	7.6	14.7
LNG exports	**14.6**	**14.6**	**15.4**	**24.9**	**39.1**	**41.8**	**39.5**	**40.2**
European Union (27)	0.0	0.0	0.0	5.2	17.4	14.0	14.3	15.8
Rest of Europe	0.0	0.0	0.1	1.7	3.1	17.2	3.1	3.8
China	0.2	0.3	0.6	1.3	3.4	6.9	6.2	6.1
India	0.0	0.0	0.0	0.5	0.3	0.7	0.6	0.6
Japan	10.5	9.5	9.9	9.4	8.7	8.4	8.8	9.2
South Korea	3.5	2.4	2.6	2.6	3.1	2.8	3.9	2.7
Other Asia Pacific	0.3	1.7	2.3	3.3	2.4	3.7	2.8	2.0
Rest of world	0.0	0.0	0.0	0.6	0.8			
Memo item								
Imports to China								
Pipeline	33.6	38.0	39.4	47.9	47.7	45.1	53.2	58.4
LNG	26.2	34.3	52.6	73.5	84.8	94.0	109.5	93.2

Notes: * including Ukraine. ** excluding Ukraine.

Source: Oeko-Institut analysis based on BP: Statistical Review of World Energy, Energy Institute (EI): Statistical Review of World Energy.

However, the development of natural gas imports to China also shows that the extensive loss of Russian exports to Europe can, at best, only be partially compensated for by deliveries to China. The West Siberian gas fields, which previously served the European market (Urengoi, Yamburg and Bovanenkovo), are located several thousand kilometers away from the Chinese gas demand hubs. Today's infrastructure is unable to bring significant amounts of West Siberian gas to China. This uncertainty of more than 10% on the supply side of the international natural gas trade leads to considerable price turbulence on world natural gas markets and to economic vulnerability for natural gas exploration projects.

It should be borne in mind that the level of ambition of international climate change policy can also have an impact on gas prices and therefore on revenues from the sale or export of natural gas. In the World Energy Outlook 2022 projections, natural gas prices in the different world regions will be 31% to 44% lower in 2030 and 30% to 31% lower in 2050 for the climate policy oriented Net-Zero Emission scenario, compared with the Announced Pledges Scenario which includes the recent dynamics of policy plans.

Key results and takeaways

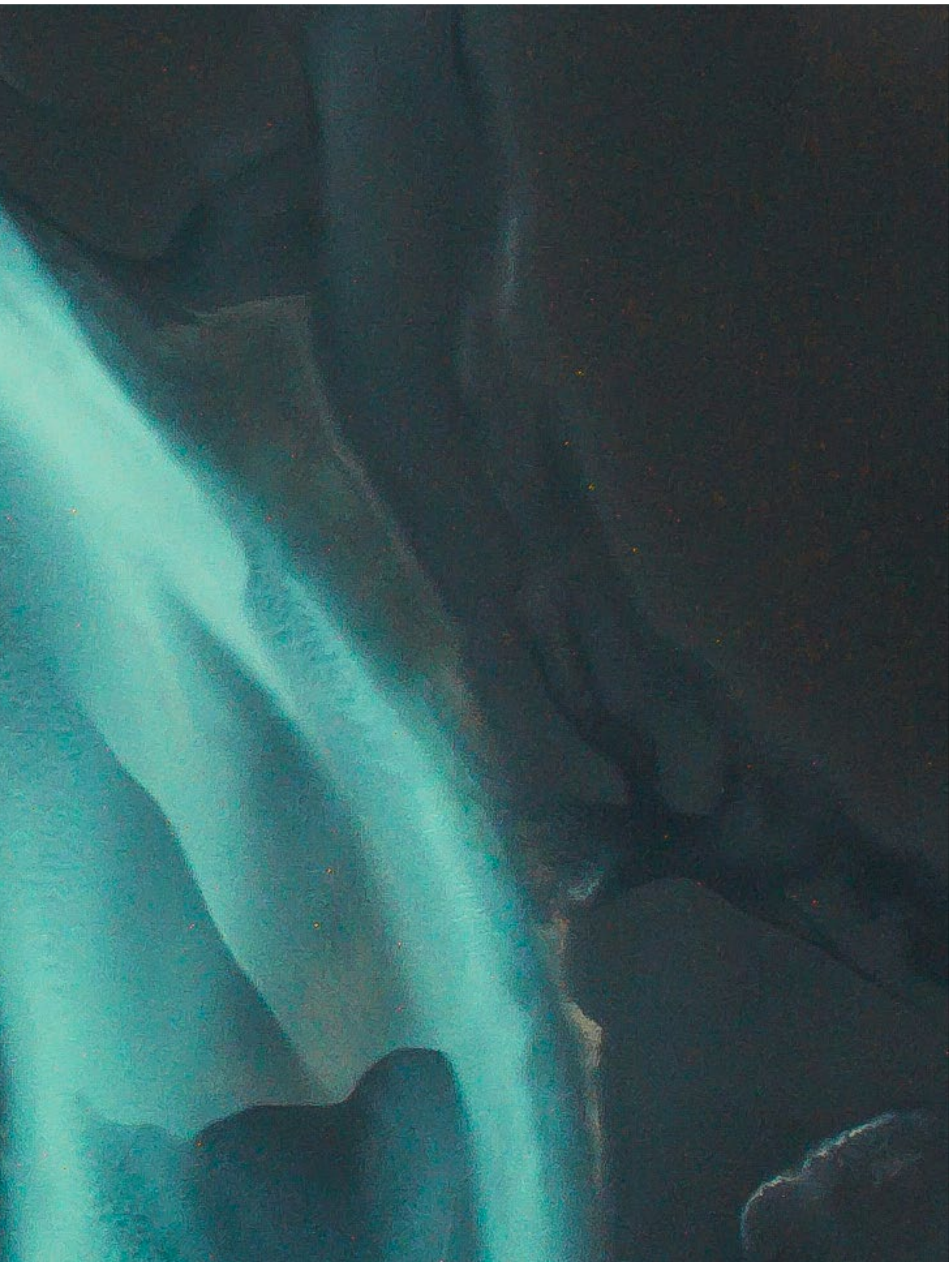
The regulatory framework for the future development of global gas consumption and supply is set primarily by international climate-change policy. Almost all countries in the world have committed to climate neutrality. Although the time horizon for achieving climate neutrality varies (most are by 2050, for some large countries by 2060 or 2070) and the binding nature of the commitments varies in some cases, a huge and relatively rapid reduction in greenhouse gas emissions, including those from the use of natural gas, is clearly on the global agenda.

The economic framework for the future development of natural gas supply is primarily determined by price developments on regional natural gas markets, which are becoming increasingly global due to the transport of LNG. There has been considerable price turbulence in recent years, but following the historic price peaks in 2022, significant price reductions have also been observed. The main uncertainty for natural gas prices, and thus for the profitability of investment in the natural gas supply chain, is whether, when, and via which transport routes natural gas exports from Russia, which have recently decreased hugely, can or will return to the global gas market.

The impact of ambitious climate change policies, which could significantly reduce the price of natural gas, is an additional uncertainty or economic vulnerability for investment in natural gas production and transport infrastructure.

6. The future of natural gas demand worldwide

A comprehensive review of recent global outlooks reveals that, in scenarios compatible with meeting climate objectives, natural gas is projected to lose momentum in the world energy system by 2050. Trends in future demand are assessed in terms of the climate impact of the underlying scenarios, regional and sectoral specificities, and technological developments with a focus on CCS.



6.1 CO_2 emissions and associated temperature scenarios

We examine projected sectoral patterns, assess the role of natural gas in the transition of energy systems and discuss the role of CCS in the different projections. The assessment is based on clustering of the different scenarios according to their climate policy ambition level in relation to a 2°C target.

- The scenarios are harmonized and clustered in this section. The methodology employed to perform the clustering is described in the following box.

- First, the uncertainty cones resulting from the Network of Central Banks and Supervisors for Greening the Financial System (NGFS) scenarios and the different ambition levels are examined on a global level and for different regional disaggregation. In the next step, other projections are added and assessed with respect to their fit with one of the temperature cones.

Methodology used to harmonize the assessment of climate policy ambition levels between different organizations and scenario families

A) In order to associate different demand scenarios with different temperature trajectories, we first start by developing CO_2 emission trajectories (uncertainty cones) that are consistent with different levels of mean global temperature increase by the end of the century. While some energy projections provide temperature levels associated with their respective scenarios, others do not. Even for the scenarios which report associated global mean temperature impact, the different assessment methods, sectoral scopes, and implementations of existing and planned policies result in a lack of common ground for comparison.

B) Therefore, we use a first set of scenarios developed by the integrated assessment modeling community for the NGFS in order to develop CO_2-emissions trajectories that are consistent with different levels of mean global temperature increase by the end of the century.

a.NGFS climate scenarios have been developed for central banks and supervisors to provide a common starting point for analyzing climate risks to the economy and financial system. They are made available on a regular basis, providing both global coverage and regional disaggregation, using integrated and harmonized transition pathways for a common set of climate risk and physical impact scenarios.

b. Scenarios account for uncertainty using three different model suites. Table 6-1 provides an overview of the main characteristics of the scenarios, including associated temperature rise, and assumed speed and depth of policy reactions, technological change, use of carbon dioxide removal, and difference in the policy ambition between regions. Table 6–2 shows the classification of the NGFS scenarios.

c. Each of the scenarios provides input to three independent modeling teams: at IIASA, PNNL and PIK[37]. Each team uses their model to project CO_2 emissions, energy supply and demand, and other central parameters of the energy and climate systems under the different scenarios.

d. The results provide uncertainty cones that are consistent with different levels of mean global temperature increase by the end of the century for the different parameters. Due to the different sectoral coverage and coverage in terms of different GHGs, the trajectories are constructed in relative rather than in absolute terms.

e. As these scenarios explicitly include a climate modeling part, their assessment of CO_2 emissions trajectories and the resulting uncertainty cones are used to cluster projections by other organizations and companies according to their compatibility with a 2°C target.

[37] The modelling teams are part of the integrated assessment modelling community. IIASA (International Institute for Applied Systems Analysis) use their integrated assessment model: MESSAGEix-GLOBIOM, hereafter the model runs with the model are referred to as: IIASA; PNNL (Pacific Northwest National Laboratory) use their integrated assessment model: GCAM, hereafter the model runs with the model are referred to as: PNNL; PIK (Potsdam Institute for Climate Impact Research) use their integrated assessment model: REMIND-MAgPIE, hereafter the model runs with the model are referred to as: PIK.

Tab. 6-1 – Classification of NGFS scenarios

Organization	Scenario	Policy ambition	Policy reaction	Technology change	Carbon dioxide removal	Regional policy variation
Orderly	Net Zero 2050	1.4°C	Immediate and smooth	Fast change	Medium-high use	Medium variation
	Below 2°C	1.6°C	Immediate and smooth	Moderate change	Medium-high use	Low variation
Disorderly	Divergent Net Zero	1.4°C	Immediate but divergent across sectors	Fast change	Low-medium use	Medium variation
	Delayed Transition	1.6°C	Delayed	Slow/Fast change	Low-medium use	High variation
Hot house world	Nationally Determined Contributions (NDCs)	2.6°C	NDCs	Slow change	Low-medium use	Medium variation
	Current Policies	3°C+	None- current policies	Slow change	Low use	Low variation

Source: NGFS (2022a).

C) Adopting the items used to classify the NGFS scenarios, the tables in Appendix 2 extend the assessment to the other energy projection scenarios. Importantly, the table also reports whether the respective scenario accounts for the Russian attack of Ukraine. This has had major implications on energy commodity flows for natural gas, coal, and oil, and has induced policy reactions in the EU and in other parts of the world.

Figure 6-1 shows trajectories of CO_2 emissions in different temperature scenarios on the global level (Panel a) for the group of Democratic industrialized economies. It uses values calculated for Europe, North America, Japan, and the rest of the world, for the time period 2020 to 2100.

On a global level, uncertainty cones can be classified as follows:

- Scenarios that are not consistent with limiting global temperature rise to below 2°C form two distinct cones where emissions remain at the 2020 level throughout the century and even increase (3°C+ scenarios) or decrease moderately up to 2050 and beyond (2.6°C scenarios).

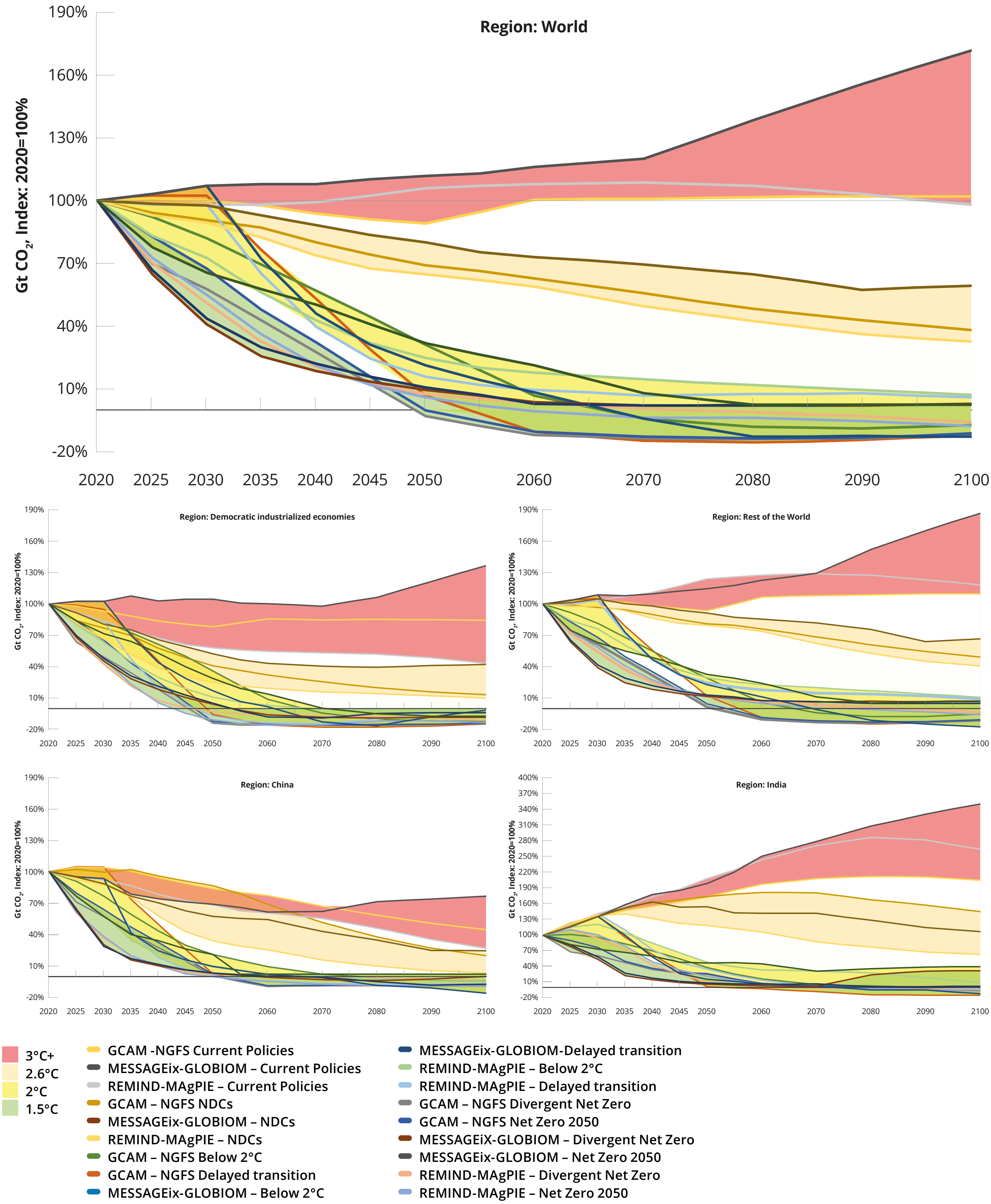
- Up to 2030, scenarios consistent with a 2°C target show a broad range of emissions trajectories, ranging from an increase of 7% to a decrease of approx. 40%. For the period 2030 to 2050, the trajectories are distinct, with a variety of possible pathways. The more climate ambitious scenarios show a steadier decline of emissions, while the less ambitious scenarios, where emissions initially even increase, show a much steeper decline in emissions after 2030. According to these figures, emissions must decrease by 70% or more, relative to 2020 levels, to stay in reach of the 2°C target.

- The figure clearly highlights that the scenarios meeting climate ambitions, with moderate emission decline up to 2050, significantly rely on net negative emissions in the period after 2050 to reach climate targets by the end of the century. For the most ambitious scenarios, net negative emissions will already be at a level of 4% by 2050, while for the scenarios with a more moderate emissions trajectory, net negative emissions will reach a level of 15% and above, relative to 2020 levels, towards the end of the century.

Countries which do not belong to the Democratic industrialized economies group account for the bulk of CO_2 emissions. Therefore, trajectories for these countries (referred to as Rest of the World, RoW) show the same basic pattern as the number at the global level, but the temperature cones are much closed together. The different paths for the 2.6°C and the 2°C cones highlight the need for continued emissions reduction and also underline the role of net negative emissions after 2050, particularly in scenarios with less rapid decline in emissions up to 2050. In these countries, net negative emissions are deployed to levels of up to 15% of 2020 emissions levels by 2050. For the remaining countries, net negative emissions are only reached after 2050.

The remaining global patterns are dominated by emissions trajectories in China and India. However, these clearly diverge. For China, 2°C-compatible trajectories allow for the plateauing of emissions by 2030 at the latest, whereas for India an increase of more than 40% could still be climate-compatible. In the time-frame to 2050, 2°C compatible scenarios require a decline in emissions of at least 80% for China, while for India, a reduction of just under 50% in emission levels is required, compared with 2020 levels. Scenarios limiting temperature increase to a maximum of 2°C degrees project net negative emissions for China starting by 2060-2070, while the bulk of the same scenarios sees net negative emissions for India starting only by 2070-2080. Some of them do so entirely without net negative emissions, and emission levels remain at around 40% of 2020 level. These emissions are compensated by net negative emissions in other parts of the world. Maximizing final levels of net negative emissions come to approx. 15-20% for both countries by the end of the century.

Fig. 6-1 – Trajectories of CO_2 emissions in different temperature scenarios, 2020–2100



Source: Oeko-Institut analysis based on Global-ScenSe-Database

Figure 6-2: Trajectories of CO_2 emissions in different energy projection scenarios and cones of scenarios with different climate ambition levels, on the global level and for different regional groupings, 2020-2050. Shows the trajectories of CO_2 emissions reported in the other projections against the cones of different ambition levels, by way of global mean temperature increase. Most of the other projections only provide numbers for the time horizon to 2050, with the exception of projections by Shell, which also provides figures to 2100. Therefore, the following analysis focuses on the time horizon to 2050. The different panels again show data on different regional disaggregation.

- On the global level, the analysis yields two distinct groups for the scenarios from other projections: The first group are scenarios clearly missing the 2°C target. These include: Teske et al. 2019 Reference, EIA ref2021, ExxonMobil, IEA STEPS, Shell Archipelagos, BP Momentum, and Equinor Walls. In the second group of scenarios, the 2°C target is within reach. These include IEA NZE[38], BP Accelerate, Shell Sky 2050, BP Net Zero, and Teske et al. 2019 2°C. The IEA APS is clearly at the outer edge of the scenario cone compatible with 2°C. The Teske et al. 2019 Scenarios represent extremes, with either their drastic speed of emissions reductions (1.5°C scenario) or emissions increase, even going beyond the 3°C+ cone (Reference Scenario). The Equinor Bridges scenarios also fall out of the two groups. Gross emissions are reduced by 75% by 2040. Adding CO_2 captured[39] and assuming that all of it is permanently stored results in a net emissions reduction of over 90% by 2040, compared with 2020 levels. Following the same logic, net negative emissions will be above 15% of 2020 emission levels by 2050.

- When zooming in on the democratic industrialized economies, the clustering of scenarios in terms of climate ambition compatibility remains largely intact. Again, two groups are distinct. Teske et al. 2019 Reference, EIA ref2021, ExxonMobil, IEA STEPS, Shell Archipelagos, and Equinor Walls. The BP Momentum scenario is the least ambitious trajectory of the 2°C compatible cones, while the Shell Sky 2050 scenario is a more balanced scenario in terms of emission-reduction ambitions; the remaining scenarios can be associated with ambitious emission-reduction trajectories, toward the lower boundary of the 2°C compatible cone. While the NGFS scenarios see the Democratic Industrialized Countries group as front-runners in reaching net negative emissions by 2050, the other projections reach net-zero emissions no later than 2050.

- For countries in the Rest of the World grouping, the clustering is less clear. The uncertainty cones which indicate the respective increases in mean global temperature are far narrower, in particular for the 2°C-compatible temperature cones (see the green and yellow areas in the respective panel of Figure 6-2). More of the other energy scenarios thus fall out of the 2°C compatible range. Again, Teske et al. 2019 Reference, EIA ref2021, ExxonMobil, IEA STEPS, Shell Archipelagos, BP Momentum, and Equinor Walls, clearly miss the 2°C-compatible range. Additionally, the IEA APS is out of the range. The BP Accelerate scenario moves to the upper boundary of the 2°C-compatible scenario cone for this country grouping. While Shell Sky 2050 is again less ambitious, BP Net Zero, Equinor Bridges and Teske et al. (2019) 2°C are towards the lower boundary of the 2°C-compatible cone. However, it must be noted that the Equinor Bridges scenario reports specific CO_2 capture on the global level, but does not indicate how it is distributed across the different regions. Taking into account the CO_2 captured would render this scenario an outlier, again exceeding the most ambitious emission reductions reported in the NGFS scenarios.

- A focus on China within the other energy projections reveals similar results to the global level, albeit with two exceptions: the Teske et al. 2019 1.5°C scenario is less extreme when compared with the NGFS scenarios, while the Equinor Bridges scenario is more moderate. Again, it must be noted that the picture might change if CO_2 capture is accounted for.

- The results on the global level are also valid when zooming in on India, however the sorting of the scenarios within the clusters shifts. For example, ExxonMobil's projection is much more moderate in its CO_2 trajectory for India, compared with its relative position for all the groupings of countries previously described. The BP Accelerate scenario clearly falls out of the 2°C-compatible cone, while the IEA APS is at the very upper edge of the scenario cone.

Following the analysis above, some of the other energy projection scenarios are incompatible with the 2°C target, according to their CO_2 emissions trajectories. This is true for the following group of scenarios (see Table 6-2): Teske et al. 2019 Reference, EIA ref2021, ExxonMobil, IEA STEPS, Shell Archipelagos, and Equinor Walls. The BP Momentum scenario clearly misses the target on the global scale, despite the emission-reduction trajectory for democratic industrialized countries being compatible with the Paris target. In contrast, the following group of scenarios achieve the necessary emission reductions for the Paris climate target: BP Net Zero, Teske et al. (2019) 2°C, Equinor Bridges and Teske et al. (2019) 1.5°C. The remaining scenarios, namely, BP Accelerate, Shell Sky 2050 and the IEA APS, fall into the cone of climate-compatible scenarios for some groupings of countries, while ambitions are too low for other groupings.

[38] Note that values for the IEA NZE scenarios were only available at the global level and are therefore not analysed in the sections with more detailed regional disaggregation.

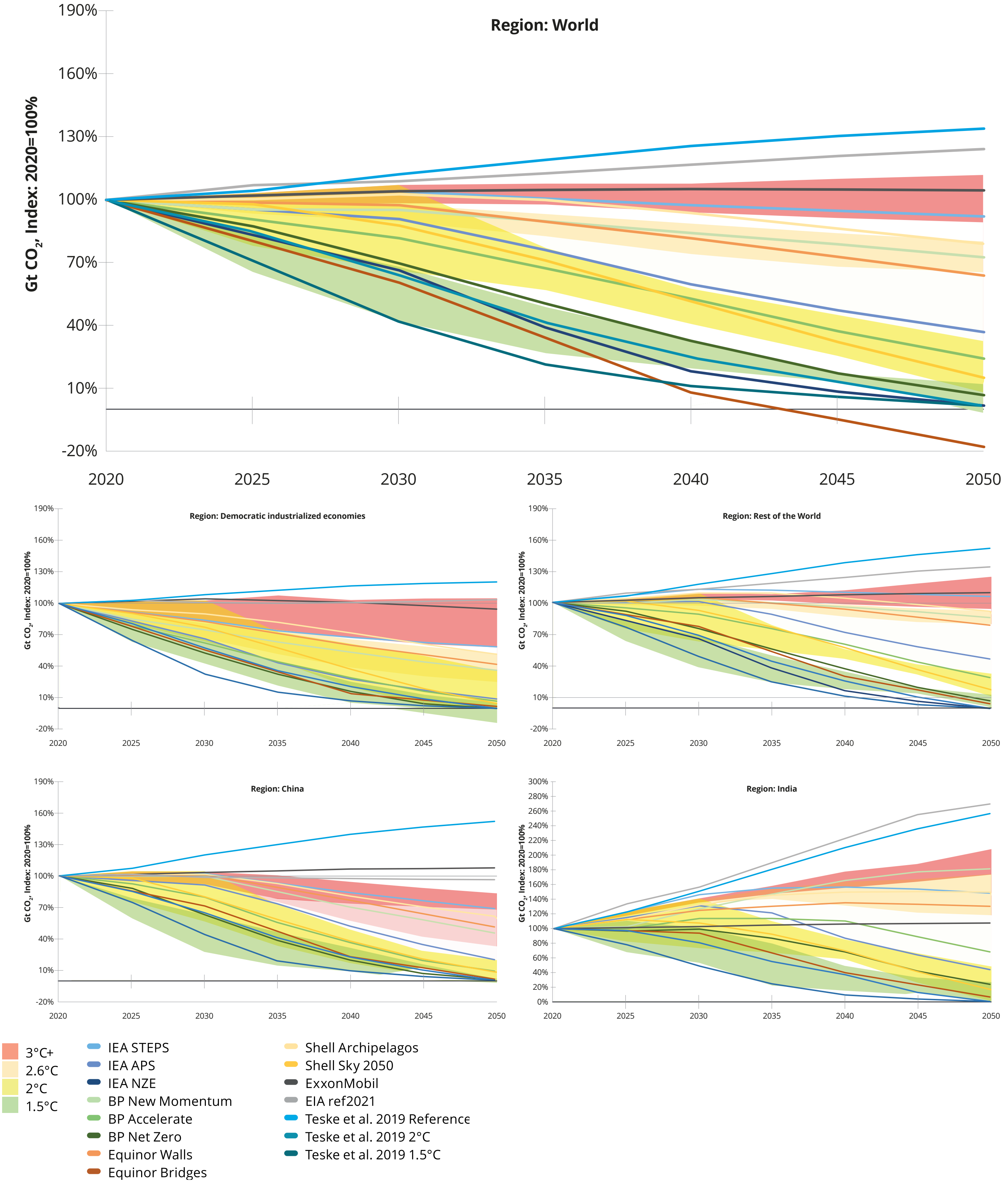
[39] There is no specification on the share of captured CO_2 that reemitted into the atmosphere as part of a carbon capture-and-use cycle as compared with the share that is permanently stored.

Tab. 6-2 – Clustering of scenarios from different energy system projections according to their CO_2 emissions trajectories

Organization	Scenario	Clearly in the 2°C compatible scenario cone	Clearly out of reach of 2°C compatible scenario cone	Unclear
IEA	IEA STEPS		X	
	IEA APS			X
	IEA NZE	X		
BP	BP Accelerate			X
	BP Net Zero	X		
	BP New Momentum		X	
Equinor	Equinor Walls		X	
	Equinor Bridges	X		
Shell	Shell Archipelagos		X	
	Shell Sky 2050			X
ExxonMobil	ExxonMobil Outlook for Energy		X	
EIA	EIA ref2021		X	
Teske et al. 2019	Teske et al. 2019 Reference		X	
	Teske et al. 2019 2°	X		
	Teske et al. 2019 1.5°	X		

Source: Oeko-Institut.

Fig. 6-2 – Trajectories of CO_2 emissions in different energy projection scenarios and cones of scenarios with different climate ambition levels, on the global level and for different regional groupings, 2020-2050.



Source: Öko-Institut analysis based on Global-ScenSe-DB.

Key results and takeaways

NGFS scenarios that are tailored to meet temperature targets by 2100 suggest that scenarios consistent with a 2°C target show a broad range of emission trajectories, ranging from a small to a significant decrease, by 2030. With a view to 2050, emissions must decrease by 70% or more, relative to 2020 levels, to stay in reach of the 2°C target. Moderate emissions decrease up to 2050 and significantly rely on net negative emissions after 2050 to reach climate targets by the end of the century. A rapid decline in emissions is the common pattern in ambitious climate scenarios at the global level for the group of industrialized democratic countries, China and the Rest of the World block, while for India stagnation or even an increase in emissions by 2035 could be compatible with a 2°C target

Other energy projection scenarios can be clustered into three groups based on their emission trajectories. The following scenarios are clearly not compatible with the 2°C target: Teske et al. 2019 Reference, EIA ref2021, ExxonMobil, IEA STEPS, Shell Archipelagos, and Equinor Walls and BP Momentum. In contrast, the following group of scenarios achieve the necessary emission reductions for the Paris climate target: BP Net Zero, Teske et al. (2019) 2°C, Equinor Bridges and Teske et al. (2019) 1.5°C. The remaining scenarios, namely, BP Accelerate, Shell Sky 2050 and the IEA APS, fall into the cone of climate-compatible scenarios for some groupings of countries, while ambitions are too low for other groupings.

6.2 Natural gas primary energy supply
This section analyzes primary energy supply from natural gas compatible with different ambitions for temperature increases by the end of the century. Figure 6-3 shows the uncertainty cones opened by the different trajectories of primary energy supply from natural gas, according to different levels of policy ambition.

- There is strong overlap in the trajectories for-hot house scenarios (3°C+ and 2.6°C scenario), which project an increase of about 20% to more than 90% relative to 2020.

- However, according to the scenario calculations, a broad range of potential supply levels can also be consistent with a 2°C target, even including a net increase in consumption on the global level up to 2050, relative to 2020 levels. Scenarios projecting an increase in consumption all involve slow technological change and a high use of CDR technologies (below 2°C CDR scenarios). The analysis changes significantly when these scenarios are highlighted in the 2°C scenarios. In this case, there is still overlap in the trajectories of the remaining 2°C-compatible scenarios, with the scenarios associated with higher levels of temperature increase projecting a plateau or even an increase in primary energy supply from natural gas by 2035. Starting from 2035 onwards, the scenarios all show a significant decline in primary natural gas supply to levels of 50% and below, relative to 2020 levels. This is also the upper edge of the scenario cone formed by the even more ambitious scenarios. Even in these scenarios, primary natural gas supply does not drop below 30% of 2020 levels by 2050.

- For the most ambitious set of climate policy scenarios, the difference in the resulting cone between the set of scenarios with a high use of CDR (Net-Zero 2050) and with a lower use (divergent Net-Zero) is much less pronounced than for the former set of scenarios. This is true on the global level, but also when zooming down to the regional level. Therefore, these scenarios are not separated out into an individual cone.

The overlap in trajectories still prevails when zooming in on the regional level.

- If the CDR-intensive scenarios are included, 2°C-compatible trajectories of natural gas supply for the democratic industrialized countries group range from a decrease in supply of 45% to an increase of about 20% by 2035, relative to 2020 levels. If they are excluded, the cone narrows for 2035 from a range of 55% to above 90%, compared with 2020 levels.

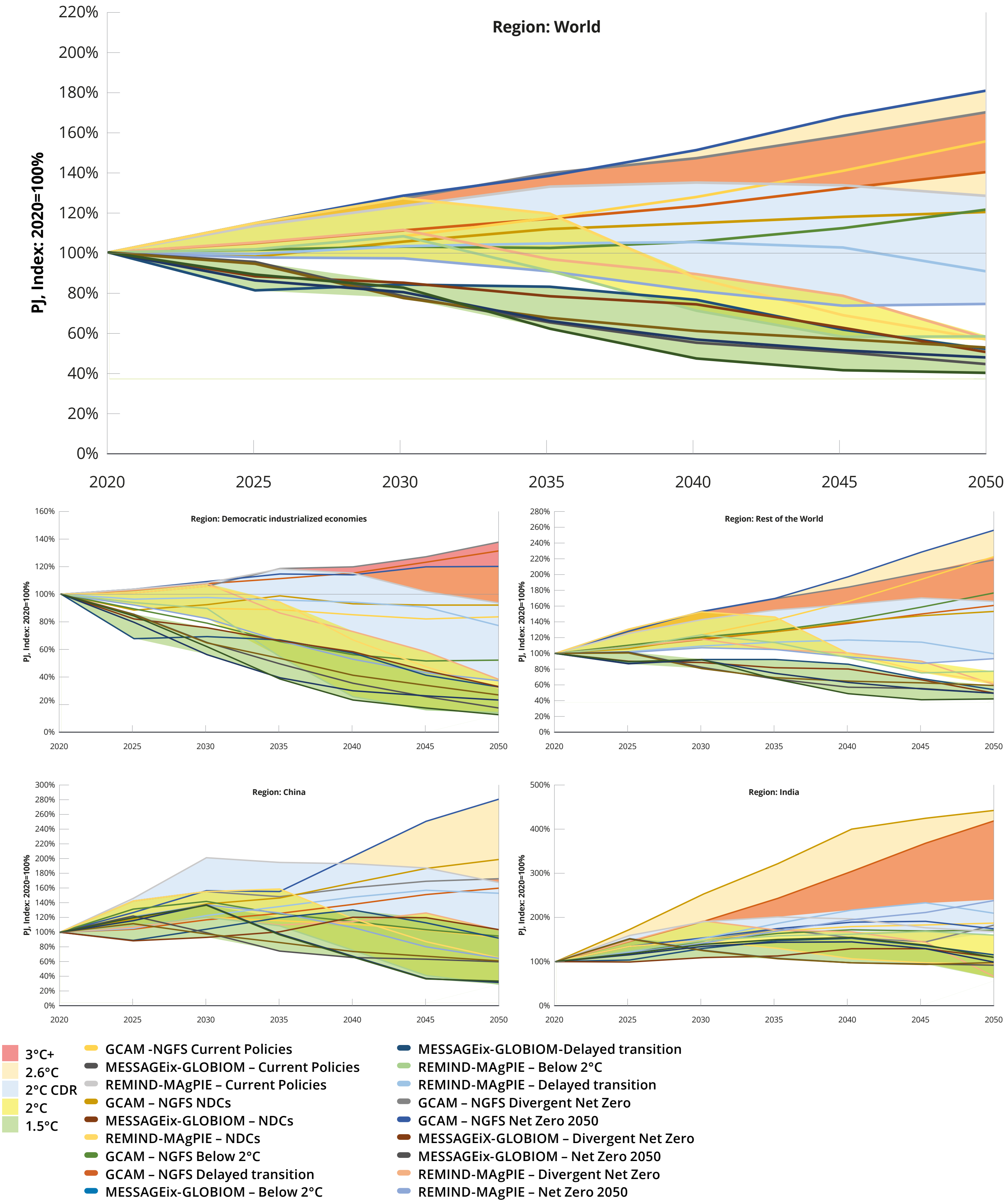
- For the 2050 perspective, there is again a large difference, depending on whether the CDR scenarios are included or not. In the former, primary natural gas supply levels remain at less than 10% below 2020. In the latter, natural gas supply is reduced by more than 60% by 2050, relative to 2020 levels.

- For the even more ambitious climate scenarios, the cone for 2050 range from more than 70% to about 90% reduction in primary energy supply from natural gas, relative to 2020 levels.

The bulk of primary energy supply from natural gas occurs in the countries found in the Rest of the World country grouping. Hence, they dominate the trend on the global level and the patterns observed on the global level are repeated for the RoW country grouping. There is a clear divergence between the trajectories for 2°C-compatible scenarios and the even more ambitious set of scenarios. For the CDR-intensive scenarios, the former can be associated with an increase in primary natural gas supply of up to almost 70% by 2045, and only a slight decline to approx. 60% by 2050. For scenarios employing less CDR, trajectories are notably different. Although they include an increase of more than 40% by 2035, relative to 2020 levels, primary energy supply from natural gas declines to levels between 60% and 80% by 2050. For the more ambitious scenarios, supply trajectories plateau by 2025 at latest and then decline to between approx. 45% to 60% by 2050, relative to 2020 levels.

For China, there is no clear picture of the trajectories of primary energy supply from natural gas for different temperature targets. Trajectories for scenarios clearly missing the 2°C targets range from an increase in demand of almost 200% to a reduction of about 10% compared with 2020 levels. For scenarios compatible with the 2°C target, the range is equally large, but shifted downwards: here, trajectories range from an increase of more than 70% to a decrease of almost 70% by 2050, compared with 2020 levels. The upper boundary of this scenario cone is again defined by CDR-intensive NGFS scenarios (below 2°C scenarios). The other 2°C scenarios and the even more ambitious scenario cone have a high degree of overlap from 2040 onwards. 2050 levels range from a reduction of 70% to an increase of 4%, compared with 2020 levels. For India, the general trends in trajectories are quite similar to those observed for China.

Fig. 6-3 – Development of primary energy supply for natural gas for different NGFS scenarios, world and different country groupings, 2020–2050



Source: Oeko-Institut analysis based on Global-ScenSe-DB.

Figure 6-4 shows the trajectories for primary energy supply from natural gas consistent with different temperature increases for the EU.

- The uncertainty cones are wide and highly overlapping. Trajectories for scenarios that clearly miss the 2°C target range from an increase of more than 70% to a decrease of less than 50% by 2050, compared with 2020 levels. The range for the set of scenarios achieving the 2°C target and below also show a large spread ranging from an increase of 40% and a decrease of almost 95% by 2050, compared with 2020 levels.

- CDR-intensive scenarios are again at the upper bound of the cone, with trajectories including an increase of 40% but also decreasing by about 60% by 2050, compared with 2020 levels. Less CDR-intensive 2°C scenarios and more ambitious scenarios again overlap with a 60% to 95% decrease in primary energy supply from natural gas by 2050, compared 2020 levels.

- 2°C-compatible scenarios allow for a moderate increase in natural gas demand until 2030 at the latest, with first a slow and then a steep decline to a level below 60% in the following years. According to the scenarios, early and intensive use of CDR can extend the plateau period by 10 years and even allow for increasing shares by 2050.

- However, it must be noted that the NGFS scenarios do not include the effects and measures taken as a reaction to the Russian attack on Ukraine. The demand level projected in the scenarios for the EU can thus be regarded as an overestimate.

Figure 6-5 shows the trajectories of primary energy supply from natural gas for other energy projection scenarios (lines) against the background of scenarios for different climate ambition targets (areas, uncertainty cones) on the global level (first panel on top) and for different regional groupings (other panels). The clustering of energy projection scenarios according to their CO_2 emission trajectories as performed in the previous section is still valid for primary energy supply from natural gas but needs refinement.

- If the cone of all 2°C-compatible scenarios were to be taken as a reference, all trajectories but the Teske et al. 2019 Reference scenario could be 2°C-compatible. However, if the cones are refined further, only the five scenarios identified as clearly within the 2°C-compatible cone of scenarios in Table 6-2 overlap with the less CDR-intensive 2°C-compatible scenarios, and with the even more ambitious ones from 2020 to 2050.

- The trajectories projected in the other scenarios only overlap with the CDR-intensive 2°C-compatible set of NGFS scenarios. The IEA APS and the BP Accelerate scenario are again in between the clusters, while the Shell Sky 2050 trajectory is clearly in line with the less CDR-intensive and more ambitious climate scenarios.

The clustering is very similar when analyzing the regional grouping of democratic industrialized countries.

- Again, the Teske et al. 2019 Reference scenario is far off compared with the other scenarios. The EIA 2021ref scenario and the projection by ExxonMobil do not converge towards a 2C°-compatible trajectory.

- The trajectories for primary energy supply of natural gas imply that the Equinor Walls scenario, the BP Momentum scenario, the IEA STEPS scenario, and the Shell Archipelagos scenario could only be compatible with a 2°C target in a CDR-intensive world.

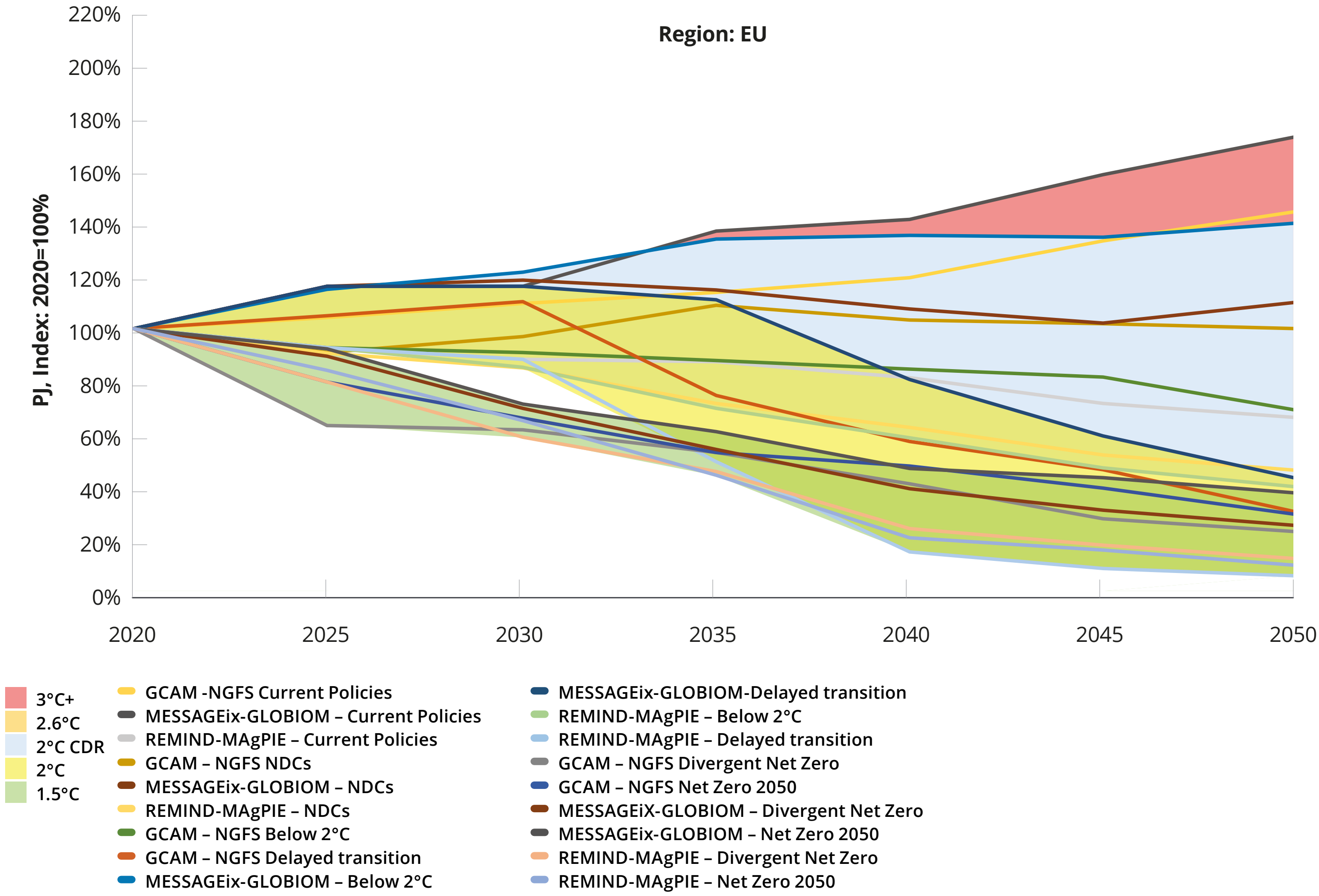
- Trajectories in the other scenarios are consistent with a less CDR-intensive world and scenarios with even more stringent climate targets.

For the rest of world, the clustering of the trajectories of primary energy supply from natural gas resembles the global picture. Trajectories of the four projections clearly in the 2°C-compatible set of scenarios have a high degree of overlap with the cone of most ambitious climate scenarios. The trajectory for the Shell Sky 2050 scenario is somewhat in between the less CDR-intensive 2°C-compatible scenarios and the more stringent ones. The IEA APS and the BP Accelerate scenario follow a trajectory that would be consistent with a CDR-intensive 2°C-compatible world, however, the projected values are at the lower edge of this cone.

For China, only the trajectories of four scenarios are outside the 2°C-compatible scenario cone. These are: the Teske et al. 2019 Reference scenario, the BP Momentum scenario, the EIA 2021ref scenario, and the Equinor Walls scenario. The value of 2050 of the IEA STEPS scenario and the projection from ExxonMobil are only compatible with the CDR-intensive 2°C scenarios. Given the broad span of the uncertainty cones formed by the other 2°C-compatible scenarios, the trajectories of the other energy projection scenarios could be in line with one of them.

For India, there is divergence between the clustering according to the CO_2 emission trajectories, as performed in the previous section, and those implied by the trajectories of primary energy supply from natural gas for the other energy projection scenarios, as shown in Figure 6-5.

Fig. 6-4 – Development of primary energy supply for natural gas for different NGFS scenarios, EU, 2020-2050



Source: Oeko-Institut analysis based on Global-ScenSe-DB.

- The clustering remains unchanged for the Teske et al. 2019 scenario, the EIA 2021ref scenarios, the BP Momentum scenario and the IEA STEPS scenario.

- However, the BP Accelerate scenario also clearly misses the 2°C-compatible cone, as does the BP Net Zero scenario. At the same time, the Sky Archipelagos scenarios is at the upper boundary of the 2°C-compatible scenarios cone involving CDR. IEA APS and Equinor Walls, which also broadly overlap here.

- The projected trajectory by ExxonMobil is consistent with the cone formed by the less CDR-intensive and the more stringent scenarios. The Shell Sky 2050 scenario is at the lower boundary of the most ambitious scenario cone, as is the Equinor Bridges scenario. Teske et al. 2019 2°C and 1.5°C are even more ambitious than the scenarios forming the 1.5° scenario cone.

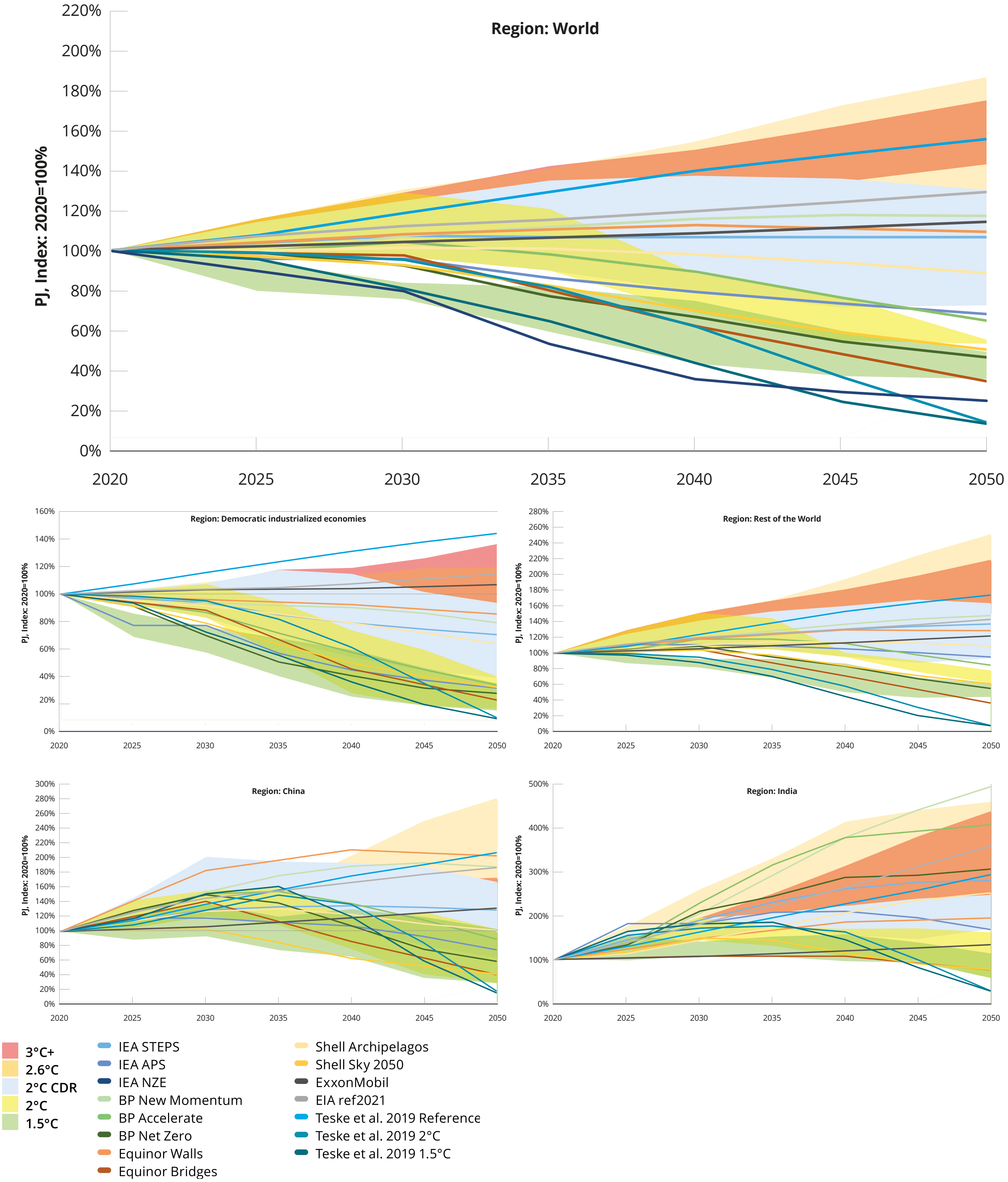
Figure 6-6 shows the development of primary energy supply from natural gas in different projections and uncertainty cones with different climate ambition levels for the EU, for the period 2020 to 2050.

- The trends are broadly in line with the trends for the democratic industrialized countries, despite some significant changes. The CDR-intensive 2°C-compatible scenarios (mainly in the blue-shaded area) open a large scenario space of possible trajectories that could be consistent with the Paris target. Trajectories of primary energy supply from natural gas of all projections therefore end up in 2°C-compatible scenario cone.

- However, the trajectories of the following scenarios are only compatible with a CDR-intensive 2°C world: Teske et al. 2019 Reference, EIA 2021ref, ExxonMobil, BP Momentum, Shell Archipelagos, IEA STEPS. These scenarios show a moderate increase in primary energy supply from natural gas, plateauing, or even declining, to below 50% by 2050, relative to 2020. The other scenarios all show a strongly declining trajectory, declining from 75% to approx. 95% by 2050, relative to 2020. They are consistent with the cone of the most ambitious climate scenarios.

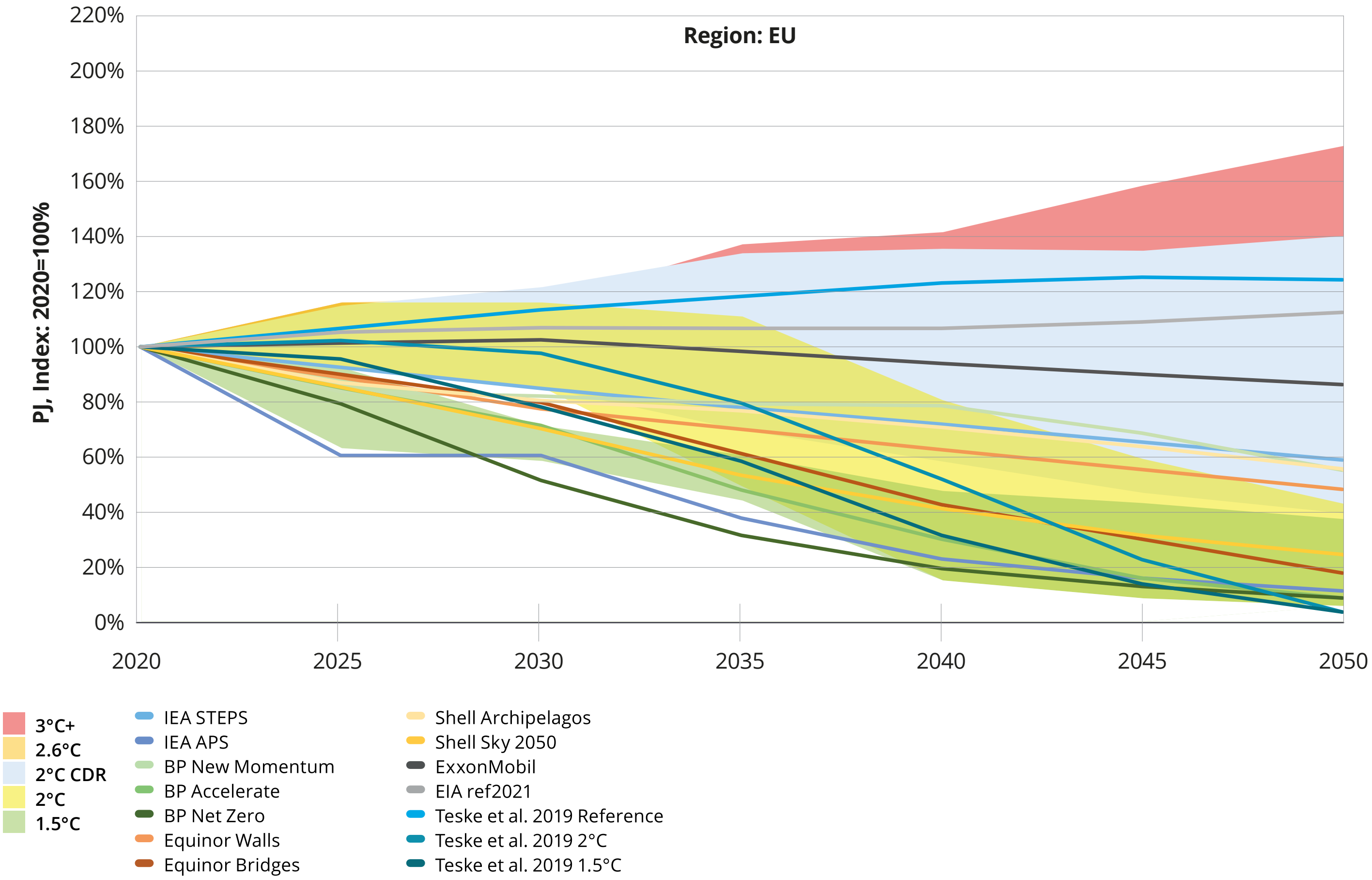
While the NGFS scenarios do not consider the effect of the Russian attack of Ukraine in their projections, all the scenarios taking the invasion into account (namely all IEA, BP, Equinor and Shell scenarios) show a decline in primary energy supply from natural gas from 2020 to 2025. However, the magnitude of the decline depends on the overall ambition of the scenario. All scenarios not clearly out of reach of the 2°C target show an increase in the speed of decline after 2030 at the latest.

Fig. 6-5 – Development of primary energy supply for natural gas in different energy projection scenarios and cones of scenarios with different climate ambition levels, on the global level and for different regional groupings, 2020-2050



Source: Oeko-Institut analysis based on Global-ScenSe-DB.

Fig. 6-6 – Development of primary energy supply for natural gas in different energy projection scenarios and cones of scenarios with different climate ambition levels, EU, 2020-2050



Source: Oeko-Institut analysis based on Global-ScenSe-DB.

6.2.1. Regional contribution to changes in total primary energy supply from natural gas

Figure 6-7 shows the change in primary energy supply from natural gas from 2025 to 2050, by energy projection and the contribution of different regions to the change. There is a clear divergence in the development of natural gas primary energy supply between scenarios in the 2°C-compatible cone of scenarios, those clearly out of reach of the 2°C-compatible cone, and those that cannot be clearly grouped into either of the clusters.

Scenarios out of reach of the 2°C-compatible scenario cone have the following characteristics:

- Natural gas primary energy supply increases by 21%-22% at most from 2025 to 2050 (BP New Momentum and EIA ref2021). However, even with no climate ambition, some scenarios see a more moderate increase of 3%-6% or even a decline in natural gas primary energy supply by 12% in the period 2025 to 2050. If the same comparison is made between 2020 and 2050 a more pronounced increase arises, according to the EIA ref2021 scenario with an increase of 31% (not shown in Figure 6-7). Relative change in the IEA STEPS, Equinor Walls and ExxonMobil scenarios increases by a few percentage points.
- There are regions where primary energy supply from natural gas increases, but also where it decreases. In absolute terms, the US and the EU contribute most to the decrease, while the increase is dominated by India, China, the Middle East and, in some of the scenarios, also by other countries (Rest of World). Notably, Africa also significantly contributes to the total increase. Given the small share of primary energy supply from natural gas that can be attributed to Africa in 2020, the scenarios assume a huge extension of natural gas use in African countries.

Scenarios that are either in the 2°C-compatible scenario cone or are not clearly clustered in one of the groupings have the following characteristics:

- Total primary energy supply from natural gas decreases substantially from 2025 to 2050. The total decline ranges from 60% to 70% for BP Net Zero and Equinor Bridges. The two most ambitious scenarios by Teske et al. 2019 project a decrease of primary energy supply from natural gas of more than 90%. None of the scenario foresees a full termination of natural gas primary energy supply by 2050. For scenarios labeled as unclear, total primary energy supply from natural gas also declines by 30% to 50% in the period 2025 to 2050.
- Solely the BP scenarios project an increase in natural gas primary energy supply within India and, to a much smaller extent, Africa, in the period 2025 to 2050. In all other scenarios and for all other regions, a decline in primary energy natural gas supply is projected.
- Throughout the scenarios, the US shows the largest total decrease in natural gas primary energy supply. Depending on the scenario, the decrease in natural gas primary energy supply in Russia, the EU and Middle East are the next largest contributors. China also contributes 3%-6% to total decrease. Countries grouped as the Rest of the World contribute 6%-17% to the bulk of the scenarios, while in the Equinor Bridges scenario they contribute 37%. Japan, India, and Africa account for smaller fractions of total decline (2%-4% each). At the global level, the picture does not change if the period is extended from 2020 to 2050. At the regional level, the US is the largest contributor to total reduction. Depending on the scenario, the decrease in natural gas primary energy supply in Russia, the EU and Middle East are the next largest contributors. China's contribution amounts to 3%-8% in the same time frame.

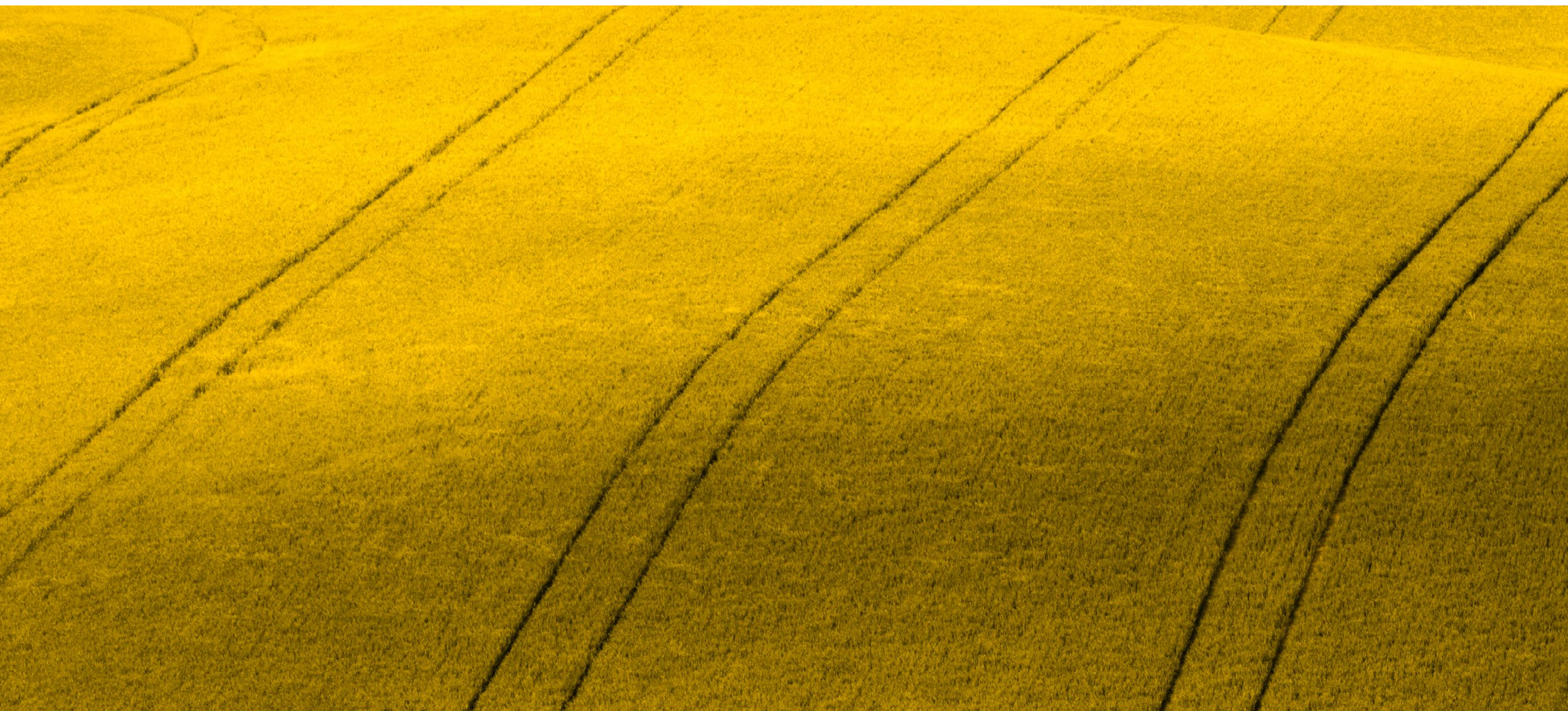
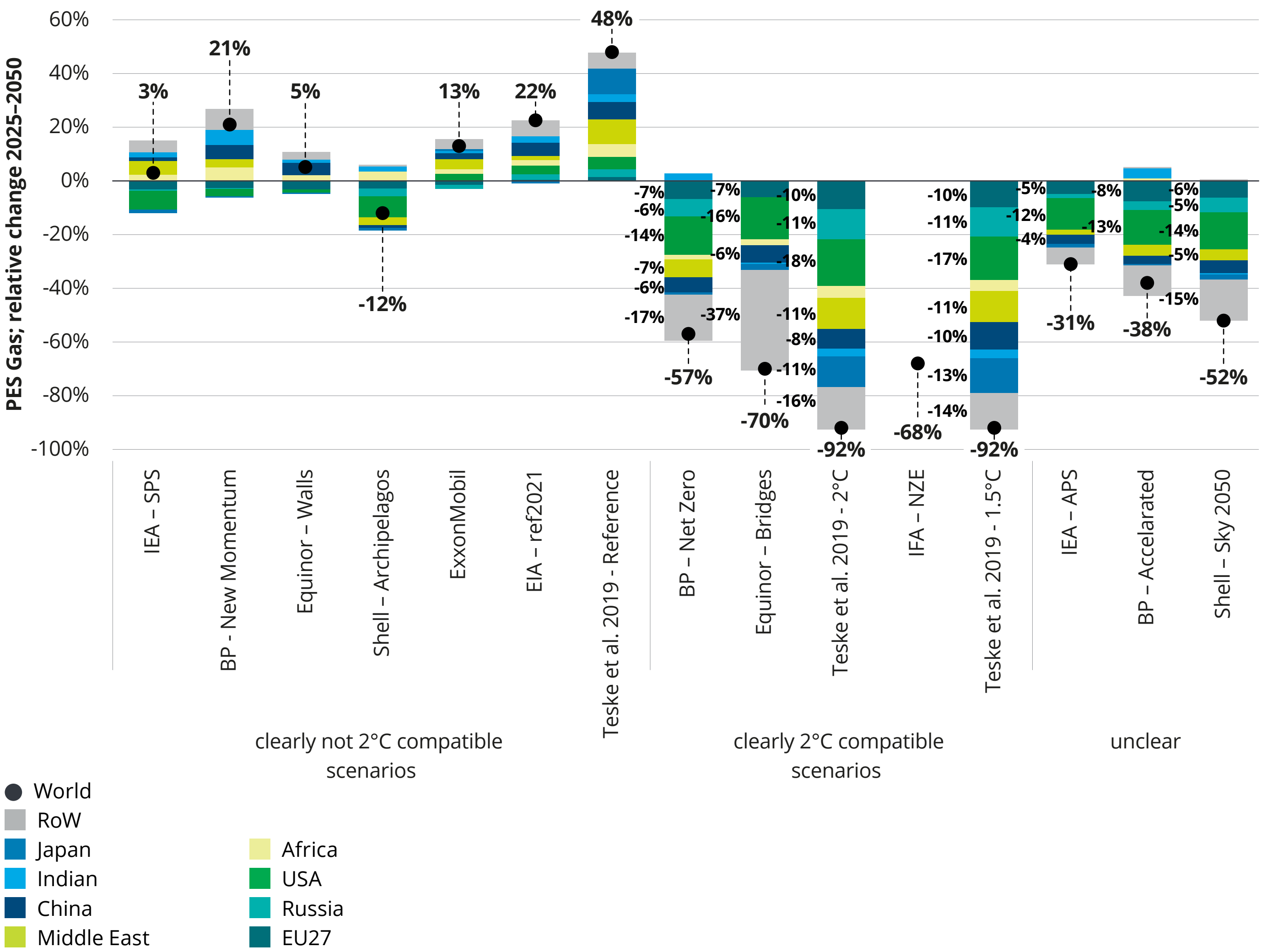
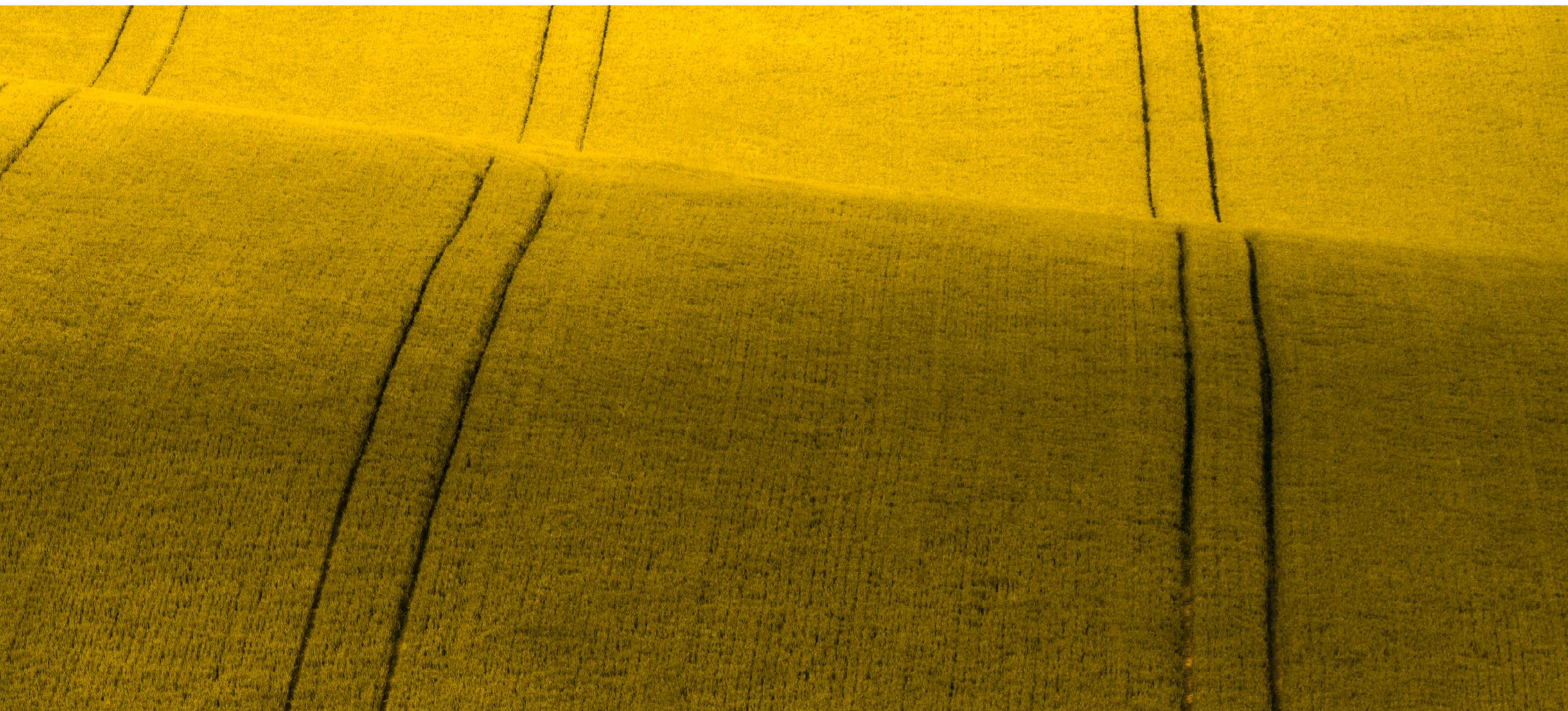


Fig. 6-7 – Change in primary energy supply from natural gas by region 2025-2050



Source: Oeko-Institut analysis based on Global-ScenSe-DB.

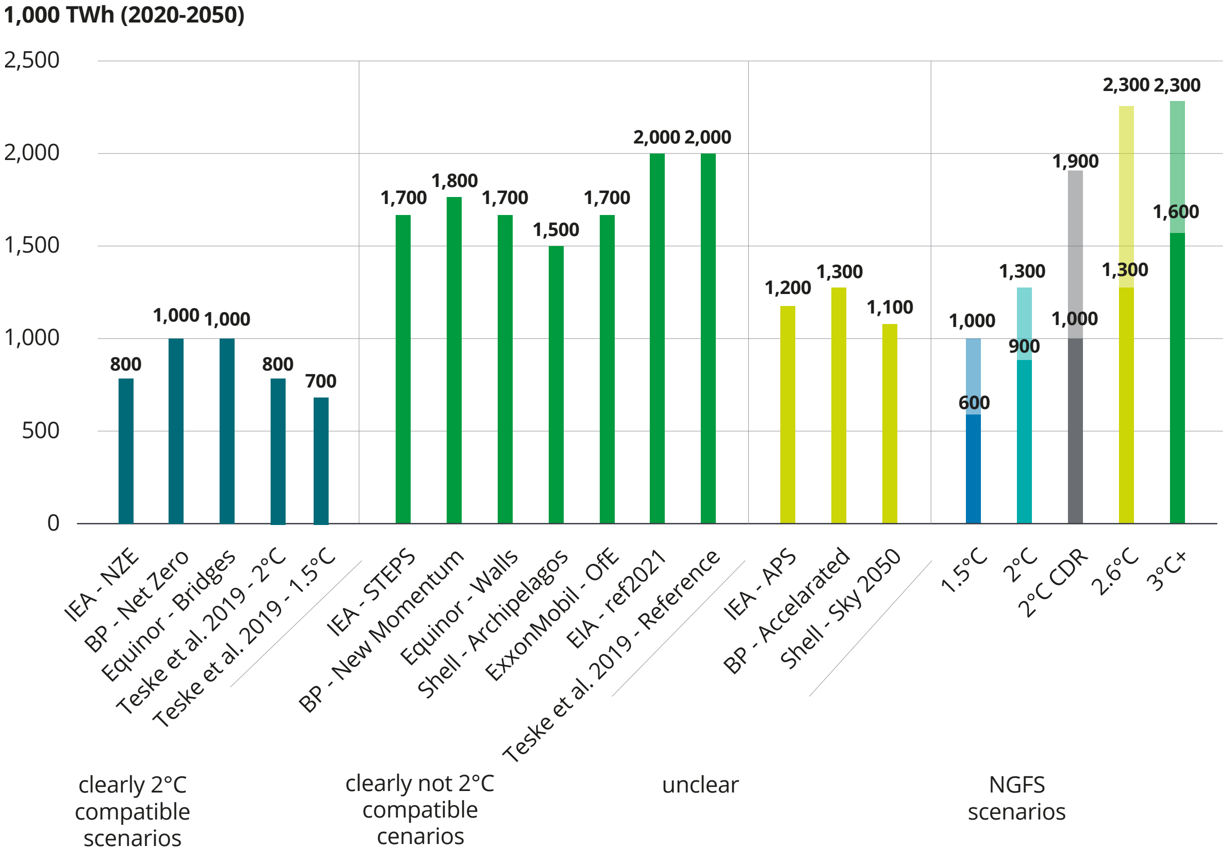


6.2.2. Cumulative primary energy supply from natural gas

Figure 6-8 shows the cumulative primary energy supply from natural gas for the period 2020 to 2050 for different climate scenarios and other projections. The right part of the figure shows the range of cumulative primary energy supply from natural gas as projected by the NGFS scenarios. The values are presented according to the target mean temperature increase by the end of the century, as established in the previous sections. The most ambitious climate scenarios project cumulative primary energy supply from natural gas for the period 2020 to 2050 in the range of 630,000 to 1,030,000TWh. The range increases from 900,000 to 1,230,000TWh for the less CDR-intensive scenarios, and from 980,000 to 1,900,000TWh for the more CDR-intensive scenarios. Notably, the maximum natural gas primary energy supply for the scenarios missing the 2°C target is approx. 2,300,000TWh, which is only 20% higher than in the CDR-intensive 2°C scenarios, while for the more ambitious scenarios, the value is a half to two-thirds.

Values for cumulative primary energy supply from natural gas in the period 2020 to 2050 for the other energy projection scenarios fall well within the ranges resulting from their clustering according to their 2°C compatibility. For 2°C-compatible scenarios, values range from 670,000 TWh for the most ambitious, Teske et al. 2019 1.5°C scenario, and 1,050,000TWh for the BP Net Zero scenario. The IEA NZE projects 820,000TWh primary energy supply from natural gas during this period. Cumulative values projected by scenarios clearly missing the 2°C-compatible cone are close together, ranging from 1,530,000TWh for IEA STEPS to 1,750,000TWh for ExxonMobil. The EIA 2021ref projection exceeds 2,000,000TWh. These ranges are well in line with ranges shown in the NGFS scenarios, which clearly miss the 2°C target, and the CDR-intensive 2°C scenarios. Figures for the three scenarios for which the clustering remains unclear range from 1,120,000TWh to 1,310,000TWh. These values mostly exceed the range defined by the less CDR-intensive scenarios and are somewhat below the average for the CDR-intensive scenarios.

Fig. 6-8 – Cumulative primary energy supply from natural gas for the period 2020 to 2050 for different climate scenarios and other projections



Note: Cumulative PES for the period 2020 to 2050 calculated as 2.5*value for 2020, 5*values for 2025 to 2045 and 2.5*value for 2050.
Source: Oeko-Institut analysis based on Global-ScenSe-DB.

Key results and takeaways

Clustering according to trajectories of primary energy supply from natural gas is consistent with clustering based on CO_2 emission trajectories.

According to the scenario calculations on the global level until 2050, a broad range of potential natural gas supply levels can also be consistent with a 2°C target, even including a net increase in consumption. Scenarios projecting an increase in consumption all involve slow technological change and a high use of CDR technologies. When these scenarios are excluded, the overlap with scenarios with higher increases in temperature levels persists only up to 2035. Thereafter, the remaining ambitious climate scenarios all show a significant decline in primary natural gas supply to levels of 50% and below, relative to 2020 levels. Even in these scenarios, primary natural gas supply on the global level does not drop below 30% of 2020 levels by 2050.

2°C-compatible scenarios suggest that natural gas use in the EU plateaus until 2030-35 at the latest and then strongly declines. Intensive use of CDR ambitions extends the plateau by about a decade. However, these scenarios do not take into account the EU reaction to the Russian attack of Ukraine and associated measures leading to a reduction in natural gas use in the short term but also in the long term.

Clustering and trends in primary energy supply from natural gas are consistent between the NGFS scenarios and the other energy projection scenarios when the CDR-intensive 2°C scenarios are excluded, also when zooming in on the regional level. Projections for India diverge. On a regional level, the US contributes most to the total reduction in natural gas use on the global level. Depending on the scenario, Russia, the EU and Middle East are the next largest contributors.

For the period 2020 to 2050, cumulative primary energy supply from natural gas in the range of 630,000 to 1,030,000TWh is compatible with reaching the 1.5°C target. When the target is relaxed to 2°C, the range increases from 900,000 to 1,230,000TWh for the less CDR-intensive scenarios, and from 980,000 to 1,900,000TWh for the more CDR-intensive scenarios.

6.3. Sectoral patterns of natural gas demand in global projections

To further explore the factors guiding future natural gas demand, the sectoral decomposition of natural gas demand trajectories in different scenarios is analyzed in this section. Based on data availability, three sectors are considered: the power sector, industry, and "buildings and other".[40]

Figure 6-9 provides an overview of the sectoral demand patterns projected by the NGFS scenarios:

- For the 1.5°C scenarios, significant differences between trends for the total maximum natural gas usage and sectoral ranges can be observed. The power sector is projected to undergo a strong decline in natural gas demand; it has the largest reduction in natural gas usage across all sectors. Natural gas demand in the industrial sector declines at a lower rate. In contrast, the trajectory of demand in the buildings and other sectors shows a significantly broader range by 2050.

- For the 2°C scenarios, the power sector shows no clear patterns. While IIASA projects a significant increase, PNNL projections show almost unchanged demand and the PIK modeling indicates a major reduction of natural gas in the power sector. For the industrial sector, only IIASA projects a moderate increase, the other models indicate a decrease in consumption. Similar to the 1.5°C scenarios, a broader range of natural gas demand is projected for the buildings and other sectors; this range is, however, much less extreme than for the power sector.

- For the 2.6°C scenario cluster, the natural gas demand from the power sector again shows a broad range. On the one hand, the lower bound in 2050 shows a decrease of natural gas consumption for the power sector by 2050. On the other, the upper bound increases drastically across the decades. In a different manner, by 2050, the projections suggest a relatively stable natural gas demand in the industrial sector but with some decreasing tendencies. The trends in the buildings and other sectors are again very diverse.

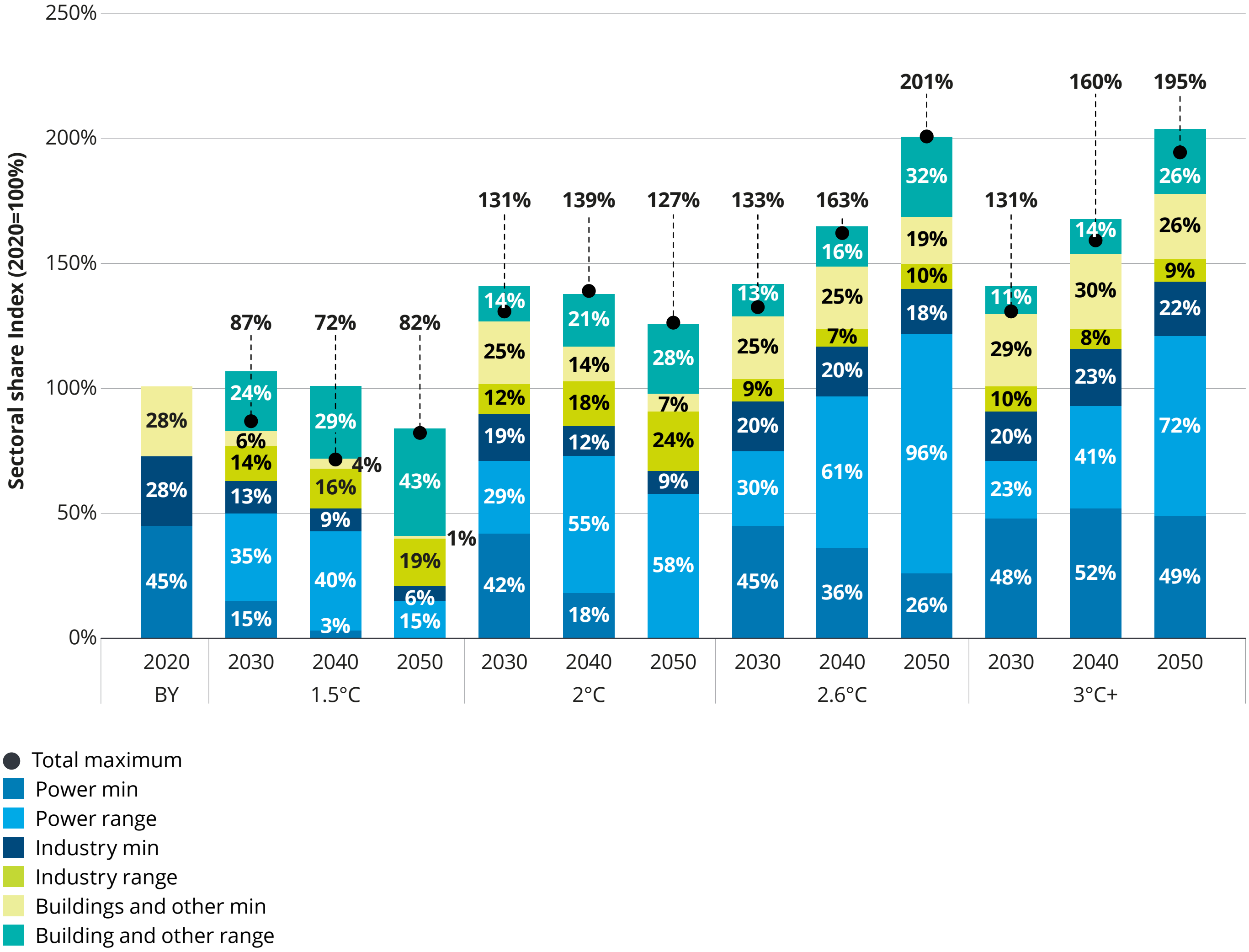
- For the 3°C+ scenario cluster the power sector is projected to have strong increases in natural gas usage by 2050. In contrast, the industrial sector has a projected range for 2050 which represents a relatively stable demand for natural gas over time. The buildings and other sectors, however, again reflects a significant divergence between the different NGFS projections.

- Across most scenarios, the power sector appears to be the main driver behind an overall projected decline or increase in natural gas demand between 2020 and 2050. In contrast, the industrial sector tends to show more stable natural gas usage with smaller projected changes in each scenario. Finally, only limited common trends can be identified for the buildings and other sectors as modeled in the NGFS projections.[41]

[40] The power sector refers to the production of electricity, in this case, the transformation of energy from natural gas to electricity (and heat) in gas-fired power plants. However, most of the studies only provided data on electricity generation by fuel. To estimate primary energy supply, an average electric efficiency of 40% was assumed. The industrial sector and industry can be understood as the amount of natural gas that is directly used in the sector. Some studies present data on non-energy use of natural gas. For reasons of consistency, these values were included in the industry sector totals. The remaining demand is dominated by demand for heating and cooling in buildings.

[41] Among the NGFS modelling exercises, the calculations by IIASA incorporate relatively strong CCS activities. Consequently, in comparison with the other two models (PIK and PNNL), the IIASA scenarios tend to project significantly higher volumes of natural gas demand, especially for the power sector.

Fig. 6-9 – Sectoral breakdown of NGFS global natural gas demand projections, 2020–2050



Source: Oeko-Institut analysis based on Global-ScenSe-DB.

The analysis for the other projections (see Figure 6-10) mirrors the trends projected in the NFGS scenarios:

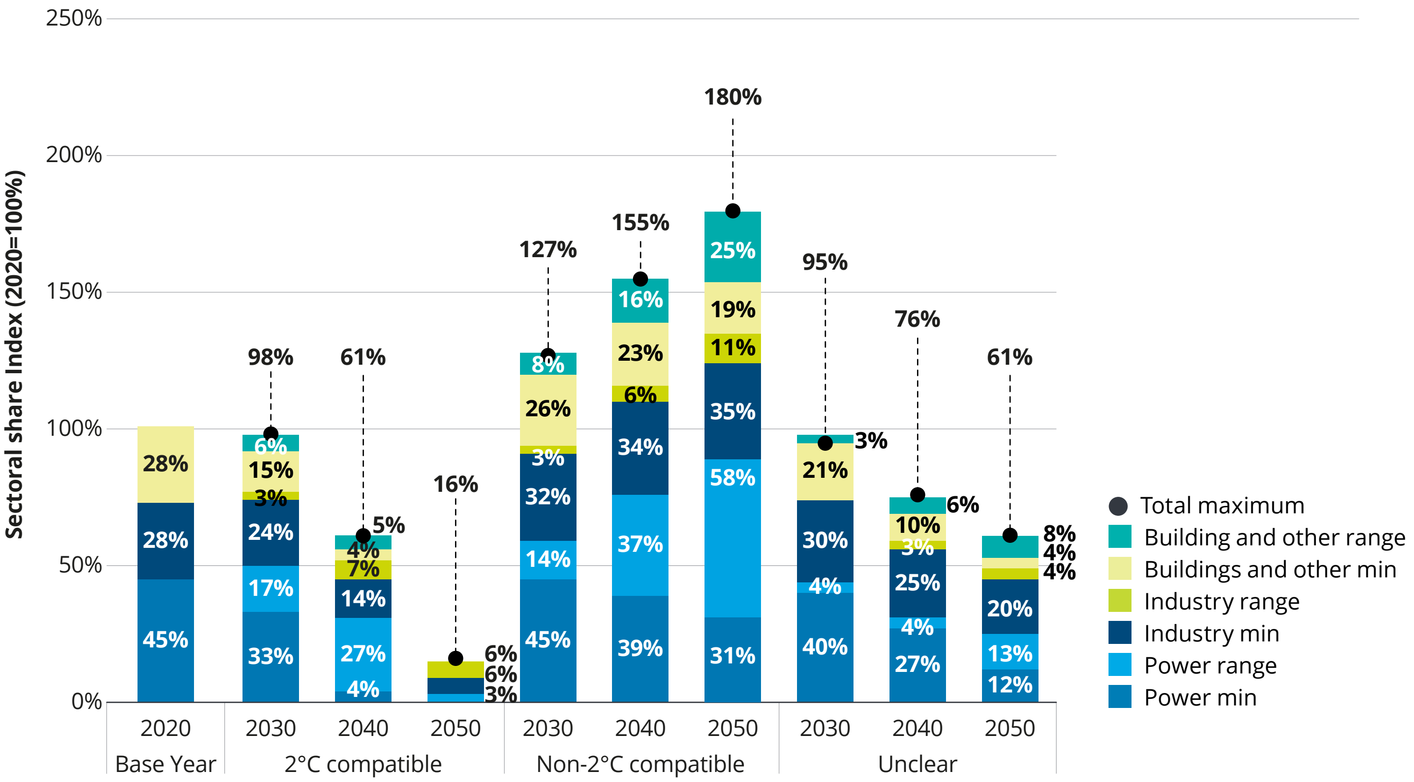
- For the 2°C-compatible scenarios, natural gas demand from the power sectors is indefinite up to 2030. Scenarios project either a slight increase or decrease by 2030. Scenarios consistently see a radical decrease in the two subsequent decades. For industry and the buildings and other sectors a more steady and strong decrease of consumption is projected by 2050.

- For the scenarios in the gray zone between the 2°C-compatible and the definitely 2°C-incompatbile projections, the same pattern can be observed but at a much slower pace. In particular, industrial demand shows a much smaller decline. The power sector will still demand natural gas in 2050, as will the buildings and other sectors, but the levels are substantially lower, compared with 2020.

- For the scenarios assessed as not compatible with the 2°C target, natural gas consumption increases for all sectors and for the entire period up to 2050.

- In contrast to the NGFS scenarios, none of the other projections shows an increase in natural gas consumption in any of the sectors. The power sector dominates total natural gas consumption trends and levels; the lowest variations can be observed for the industrial sectors.

Fig. 6-10 – Sectoral breakdown for other global natural gas demand projections, 2020–2050



Source: Oeko-Institut analysis based on Global-ScenSe-DB.

Key results and takeaways

Across most scenarios, the power sector appears to be the main driver behind an overall projected decline or increase in natural gas demand between 2020 and 2050. In contrast, the industrial sector tends to show more stable natural gas usage with smaller projected changes in each scenario. Finally, only limited common trends can be identified for the buildings and other sectors as modeled in the NGFS projections.

The analysis for the other energy projection scenarios mirrors the trends projected in the NFGS scenarios. In contrast to the NGFS scenarios, no other projections assume a major contribution of CCS that would allow an increase in natural gas consumption in any of the sectors.

Methodology used to assess the role of natural gas in the transition of the energy systems

A) All scenarios describe the transition of the energy systems from their current states towards 2050. While the analysis in the previous sections took an isolated look at the trajectories of natural gas primary energy supply, in this section we widen the focus to examine the role of natural gas in the respective transition of the energy systems. This view offers a comprehensive understanding of the stages of transition and the role that natural gas is projected to play at these stages, compared with more emission-intensive energy carriers, on the one hand, and to carbon-free energy carriers, on the other. The relative share of natural gas in total primary energy supply mirrors the role of this energy carrier in the current energy system.

B) As described in section 2, natural gas currently plays very different roles in the energy systems across the world. Also, the final share of the respective carriers can vary significantly, depending on the extent to which CCS and CDR technologies are applied and on the climate/policy ambition level of the respective scenario. Nevertheless, a common denominator for scenarios targeting emission reduction is a reduction of share of fossil fuels and an increase of shares of carbon-free carriers.

C) The trajectory from the starting point in 2020 towards the point in 2050 where the emission intensity of the energy system is reduced can take two stereotypical pathways: The relative share of natural gas can increase, while the share of carbon-free energy carriers increases only moderately, or vice versa, the share of carbon-free carriers can compensate the decline in the shares of emission-intensive fuels, while the shares of natural gas remain largely unchanged. The first describes a paradigm where natural gas serves as a transition fuel, and the second a transition that goes directly from emission-intensive to renewable-based, leaving out an intermediate ramp-up of natural gas-based capacities.

D) We use ternary diagrams to examine the transition pathways for different energy systems. The diagram can be interpreted as follows:

a. Each point in the graph corresponds to a combination of total primary energy supply from three different clusters of sources: coal, oil, and other fossil fuels (including all types of coal, refinery products, hydrogen, and hydrogen-based products without CO_2 capture and storage), carbon-free technologies (including all types of RES-E, nuclear, low carbon hydrogen, and hydrogen-based energy carriers) and natural gas. The share of coal, oil, and other fossil carriers is noted on the horizontal axis. The further to the right, the higher the share of these carriers in the mix for a given year and scenario. Points on the same line going from lower left to upper right (dotted brown lines) have the same share of these carriers in total primary energy supply. Points on the same horizontal line have the same share of natural gas in the mix (dotted blue lines). Hence, if the arrow moves horizontally, the share of natural gas does not change. Points on the same line from upper left to lower right have the same share of carbon free technologies in primary energy supply (dotted green lines).

b. Each arrow in the graph corresponds to the development of shares in one scenario, where the origin of the arrow corresponds to the split of shares in 2020 and the tip of the arrow corresponds to the split of shares in 2050.

c. The shape of the arrow describes the energy transition that builds the base for the respective scenario. The further to the left and down the arrow starts, the more emission-intensive the initial energy system. The further left and down the arrow ends, the less emission-intensive the final energy system by 2050. The more pronounced the arrow moves up vertically, the higher the intermediate role of natural gas. The straighter the arrow goes to the lower left corner, the less natural gas is involved in the transition.

6.4. Assessing the role of natural gas in transition trajectories

The following paragraphs analyze the transition pathways implied by the different projections for different geographical regions with a focus on the role of natural gas in these transitions. Figure 6-11 shows a ternary diagram depicting transition paths of primary energy supply for the energy system for different regional groupings, for different NGFS scenarios (left side) and different other energy projection scenarios (right side), for the period 2020-2050. For a detailed description of the methodology and for information on how to interpret a ternary diagram, see the notes below Figure 6-11 or Box 4. The pathways in the graphs are clustered and color-coded according to their ambitions in reaction to different maximum mean increases in global temperature.

On the global level, the energy system starts off with an approx. 24% share of natural gas in the primary energy supply mix in 2020, of which more than 50% can be attributed to coal and oil, and just above 20% comes from carbon-free sources and technologies. For some of the NGFS scenarios that clearly miss the 2°C target, the share of coal and oil decreases only slightly by 2050 (the arrows do not move to the right a lot). Except for the most ambitious climate scenarios (Divergent Net Zero and NetZero 2050), the energy system pathways of NGFS scenarios produced by IIASA all go through a period when the share of natural gas increases in total primary energy supply (all pathways where the arrow goes up as compared with the starting point), and two end up at higher shares of natural gas in primary energy supply by 2050, compared with 2020. For all other scenarios, the final level of natural gas in primary energy supply by 2050 is clearly lower than it was in 2020, and the energy systems do not go through a significant time period when the share of natural gas increases, compared with 2020 levels.

Even for the set of 2°C-compatible scenarios, the final split of shares of the different energy carriers in the total primary energy supply diverge significantly. The share of carbon-free energy carriers is higher for the more ambitious scenarios and for those with less intensive and early CDR deployment. The most ambitious scenarios project shares of more than 70%, and more than 80% for carbon-free energy carriers, and 6% to 11% for natural gas. Scenarios with high CDR intensity carbon-free carriers account for below 60% to above 70%, while natural gas is at 10% to 20%.

The right panel of Figure 6-11 shows the transition pathways of the energy systems as laid out by the other energy projection scenarios. Emerging from the same starting point, the pathways are different in their trajectories and their final end points. Scenarios not in the 2°C-compatible scenario cone mostly still plateau in their share of natural gas in the primary energy supply mix or even decline. The share of carbon-free energy carriers increases for all scenarios, with a level of above 30% to below 50%. In the Shell Archipelagos scenario, the energy systems become more coal- and oil-intensive but the share of carbon-free carriers also increases, while the share of natural gas declines.

For the scenarios in the 2°C-compatible cone, two groups can be identified: the BP Net-Zero and the Equinor Bridges scenarios result in shares of carbon-free energy carriers that amount to approx. 80%, with the remaining equally split between natural gas, coal, oil, and other fossil energy carriers. The two Teske at al. 2019 scenarios project the share of carbon-free carriers at above 90% and the share of natural gas at 2% of primary energy supply at the global level.

When comparing the pathways of the energy transition in the 2°C-compatible energy projection scenarios (green scenarios in the right panel) and the most ambitious NGFS scenarios (green scenarios in the left panel), a difference in the trajectories can be observed. The pathways of the other projections are flatter than the NGFS scenarios, tending to demonstrate a rapid decline of natural gas shares later. Hence, these scenarios follow the sequence of substituting the most emission-intensive fuels with carbon-free energy carriers, while the share of natural gas remains relatively similar. Moreover, they project a rapid decline of natural gas shares as the final step of decarbonization. The most ambitious climate scenarios follow a more stringent paradigm, where emission-intensive fuels are directly substituted with carbon-free carriers while the share of natural gas also starts declining at an earlier point in time.

The other energy projection scenarios that cannot be clearly attributed to one of the uncertainty cones results in shares of between 60% and 70% for carbon-free carriers, 10% to 15% for natural gas and 20% to 25% for coal, oil and other fossil carriers, respectively. The trajectories of the pathways are steeper than those of the more ambitious energy projection scenarios, indicating an earlier and smoother decline in the share of natural gas.

The trends in the transformation paths of the energy system for the different NGFS scenarios and other energy projections observed on the global level are repeated at the level of democratic industrialized countries, but with less cohesion in the different groups. The energy systems start at more than 25% to 30% of natural gas in the energy systems for 2020, around 25% carbon-free energy carriers and the rest coming from coal, oil and other fossil fuels. In the left panel climate scenarios from IIASA and PNNL do not achieve the 2°C target, resulting in higher shares of natural gas in the energy systems for this grouping of countries than they begin with in 2020, at 37% and 38% respectively. Notably, for these two organizations, the relative increase up to 2050 also prevails for the 2°C-compatible scenarios with early and intensive use of CDR. Though missing the 2°C target, the share of natural gas still declines up to 2050 in the respective PIK scenarios. This is also true for all the other scenarios that achieve the 2°C target. Here, the share of natural gas in primary energy supply is 10% or even much lower. Coal, oil and other fossil fuel contribute 8% to 19%, while the rest is supplied by carbon-free energy carriers. A rapid decline in the shares of natural gas mostly starts in 2025, or at the latest 2030. Note that the NGFS scenarios do not take into account the consequences of the Russian attack of Ukraine for the role of natural gas in the transition pathways of the energy systems, therefore potentially overestimating its role for the EU and the rest of Europe.

The other energy projection scenarios that are clearly out of reach of the 2°C compatible scenario cone see either an increase in the share of natural gas in the energy system mix for the democratic industrialized countries group by 2050, stagnation or a small decline. Increased levels range between 29% and 34%; the level of decline is 20% by 2050. All other scenarios in the right panel project a relative decline in the role of natural gas in the energy system. For the other energy projection scenarios, where clustering according to the CO_2 emissions trajectory is unclear, the share of natural gas in the energy mix decreases from 10% to 15% by 2050. Again, the 2°C compatible energy projection scenarios can be clustered into two groups: The two Teske et al. 2019 scenarios end up with a share of 3% for natural gas in the primary energy mix by 2050. BP Net-Zero and Equinor Bridges end up 10% higher, at approx. 13%. Most of the difference is due to a higher share of carbon-free energy carriers in the Teske et al. 2019 scenarios. There is no clear picture for the trajectories. The two Teske et al. 2019 scenarios and the Equinor Bridges scenario go through a phase of stagnation or at most moderate decline in the share of natural gas up to 2030 or even 2035, followed by a more rapid decline in the subsequent years, while in the BP Net-Zero scenario, the decline starts in 2025. For the three unclear energy projections, the pathways are somewhere in between, with the rapid decline starting from 2025 to 2030.

The third twin panel in Figure 6-11 shows the transformation paths of primary energy supply for the energy system of the Rest of the World country grouping for the period 2020 to 2050. In 2020, approx. 20% of primary energy supply originated from natural gas, 20% from carbon-free sources and the rest from coal, oil and other emission-intensive energy carriers for this country grouping. Hence, the initial state of the energy systems is more emission-intensive and carbon-free energy carriers and natural gas play a smaller role, compared with the DICE country grouping. The following transition patterns can be observed for the RoW grouping:

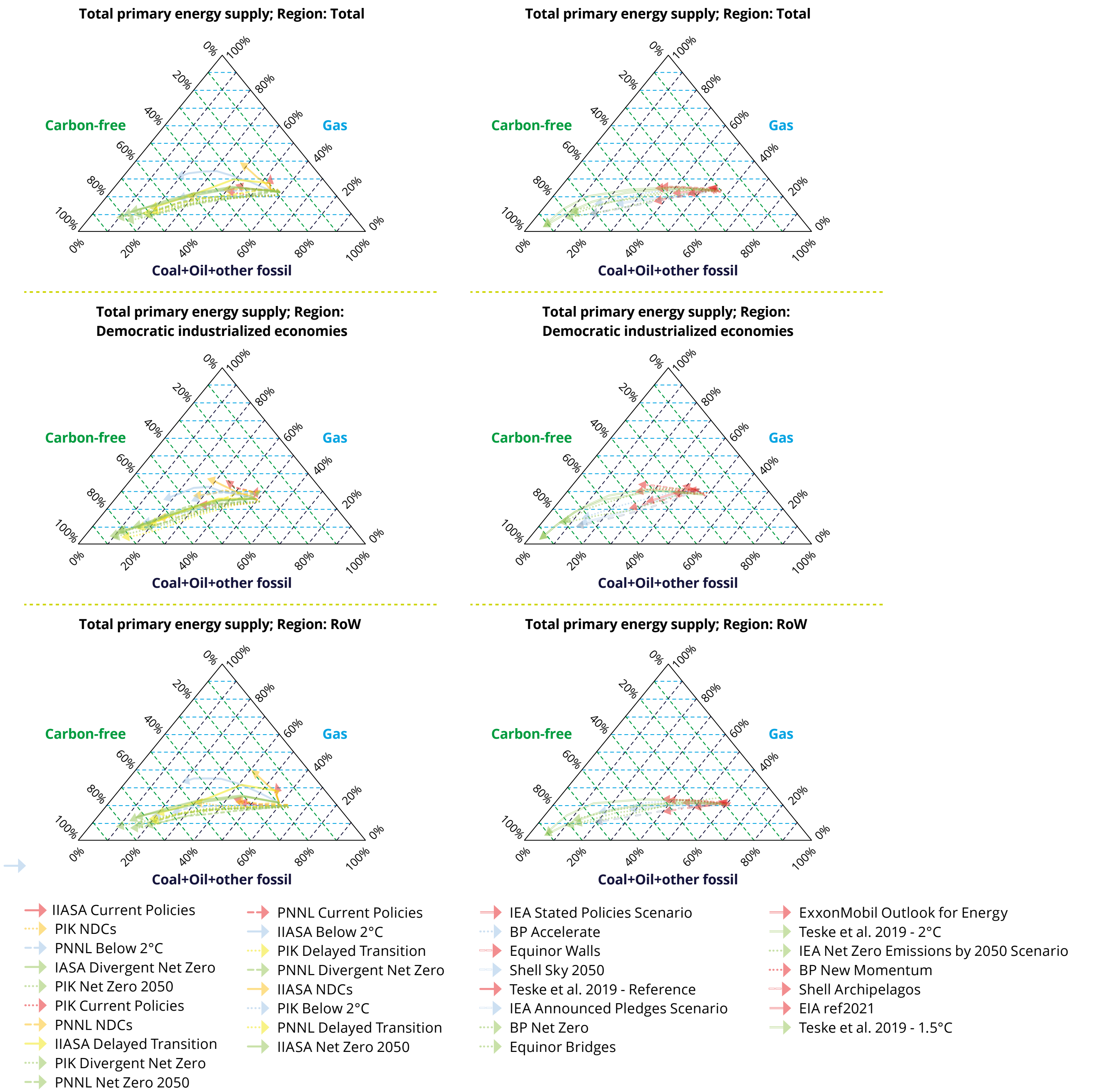
- Only the scenarios which clearly miss the 2°C target project an increase in the share of natural gas by 2050, relative to the level of 2020. The exception is the CDR-intensive Below 2°C scenario by IIASA, which projects an increase to 33% by 2050. All other NGFS scenarios project a decline in the share of natural gas in primary energy supply by 2050, relative to 2020 levels. The more ambitious the NGFS scenario, the lower the final share of natural gas. This share decreases from 15% to 10% for the scenarios targeting 2°C, and 7% to 8% for the most ambitious scenarios. The share of carbon-free energy carriers is between 73% and 83% by 2050.

- The pathways of the energy system transitions are divergent. The first set of scenarios project a slight intermediate increase in the share of natural gas and project a short plateau in the share up to 2025, and a steady decline afterwards. This is true for the most ambitious climate scenarios from PIK and IIASA. In other scenarios, the plateau is longer and extends from 2030 to 2035, with a more rapid decline afterwards.

- As for the scenarios of the other energy projections, none shows a significant increase in the share of natural gas for the RoW country grouping, even for those scenarios clearly not consistent with a 2°C target. The four scenarios that are clearly compatible with a 2°C target diverge in the share of natural gas in the 2050 energy carrier mix. While BP Net-Zero and Equinor Bridges project a share of around 10%, the share is only 2% for the two Teske et al. 2019 scenarios. For the three unclear scenarios, 2050 shares decline to between 10% and 17%. For the three unclear scenarios, the share of coal, oil and other fossil energy carriers remains as high as 18% to 28% in 2050.

- All climate-sensitive scenarios show a long plateau in the share of natural gas up to 2035 or even 2040. While in the Teske 1.5°C scenario large shares of coal, oil and other fossil energy carriers are quickly replaced with carbon-free alternatives, the transition process is much slower in all other scenarios.

Fig. 6-11 – Transition paths of primary energy supply for the energy system for different regional groupings, 2020-2050, for different NGFS scenarios (left side) and different other energy projection scenarios (right side)



Note: How to read the graph: 1.Each point in the graph corresponds to a combination of total primary energy supply from three different clusters of sources: coal, oil and other fossil fuels (including all types of coal, refinery products, hydrogen, and hydrogen-based product without CO_2 capture and storage), carbon-free technologies (including all types of RES-E, nuclear, low carbon hydrogen, and hydrogen-based energy carriers) and natural gas. The share of coal, oil and other fossil carriers is noted on the horizontal axis. The further to the right, the higher the share of these carriers in the mix for a given year and scenario. Points on the same line going from lower left to upper right (dotted brownlines) have the same share of these carriers in total primary energy supply. Points on the same horizontal line have the same share of natural gas in the mix (dotted blue lines). Hence, if the arrow moves horizontally, the share of natural gas does not change. Points on the same line from upper left to lower right have the same share of carbon-free technologies in primary energy supply (dotted green lines). 2. Each arrow in the graph corresponds to the development of shares in one scenario, where the origin of the arrow corresponds to the split of shares in 2020 and the tip of the arrow corresponds to the split of shares in 2050. 3. The shape of the arrow describes the energy transition that builds the base for the respective scenario. The further to the left and down the arrow starts the more emission-intensive the initial energy system. The further left and down the arrow ends, the less emission-intensive the final energy system in 2050. The more pronounced the arrow moves up vertically, the higher the intermediate role of natural gas. The straighter the arrow goes to the lower left corner, the less natural gas is involved in the transition.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The first twin panels in Figure 6-12 detail the transformation paths of primary energy supply for the energy system of China for the period 2020 to 2050. China starts off with a little less than 10% of primary energy supply originating from natural gas, significantly lower than the level at the global scale, for the RoW group of countries and the DICE countries. Only 15% comes from carbon-free energy carriers in 2020; the energy system is dominated by coal, oil and other fossil energy carriers to a much larger extent than the energy system on a global scale and of groupings like DICE or RoW. The following transition patterns can be observed for China:

- Only three of the NGFS scenarios project an increase in the share of natural gas in primary energy supply in the Chinese energy system by 2050, two of them are not compatible with a 2°C target and one is the CDR-intensive Below 2°C scenario by IIASA. All other NGFS scenarios project a reduction in the relative share of natural gas from the already low level, compared with other regions in 2020.

- As for the transition pathways, several on the scenario not compatible with a 2°C target project an intermediate period where the role of natural gas grows, more than doubling its share by 2035 in one scenario but only increasing by a few percentage points by 2030 for the other scenarios at the most. Overall, there is no large intermediate increase in the share of natural gas in total primary energy supply. Coal, oil and other emission-intensive fossil energies mostly lose their shares to carbon-free alternatives.

- For the other energy projection scenarios, trends are somewhat different. Many of the scenarios that are clearly not compatible with 2°C suggest a small increase in the share of natural gas in primary energy supply by 2050, compared with 2020 levels. The other scenarios project a more or less pronounced decline. The two ambitious scenarios by Teske et al. 2019 suggest pathways in which natural gas gains in importance in the energy system during the transition, before ending up with a share of only 2% by 2050. In the other scenarios, there is a more or less steady decline in the share of natural gas in the primary energy mix, suggesting that carbon-free energy carriers directly substitute coal, oil and other fossil energy carriers, and do not rely on natural gas as a transition fuel.

The second twin panels in Figure 6-12 show the transformation paths of primary energy supply for the energy system of India for the period 2020 to 2050. The picture is much less clear here. For once the initial share for 2020 is different for the different organizations. This is due to the fact that 2020 is a modeled year rather than a historical one for the NGFS scenarios. All models include infrastructural and ramping restrictions, which lead to negligible deviations for most regions; for India, there is a notable deviation from the share of 6% calculated based on historical primary energy supply values reported by the IEA. The following transition patterns can be observed for India:

- In terms of the share of natural gas by 2050, there is a clear divide between scenarios meeting the 2°C target and those missing it. For the NGFS scenarios, the first group tends to project growth importance of natural gas for the energy mix, with shares reaching 25% and more; the second group clearly shows a decline or stagnation at best.

- Transition pathways projected by the NGFS scenarios mostly do not project a strong intermediate increase in the share of natural gas in primary energy supply for India. Rather, the share plateaus at low levels or even declines further.

- Similar to the non-2°C-compatible NGFS scenarios, the respective scenarios of the other energy projections show an increase in the share of natural gas in the energy mix for 2050, but only reach a maximum level of 13%. The other scenarios project a decline. All three BP scenarios show an increase in the share of natural gas for India, no matter how ambitious the climate policy is.

- The two 2°C-compatible Teske et al. 2019 scenarios project an intermediate increase in the share of natural gas in the primary energy mix to levels of 10% to 13% by 2035 and a decline to 2% by 2050. Also in all three BP scenarios, there is a long-term increase for the natural share. The other scenarios project a decline or a plateau at best. Compared with China, however, the picture in India is less clear, with some studies indicating an intermediate increase in the role of natural gas in the energy mix in India.

- The third twin panels in Figure 6-12 show the transformation paths of primary energy supply for the energy system of the EU for the period 2020 to 2050. The EU starts off with a little less than a quarter of primary energy supply originating from natural gas, which is lower than the level for the democratic industrialized countries in total, with more than 30% coming from carbon-free energy carriers. This is somewhat higher than for democratic industrialized countries in total, with the rest of the supply coming from coal, oil and other fossil fuels. The transition pattern observed for the EU generally follows those for the democratic industrialized economies.

- Five of the NGFS scenarios project a substantial increase in the share of natural gas in primary energy supply in the energy system. Four of them are clearly not compatible with the 2°C target, namely the Current Policies and the NDCs scenario from IIASA and PNNL, ending up at levels from 27% to 40% by 2050. Additionally, the scenario with rapid and intensive use of CDR, while also being compatible with the 2°C scenario projected by IIASA, culminates with a 36% share for natural gas in the primary energy supply mix for 2050. In all other NGFS scenarios, the share of natural gas sharply declines.

The most moderate decline, at 17%, is for the CDR-intensive Below 2°C scenario from PIK. For the other scenarios, the share goes down to a mere 1% by 2050. For the 2°C-compatible scenarios with an early and intensive use of CDR, the share remains as low as 52% to 56% in the IIASA and PNNL scenario, respectively. For the other 2°C-compatible climate scenarios, the share of carbon-free energy carriers is at least 75% and up to 89%. The pathways differ depending on the stringency of the climate targets. For the scenarios targeting 2°C, the shares of natural gas stagnate by 2030 to 2035, and rapidly decline thereafter. For the more ambitious climate scenarios, the decline is smoother and starts earlier on. However, it must be noted that none of the NGFS scenarios take into account the polices and measures taken by the EU as a reaction to the Russian attack of Ukraine, which include substantial efforts to reduce natural gas dependency well before 2030.

- The picture is different for the other energy projection scenarios. All but one scenario projects a decline of the relative share of natural gas in primary energy supply in the EU by 2050. The exception is the Teske et al. 2019 scenario. The scenarios which are clearly not 2°C-compatible project an average share of 18% for natural gas in the energy mix by 2050, excluding the outliner scenario with 28%. The scenarios that are clearly compatible with the 2°C target end up with shares of 9% for Equinor Bridges and 1% to 4% for BP Net Zero and Teske et al. 2019 1.5°C and 2°C. The scenarios that are not clearly attributable to the two groups also show very low levels, at 4% to 7%, for the share of primary energy supply from natural gas in the energy mix for the EU.

- The role of natural gas in the transition pathways for the EU energy system is very different between the scenarios. There are two clusters: one cluster shows a rapid and steady decline in the share of natural gas. This is true for three unclear scenarios and for the Equinor Bridges and the BP Net-Zero scenario. Only the two Teske scenarios, which do not account for the EU reactions to the Russian attack of Ukraine, show a long period in which the share of natural gas remains rather steady and then rapidly declines after 2030/2035.

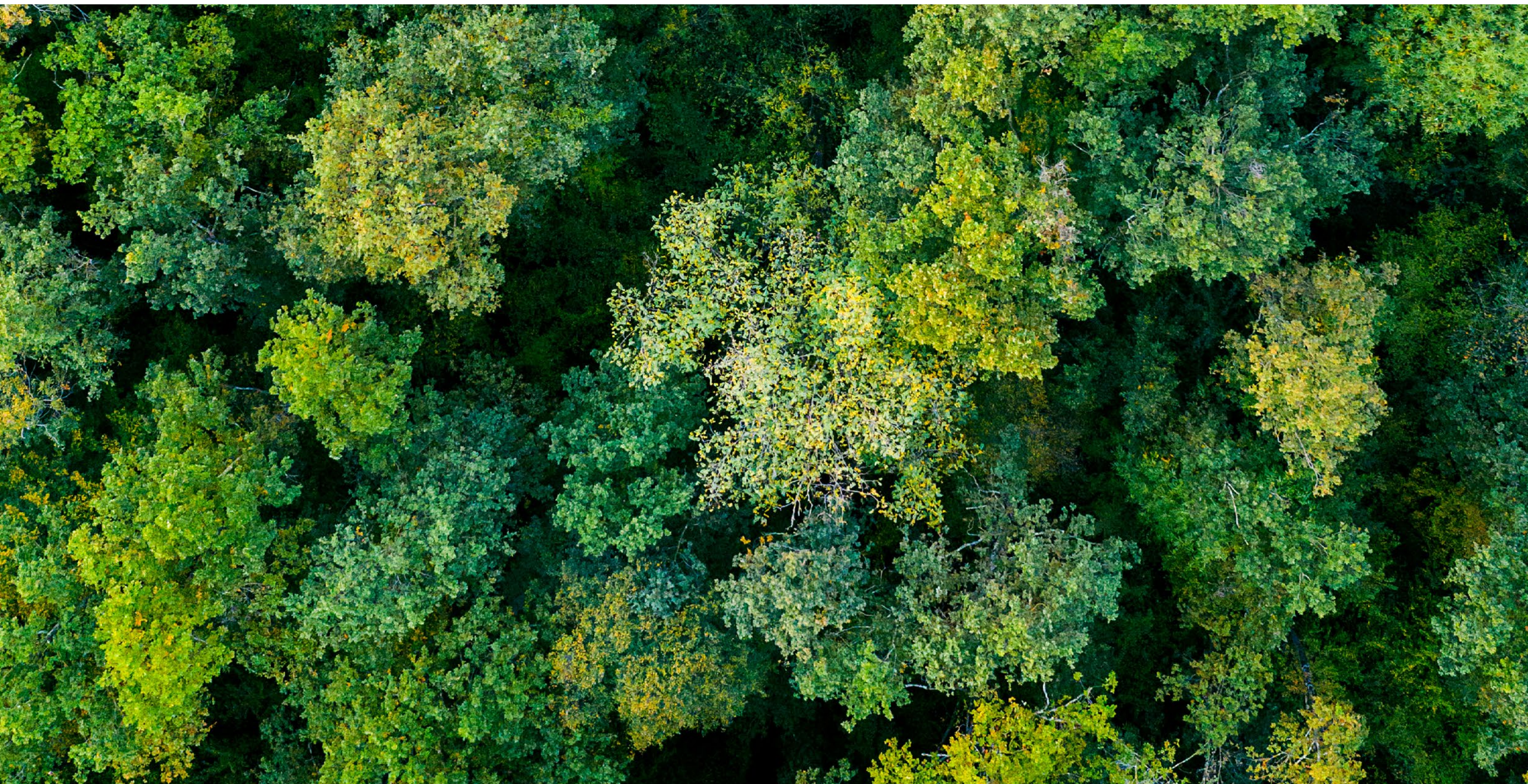
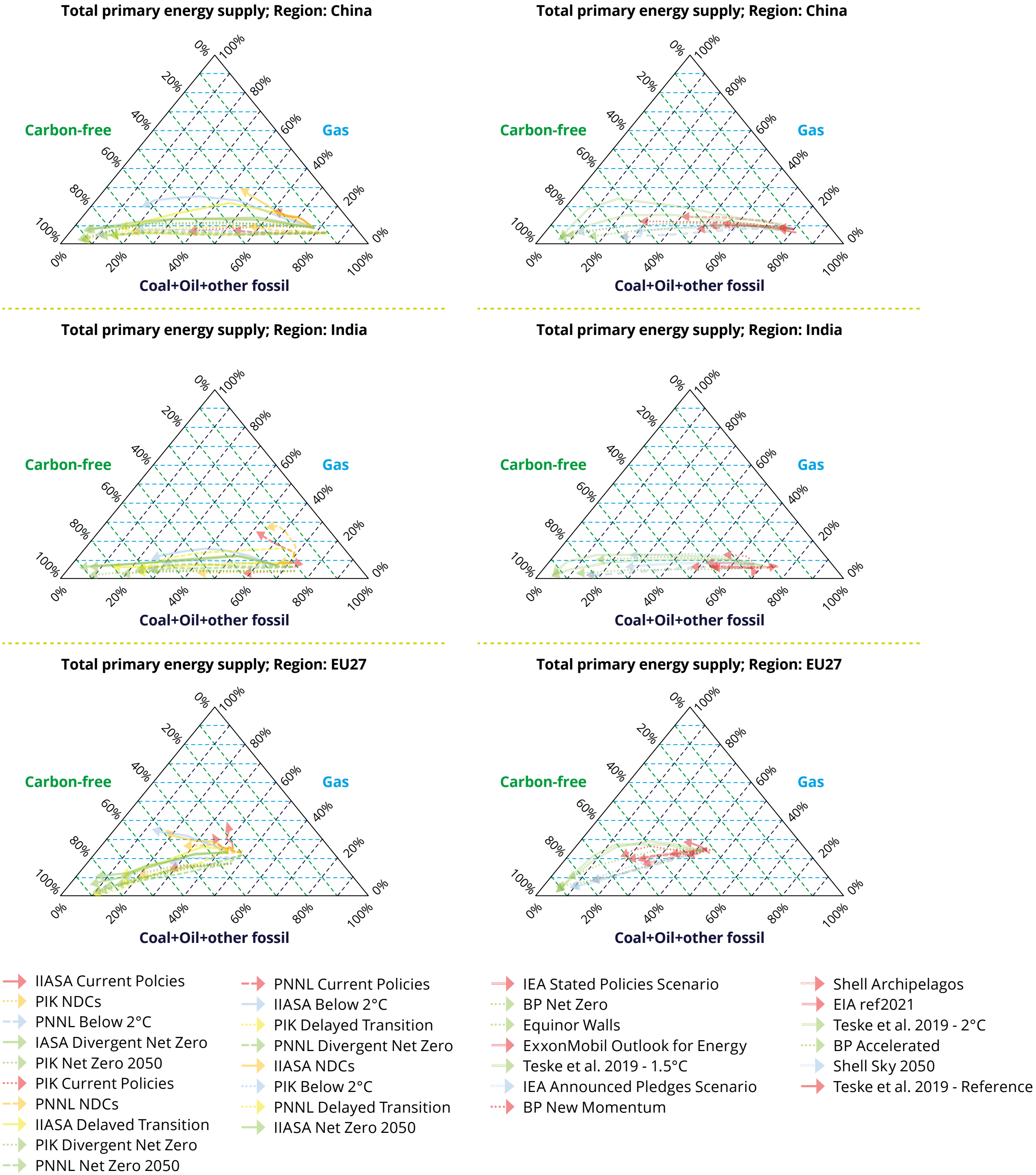


Fig. 6-12 – Transition paths of primary energy supply for the energy system of the EU, 2020-2050, for different NGFS scenarios (left side) and different other energy projection scenarios (right side)



Source: Oeko-Institut analysis based on Global-ScenSe-DB.

Key results and takeaways

The bulk of the scenarios project a decline in the share of natural gas in global primary energy supply for 2050, compared with 2020 levels. In all scenarios that are compatible with a 2°C target, the relative role of natural gas in the energy mix significantly declines by 2050 relative to 2020.

The transition pathways also broadly diverge from the energy system transformation paradigm that prevailed up to 2020. Previously, in relative terms to total primary energy supply, carbon-intensive energy carriers tended to be replaced equally by carbon-free energy carriers and natural gas. In the reviewed scenarios of the future energy transition, there is a demonstrable shift towards carbon-free energy carriers, which take on a predominant role.

6.5. The role of Carbon Capture and Storage (CCS) and Carbon Removal

For ambitious climate protection strategies, the storage of CO_2 in geological forms or other long-term integration (in soils, through weathering, in durable products) plays an important role. Different fields of application need to be distinguished:

- In some modeling exercises, CO_2 storage is contemplated for sectors in which other emission-reduction measures are possible, but for various reasons (ramp-up trajectories, costs) fossil fuels should continue to be used at least in the medium term. These are primarily large-scale power generation plants and emission-intensive industries that are operated with coal, mineral oil or natural gas.

- In some sectors, emission reductions cannot be achieved through classical strategies (energy efficiency, electrification, fuel switching). These sectors are often referred to as hard-to-abate sectors. Two types must be distinguished here: (1) hard-to-abate sectors with concentrated CO_2 streams, and (2) those with diffuse emissions of CO_2 and other greenhouse gases. For the first type, the most important of these sectors is cement production, where most of the CO_2 emissions occur as process emissions (non-energy-related) in cement clinker production. Global emissions from cement clinker production amount to approx. 1.7 billion tons CO_2 with a clear upward trend in recent decades (Andrew, 2023). For these sectors, capture and storage of CO_2 is one of the few options for achieving climate neutrality. Typical examples of the other type of sectors are agriculture and waste disposal. Here, emissions are diffused, with the result that direct capture is not an option. For these sectors, compensation via negative emissions is one of the few available mitigation options, next to changes in behavioral patterns and practices.

- In many long-term projections and modeling exercises, CO_2 storage plays a role, not only as an emission-reduction measure, but as an option for removing CO_2 from the atmosphere. This is achieved by capturing the biogenic CO_2 originating from the combustion of short-lived biomass and storing it permanently (Bioenergy, Carbon Capture and Storage, BECCS) or by filtering CO_2 from the atmosphere (Direct Air Capture) and then storing it permanently (Direct Air Capture and Storage, DACCS). This option plays an important role for projections in which the emission reduction necessary for achieving the targeted maximum temperature increase levels by the end of the century is either missed or delayed (IPCC, 2018b). In this case, net removal of CO_2 from the atmosphere (negative emissions) takes place in the subsequent decades to compensate for the overshoot (Overshoot or Delayed Transition scenarios). The net removals in these scenarios amount up to 5.4 Gt CO_2 annually in the second half of the century.

- Finally, carbon capture (biogenic or with DAC) is key to producing climate-neutral CO_2. This feedstock will be crucial for the energy transition in processes for which the potential of bio-energy is limited, for example to replace natural gas in some industrial processes (methanol supply for chemicals) or to produce sustainable fuels for maritime transport and aviation.

Regardless of the above-mentioned hurdles, these strategies must also be evaluated with respect to the following:

- Although storage capacity is associated with considerable uncertainties at the global level, it is very large overall (OGCI, 2022). However, the regional distribution of storage potential is uneven and only partially coincides with the spatial distribution of the relevant emission sources. Europe, the United Kingdom and Norway hold the largest storage potential capacities (Shirizadeh et al., 2023).

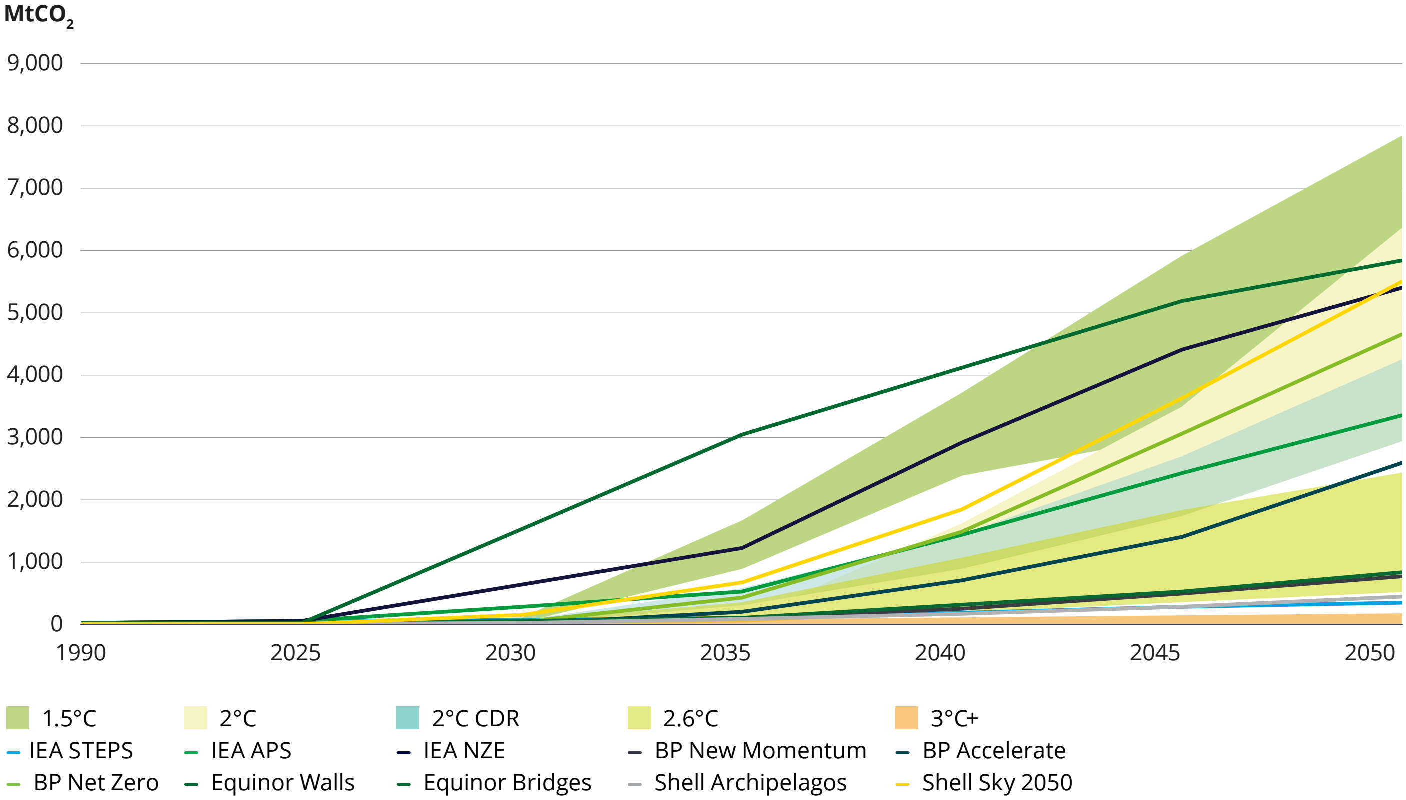
- At the technical level, the capacity of storage infrastructure and upstream process stages (especially with a view to transport), and above all the corresponding ramp-up processes form the main bottleneck.

- For the costs of the CCS process chain, the initial concentration of CO_2 is key. The capture is relatively cheap for highly concentrated CO_2 streams and becomes increasingly expensive as the concentration decreases. Hence, CO_2 capture is most effective for CO_2 arising from process streams with high CO_2 concentration or from the combustion of fossil (or biogenic) energy carriers in a pure oxygen environment, rather than in air. Pure oxygen combustion is expensive and the willingness to pay for such abatement options for power and heat generation is rather low due to the existence of increasingly cost-effective renewable energy alternatives. Increasingly cost-competitive alternatives to CCS (such as direct iron reduction using hydrogen) also exist for some industrial processes involving highly concentrated CO_2 streams (such as conventional primary steelmaking). Most importantly, these alternatives are compatible with long-term climate neutrality due to the lack of unabated emissions.

- For the hard-to-abate sectors, the situation is twofold. For sectors with highly concentrated CO_2 streams, the question of whether to opt for CCS again depends on the existence of alternatives and the compatibility of these sectors with long-term compatibility with a climate-neutral energy system. When used in cement production, CCS is clearly a cost-effective alternative. The development for refineries is much less clear, however. Under stringent climate policy frameworks, the high willingness to pay for sustainable aviation fuels (the production of which requires carbon as a feedstock) could mean that options with low initial CO concentration such as direct air capture are still viable.

- The most cost-intensive options are net removal options, for which the high costs of CO_2 capture from the atmosphere (via BECCS or DACCS) are the dominant factor and where it cannot be directly attributed to high willingness to pay services such as aviation.

Fig. 6-13 – Ramp-up of CO_2 capture and storage capacity, world, 2020–2050



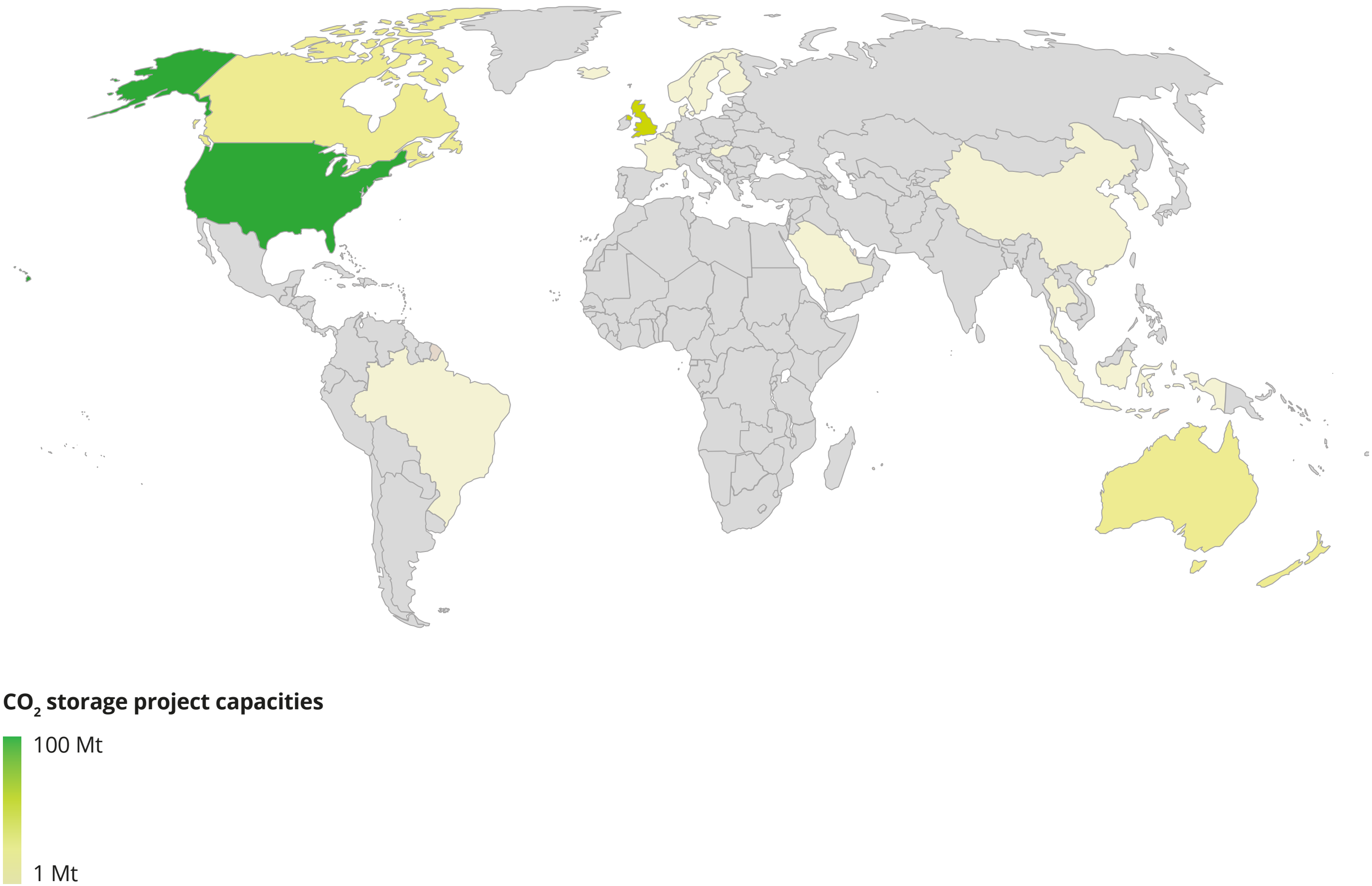
Note: Report CO_2 captured: BP, Equinor, Shell; report CO_2 stored: NGFS scenarios; report both values: IEA; value for CO_2 captured is reported in figure, Teske et al. 2019, EIA 2021 and ExxonMobil 2022 do not report CO_2 emissions stored or captured, in their datasets. The figure is somewhat imprecise in mixing CO_2 captured and CO_2 stored. CO_2 reported as captured can originate from different activities and have different uses: blue hydrogen production, BECCS, DACCS and can go either to CO_2 storage or to CCU. CO_2 storage or CO_2 stored can also come from the sources listed above, but the difference between CO_2 captured and CO_2 stored is CCU. However, the CCU can have two forms: long-term use in materials (with no emissions effect In the short term, 20-50 years) or use in energy products where it is again associated with net-zero emissions. Therefore, CO_2 captured can exceed CO_2 stored. And while the first is an indicator for the required ramp-up of capturing capacity, the second indicates CO_2 storage infrastructure needs. Requirements for CO_2 transport infrastructure will be somewhere in between, as some of the CO_2 captured will be used or stored on site.
Source: Oeko-Institut analysis based on Global-ScenSe-DB.

Figure 6-13 shows the level of annual CO_2 stored in the projections analyzed here.[42] The overview shows first that CO_2 storage in the vast majority of studies ramps up after 2030 at the latest, then quickly reaches a level of up to 1.5 Gt CO_2 annually by 2035. Values of up to 3.5 and 8 Gt CO_2 can arise for the time horizons 2040 and 2050 respectively. Similarly noteworthy are the NGFS scenarios, which achieve the 2°C target. These assume a very early ramp-up of CO_2 storage (0.3 to 0.6 Gt per year for the CDR-intensive 2°C scenarios by 2035 and 0.9 to 1.7Gt per year for the 1.5°C-compatible scenarios by 2035). The energy projections that do not fall within the 2°C compatible scenario range project much lower annual storage volumes by 2035 while staying at lower levels up to 2050. For 2050, the set of 2°C-compatible energy projections are well within the range of the storage level observed for the respective NGFS scenarios. The same is true for 2035 and the ramp-up observed afterwards. The exception is the Equinor Bridges scenario in which CO_2 injection starts ramping up quickly after 2025 and reaches a level higher than 3.0Gt CO_2 annually by 2035. Bearing in mind that the projections do not cover many of the sectors in which CO_2 storage will become necessary in the period up to 2050, the levels that they project appear to be even more at the high end of the ranges (areas in the background of the graph). It is also interesting to note that the scenarios with very high CO_2 injection rates are by no means those scenarios with the highest cumulative natural gas consumption. While the BP Net-Zero scenario projects the highest cumulative supply of the 2°C-compatible scenarios, storage rates for IEA NZE and Equinor bridges are significantly higher for all periods. There is also no clear relation between final levels of natural gas consumption and CO_2 storage levels. Relative levels of primary energy supply from natural gas in 2050 are lower for the IEA NZE and the Equinor Bridges scenario than for the BP Net-Zero scenario.

Unlike the NGFS scenarios, none of the other projections assumes a major contribution of CCS in the somehow 2°C-compatible scenarios that would allow an increase of natural gas consumption in any of the relevant sectors.

[42] Note that due to the different scopes of the scenarios the comparison is not straight-forward. While the models used in the NGFS suite and the one used in Teske et al. (2019) cover all emission sources including the LULUCF sector, non-energy related emissions from agriculture as well as emissions from waste, the models underlying the other scenarios have a much narrower scope. IEA does not cover LULUCF, non-energy agriculture, and waste; BP does not cover LULUCF, non-energy agriculture, non-cement industrial process emissions, and waste; Equinor does not cover non-CDR LULUCF, non-energy agriculture, industrial process emissions, and waste; Shell does not cover non-energy agriculture, and waste; and ExxonMobil does not cover agriculture, LULUCF, industrial process emissions, and waste. These differences in scope are relevant because selected industrial sectors like cement production and waste, as well as animal stocks, agricultural practices, marsh lands and deforestation that constitute hard-to-avoid emissions will trigger the need for compensation by CO_2 removal and storage.

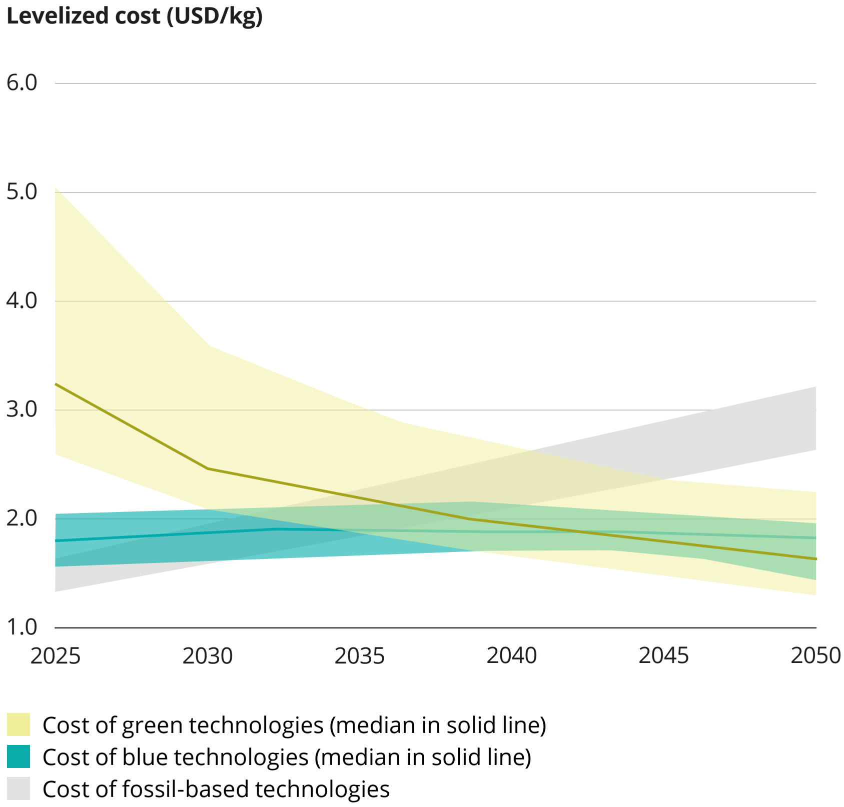
Fig. 6-14 – Annual CO_2 injection capacities of CCS projects worldwide as of 2022 (operating, under construction, and under development)



Source: Oeko-Institut analysis based on data from Global CCS Institute (GCCSI) project database: https://co2re.co/FacilityData

Importantly, the current status of CCS projects is relatively low, compared with long-term model expectations. The GCCSI project database (GCCSI, 2023) shows projects with a storage capacity of just under 43MtCO_2 in operation (73% of it for Enhanced Oil Recovery), capacity under construction of just under 10Mt CO_2 (mainly for dedicated geological storage), projects in an advanced stage of development with a total capacity of 99MtCO_2, and projects in an early stage of development with an annual storage capacity of another 92MtCO_2 (both groups mainly for dedicated geological storage). Most of the projects under development are scheduled to come on stream in the 2020s. In view of the new capacities of 200Mt CO_2 expected for the coming decade, the above-mentioned ramp-up models as shown in Figure 6-14 appear extremely ambitious. Moreover, a large proportion of the projects currently pursued are in the US (80MtCO_2), Northern Europe (66Mt CO_2), and Australia (16MtCO_2), and thus not in regions where natural gas is partly expected to play a role as a transitional energy source (China, India). Consequently, the possibility of a significantly delayed ramp-up of CCS means that the available capacities would then have to be used entirely by the hard-to-abate sectors.

Fig. 6-15 – Outlook on production costs of clean hydrogen, 2025–2050



Source: Deloitte analysis; The production cost is computed here as LCOH (levelized cost of hydrogen), a methodology accounting for all capital and operating production costs in a levelized manner over a unit cost of produced hydrogen and its derivative (US$/kg). The green and blue areas represent the production cost distribution of 80% of clean hydrogen that can be produced in Deloitte's 2023 global green hydrogen outlook (solid lines representing the median). The cost of gray pure hydrogen directly accounts for detailed modeling assumptions (a 10% uncertainty range is added to the central estimate to account for market uncertainties).

Beyond the ramp-up speed of potential CCS projects, the use of CCS in combination with fossil fuels also faces a serious economic challenge. With the expected cost reductions of new energy carriers such as green hydrogen, the economic attractiveness of using CCS within fossil energy generation plants is decreasing. The cost comparison between green and blue hydrogen can be used as a benchmark for this competitive situation. In Deloitte's 2023 global green hydrogen outlook (Deloitte, 2023), the median break-even point between blue and green hydrogen is expected for 2040 (see Figure 6-15). Thus, the economic attractiveness of natural gas CCS options is already questioned in the medium term.

The expectation of a significant role for CCS in increasing freedom for the use of fossil energy sources must be regarded, therefore, as a high-risk strategy at least from a climate policy perspective.

Key results and takeaways

CCS is an important building block in achieving climate neutrality. However, global projections overwhelmingly show no prospects for a development path in which the use of CCS would allow an increased use of natural gas on the path to carbon neutrality.

Analyses of the development of CCS projects also show that although the potential for CO_2 storage is large in principle, the actual development of injection infrastructure in terms of capacity and spatial distribution does not provide a sufficiently robust basis for the increased use of natural gas in combination with CCS. The foreseeable development of CO_2 transport and injection infrastructure is already insufficient to neutralize greenhouse gas emissions from industrial processes.

The expected cost developments for green and blue hydrogen as indicators for the economic viability of natural gas use in combination with CCS show that huge cost reductions of the alternatives can create significant economic risk for the use of CCS beyond the hard-to-abate sectors like cement clinker production.

7. Natural gas reserves, production patterns and export infrastructure

As with any other energy carrier, analysis of future trends in natural gas must be combined with an assessment of the reserve base. The level of concentration within a limited set of countries and the globally declining demand to meet climate objectives raise risks of stranded assets.

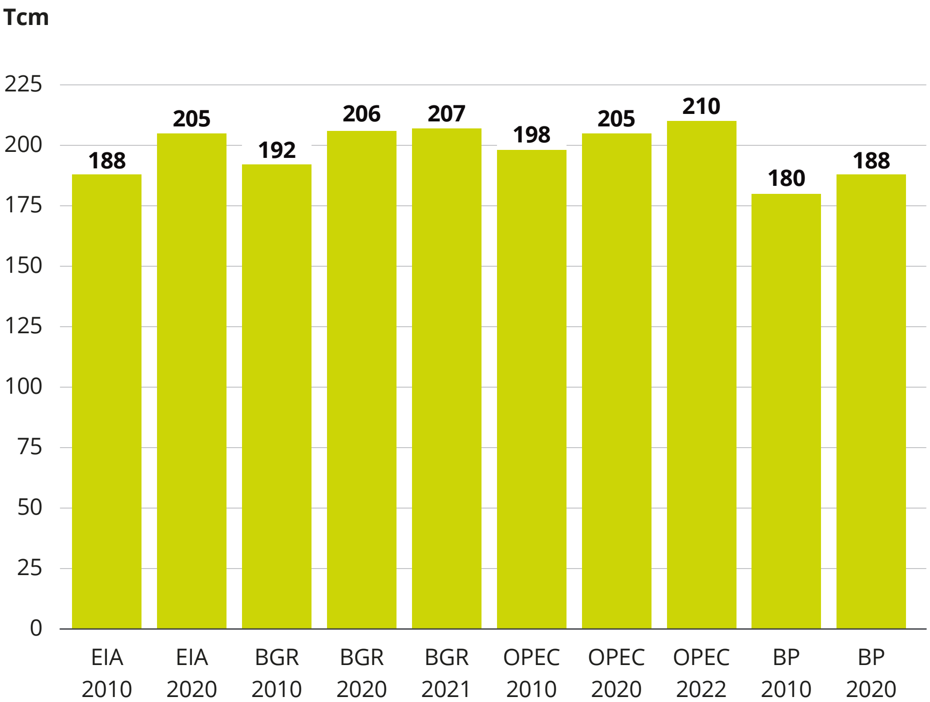
With regard to these reserves, a distinction must be made between two different categories in particular (BGR, 2022).

- Raw material reserves are defined as the part of the reserves that firstly are proven, secondly can be extracted with today's technology, and thirdly at today's prices;
- Raw material resources include two groups of reserves. On the one hand, they include those reserves that have been proven, but are currently not technically and/or economically recoverable. On the other, resources include those reserves that have not yet been proven but are geologically possible and may be recoverable in the future.

Estimates of natural gas reserves and resources are published internationally by various institutions on a regular basis. Figure 7-1 shows a series of such estimates for natural gas reserves from different institutions at different times. On the one hand, the overview shows that the reserve estimates are in comparable orders of magnitude and currently in the range of just under 190 to 210tcm, whereby the lower bandwidth value was published by a major natural gas producer and the upper values come from government agencies in the US (EIA) and Europe (BGR), and from the Association of the Petroleum Producing Countries (OPEC). On the other hand, the overview also shows that estimates of natural gas reserves have tended to increase over time; i.e., that the production of natural gas has been lower than the increase in reserve estimates. At the current level, the above estimates of natural gas reserves would be sufficient for a period of about 50 years, assuming constant production (static range).

From a global perspective, the natural gas reserves are mainly conventional deposits (approx. 95%); shale gas deposits and coal-based methane comprise only a very small part. For some countries, however, the shares are significantly larger. For example, shale gas deposits in the US account for about 80% of natural gas reserves; and coal-bed methane constitutes almost 40% of the reserves identified in Australia. In China, too, significant shares of unconventional natural gas reserves are reported for shale gas and coal-bed methane deposits, at 6% and 9% respectively.

Fig. 7-1 – Global natural gas reserve estimates, 2010–2022



Source: Oeko-Institut analysis based on (U.S. Energy Information Administration, 2023; BGR, 2011; BGR, 2023; OPEC, 2023; BP, 2022).

The estimates for the additional natural gas resources are currently more than a factor of 3 higher than the reserves (approx. 674tcm), with conventionally recoverable reserves comprising the largest share (approx. 330tcm). The second largest share (246tcm) is accounted for by shale gas deposits, while much smaller shares are accounted for by coalbed methane (7tcm) and tight gas (just under 2tcm).

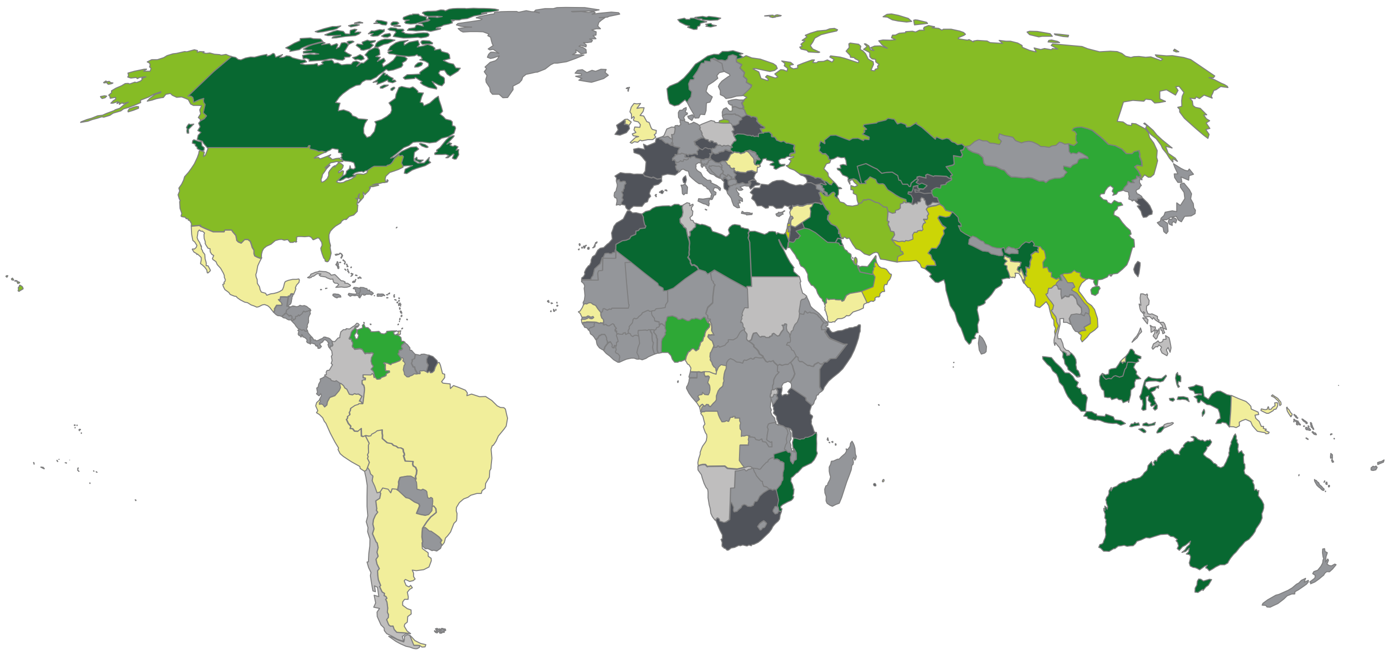
If the natural gas reserves or natural gas resources were completely burned and the resulting CO_2 released into the atmosphere, it would result in total emissions of about 400Gt CO_2 for the natural gas reserves and 1,350Gt CO_2 for the natural gas resources. The CO_2 emissions from the reserves alone would thus roughly correspond to the CO_2 emissions budget remaining for compliance with the temperature limit of 1.5°C, or exhaust the budget for 1.7°C and 2°C by just under 60% and approx. one-third respectively (IPCC, 2021; Öko-Institut, 2021). There are also methane emissions from natural gas production and transport which can further increase global warming potential, whereby this increase in climate effects depends strongly on the extraction technologies and transport routes, and ranges from 10% to 45% (IEA, 2023d; ifeu, 2023d).

An analysis of the geographical distribution of natural gas reserves (see Figure 7-2) shows their uneven distribution:

- The three countries with the largest natural gas reserves (Russia, Iran, Qatar) account for about half of the global natural gas reserves (38, 34 and 24tcm respectively).
- The countries with the 10 largest reserves (five of which have reserves of more than 10tcm) achieve a share of total reserves of about two-thirds.
- The 20 countries with the world's largest natural gas reserves comprise more than 90% of global natural gas reserves.

As to additional resources, the ten countries with the largest resources include six that do not belong to the ten most important countries in terms of natural gas reserves (Australia, Algeria, Canada, Argentina, Brazil, Mexico). From a global perspective, resources of conventional natural gas also account for about half of the total resources. For individual countries with large additional natural gas resources (the US, Canada, Mexico, Venezuela, Argentina, the UAE, Algeria, Libya, South Africa), however, the shares of shale gas in the estimated resources are well over half. In terms of resources, coal-bed methane only plays a significant role for India, Indonesia, Australia and China (one-fifth to one-third of total resources).

Fig. 7-2 – Global natural gas reserves, 2021



Natural gas reserves

- more than 10 Tcm
- 5 to 10 Tcm
- 1 to 5 Tcm
- 0.5 to 1 Tcm
- 0.1 to 0.5 Tcm
- 0.05 to 0.1 Tcm
- 0.01 to 0.05 Tcm
- less than 0.01 Tcm

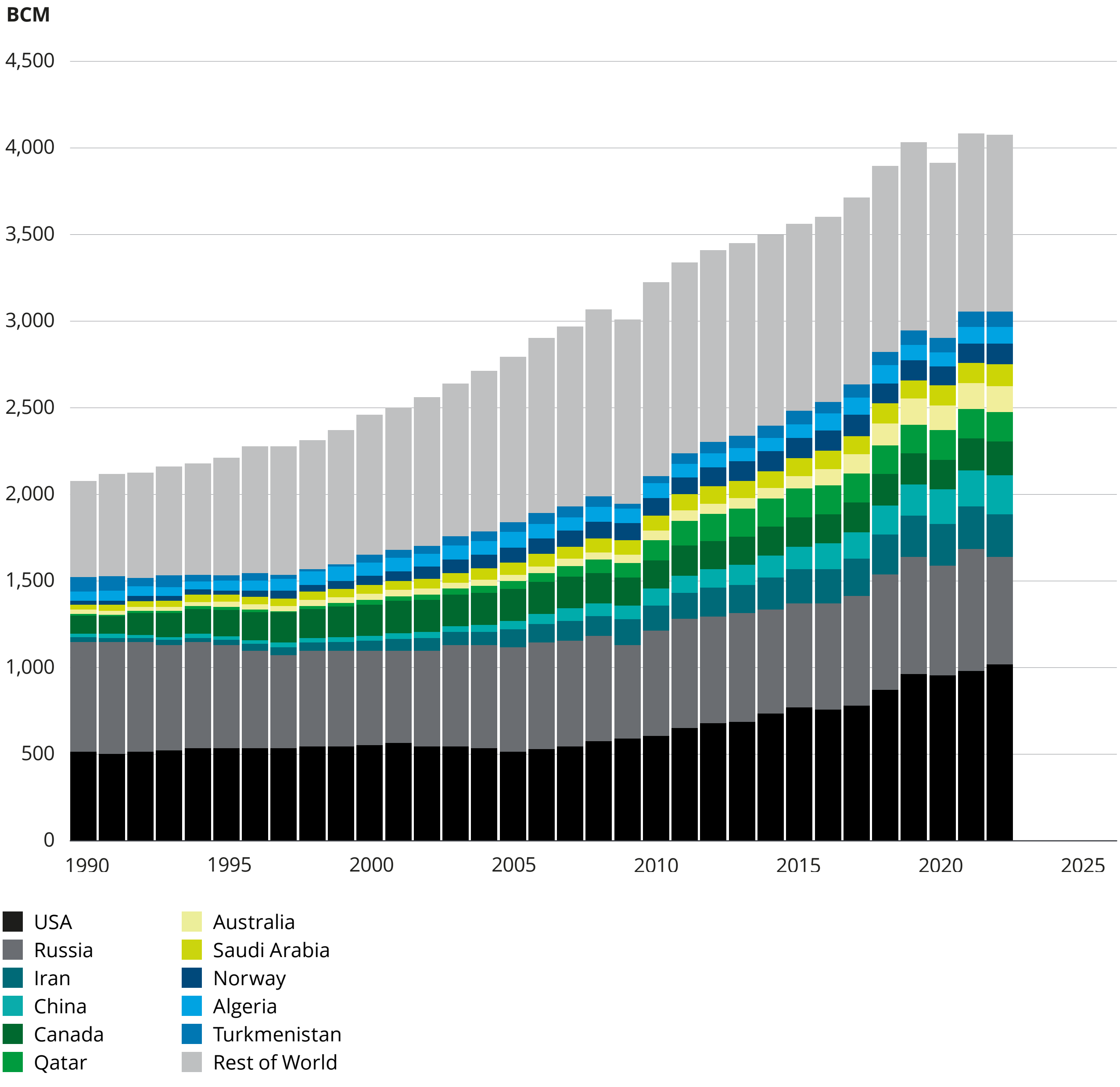
Source: Oeko-Institut analysis based on BGR, 2023.

The reserve endowment is also fundamentally reflected in the development of patterns in global natural gas production (see Figure 7-3). With global natural gas production roughly doubling from 1990 to 2022, the US share remained relatively stable at 20%-25%. The level of production in Russia remained roughly stable with some fluctuations, but its share of global natural gas production halved between 1990 and 2022. All other countries shown comprise only a few percentage points of global production, but some of them show huge increases. For example,

- natural gas production in Qatar has increased by a factor of 27 since 1990,
- in China by a factor of 14 and
- in Iran by a factor of 10;
- natural gas production in Australia, Norway, and Saudi Arabia has also increased by a factor of 3.8 to 7.4.

In none of the large natural gas producing countries shown has the level of natural gas production declined over the past three decades. In principle, however, it is also true that the shares of the major natural gas countries in global production are slightly lower than the corresponding shares of natural gas reserves. The reserve endowment of approx. 50% for the three countries with the largest natural gas reserves contrasts with a contribution to global production of just under 30%. For the ten largest countries in terms of reserves (share of reserves approx. 80%), the production share is about two-thirds. The 20 countries with the largest reserve shares (90% in total) currently account for about one-fifth of global natural gas production.

Fig. 7-3 – Global natural gas production, 1990–2022



Source: Oeko-Institut analysis based on U.S. Energy Information Administration (2023).

An important indicator of the time dimension of the usability of natural gas reserves is the ratio between reserves and current production levels. The global overview shows that the static range extends from a few years to over 100 years. The ratio of reserves to current production is particularly high in Russia, Central Asia, the Middle East and in some African states (see Figure 7-4). If the static duration of reserves is also understood as the capacity of production infrastructure, a central dilemma of natural gas policy becomes apparent. Natural gas production in some countries with large natural gas reserves would only be possible in the decades ahead if production and transportation infrastructure are significantly expanded. However, especially in areas of natural gas production (and less so for the transport infrastructure), this could lead to lock-in effects incompatible with climate policy goals at the global level, as well as for the individual countries. This applies in particular to those countries which have significant natural gas reserves, but for which the capital-intensive and relatively long-lived production infrastructure have yet to be built.[43]

A specific situation arises for the political restrictions on reserve utilization in Russia. If it is assumed that Russian pipeline gas deliveries to Europe are reduced by about 140bcm in the long term, and that the infrastructures for exporting these gas volumes to other regions of the world can only be created in the very long term, the static duration of Russian natural gas reserves could increase from approx. 60 to just under 80 years.

However, to assess the reserves situation and its development, it must also be taken into account that the use of these reserves depends to a large extent on the existence or development of the transport infrastructure. At the global level, the distribution of inter-regional natural gas transport was about evenly split between pipelines and LNG until the partial cessation of Russian gas supplies to Europe. However, since 2010, the share of pipelines has fallen by around 10% and will fall sharply in 2021 and 2022 due to the huge drop in Russian gas exports to Europe, reaching only 43% in 2022 and falling significantly again in 2023, as the redirection of Russian supplies to other countries connected by pipeline is only possible to a very limited extent. A regionally differentiated analysis of transport options is therefore of great importance (Energy Institute, 2023).

- Although Russia is no longer the world's largest exporter of natural gas (the US is), it is by far the largest exporter of natural gas by pipeline (mainly from the West Siberian gas fields to Europe). Russian pipeline exports remained relatively constant over the last decade until the huge reduction in exports to Europe, but decreased by almost 40% between 2021 and 2022. Although LNG exports have almost tripled in the last decade, they comprised only approx. 15% of total exports before the crisis.

- In the past, natural gas imports from the US came mainly through domestic pipelines. Over the past decade, however, overseas LNG exports have grown hugely and will exceed pipeline exports for the first time in 2021. Although pipeline exports from the US will double between 2011 and 2022, LNG exports will increase by a factor of 58 over the same period, with the result that approx. 56% of US exports are currently transported by LNG.

- Exports from other North American countries are mainly by pipeline and have remained relatively stable over the past decade. The same is true for the CIS countries.

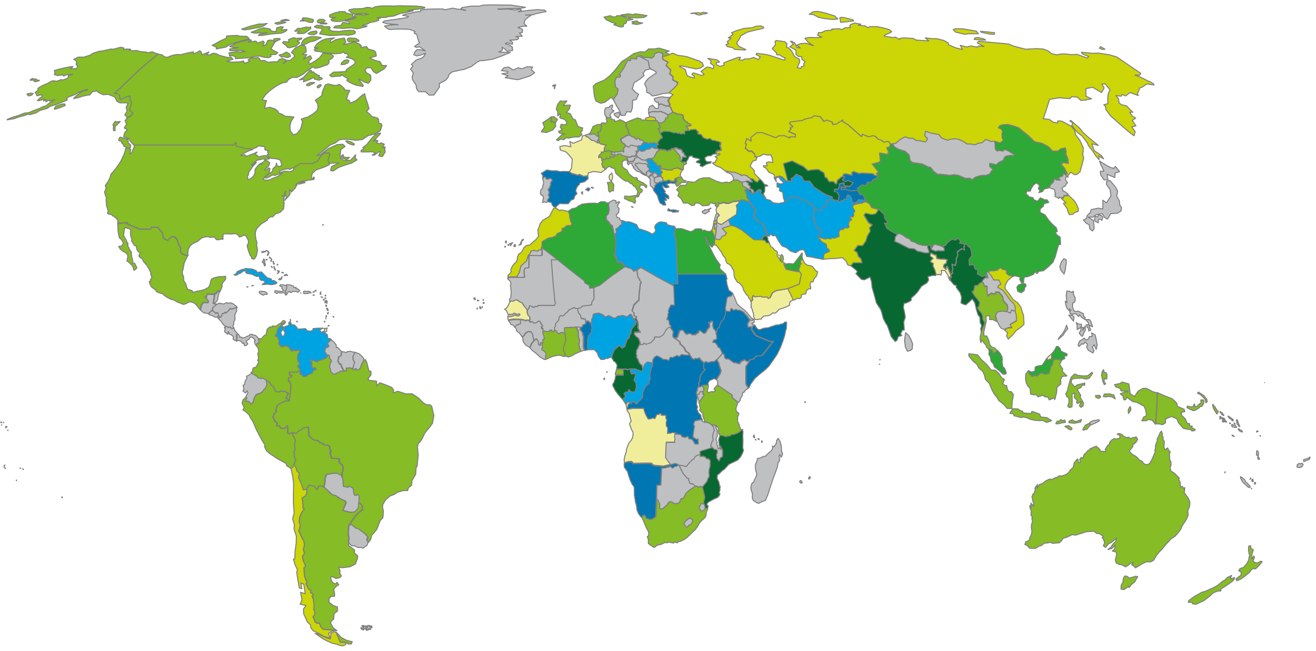
- To a lesser extent, gas is also exported by pipeline from the Middle East and Africa. Volumes from the Middle East have increased by a factor of 1.7 since 2011, while the level of pipeline deliveries from Africa has changed only slightly. For both regions, LNG exports now clearly dominate (90% of exports from the Middle East and 60% of exports from Africa).

- This steady growth of around 10 percentage points per fifth of the year was replaced in 2005 by a stagnation phase in which natural gas consumption remained at 40% above the 1990 level. The only exception was the crisis year 2009, when natural gas consumption fell by about 6%, compared with the previous year, or by 8%, compared with the starting level in 1990, mainly due to a very significant decline in the use of natural gas in industry.

- Natural gas exports from Australia and South-East Asia are almost exclusively by LNG carriers.

[43] These countries with natural gas reserves of more than 50 bcm include Mauritania, Senegal, Namibia, Sudan and South Sudan as well as Rwanda.

Fig. 7-4 – Reserve-production ratio for natural gas, 2021



Reserve/Production ratio

- less than 20 years
- 20 to 39 years
- 40 to 59 years
- 60 to 79 years
- 80 to 99 years
- 100 and more years
- Reserves but no production yet

Source: Oeko-Institut analysis based on BGR, 2023.

These developments show that the importance of LNG in the international gas trade has increased significantly in recent years. Given the decline in Russian gas supplies, this role will continue to grow massively in the future. This makes not only the development of natural gas production in the various regions of the world relevant, but also the development of LNG export infrastructures. This is, of course, a question of not only the access of reserves to the market, but also the risk of stranded assets or lock-in effects. This becomes very clear when looking at the development of liquefaction capacity for natural gas exports (Prognos, 2023):

- By the end of 2022, LNG export terminals with a capacity of 636bcm were in operation worldwide. Construction has started or final investment decisions (FID) have been made for a further 190bcm, which will come on stream in the next few years, increasing global capacity by 30%. A further 843-bcm of capacity is currently under discussion. If all these projects come on stream, total capacity would increase by more than 160%.

- The Middle East currently has the largest number of LNG export terminals in operation (141bcm), with approx. a third more under construction or at FID, and the addition of other projects under discussion could increase capacity by 55% above the existing capacity.

- Australia currently has the world's second largest export capacity (121bcm), with a 6% expansion secured and a further 17 percentage points under discussion.

- In third place among LNG export terminals are North American facilities (108bcm). Here, very large capacity expansions are under construction or have FID (83% of the existing capacity); including the projects under discussion, this could result in a 5.7-fold increase in capacity.

- Export terminals with a total capacity of 104bcm are currently in operation in Africa. Capacity additions of nearly one-fifth of the existing capacity are in the implementation phase, and discussions are underway to increase total capacity by more than 90% of the existing capacities.

- Russian export terminals currently play a limited role, with a total capacity of 42bcm, but an expansion of almost two-thirds is underway, and a further increase is being discussed, which could increase the total capacity by a factor of 4.4. This capacity level would be very relevant, especially as Russian production volumes would return to the world market via LNG exports (see section 4.2).

- Although LNG export infrastructure also plays a role in other regions of the world (notably South East Asia with 89bcm and South America with 23bcm), the expansion of LNG export capacity for these regions can only be expected in the long term.

Precisely because investment in export infrastructure is usually made only in conjunction with exploration decisions, the development of these terminal capacities is an important indicator of the magnitude of expected natural gas deliveries. The LNG export terminals currently planned and discussed will reach a total capacity which, especially in view of the climate policy framework, gives rise to expectations of stranded assets and, in some cases, lock-in effects of considerable magnitude.

Key results and takeaways

The various estimates of recoverable gas quantities are within a relatively narrow range. In fact, they have increased slightly in recent years.

Full energy use of the known natural gas reserves that can be extracted with today's technology and at today's cost would exceed the acceptable limits for climate protection by a factor of 2 to 3.

Most of the reserves are located in a few countries. Exploiting natural gas reserves in some countries with particularly large reserves (Russia, Central Asia, the Middle East, and Africa) and in countries that are not significant suppliers yet (especially in Africa) would require a huge expansion of the production and transport infrastructure. Such an expansion would be inconsistent with national and global climate change objectives and would risk creating lock-in effects or stranded assets on a large scale.

The risk of stranded assets is significant not only in the production of natural gas, but in the development of export and import transport infrastructure. This applies both to climate policy restrictions and to the huge uncertainties surrounding future revenues from the sale or export of natural gas.

8. Governance indicators of resource-abundant countries

Natural gas exploration and production projects take place in a complex technical, financial, regulatory, and geopolitical environment. Governance is a key parameter to mitigate lock-in effects and stranded assets risks.

The development of natural gas production projects is taking place in a complex framework between security of supply considerations, the existing business models of countries and companies, the search for new fields of export businesses, and a dynamically developing international climate regime. Firstly, global natural gas production must be maintained for the years ahead and the next (few) decades, and possibly even expanded for short periods. Secondly, the corresponding projects must be set up from a technical, economic, and regulatory perspective in such a way that no lock-in effects arise that make it difficult or impossible to achieve climate protection goals, the extent of stranded assets is kept as low as possible, the regionally different transformation paths are taken into account and, finally, the transformation of natural gas infrastructure towards climate-neutral and sustainably produced energy is also made possible.

This results in responsibilities for the natural gas companies, but above all in important tasks for the partly complex political regulations, which must address or take into account the above-mentioned aspects with a view to the short time periods of the upcoming transformation processes. Given these different challenges and tensions, the quality and accountability of governance in the gas-producing countries emerges as a key assessment parameter for the international support of natural gas projects. This is less relevant for the very large natural gas producers (which generally do not require such support) than for countries with significant natural gas reserves, in which considerable expansion investment for the natural gas sector is necessary or being sought. Only with high-quality and robust governance in these countries will it be possible to bring the investment needs in the natural gas sector in line with climate policy goals, strategies and instruments in the complex environment mentioned above.

In order to classify this governance quality, the Worldwide Governance Indicators (WGI) are used here, which are updated and published by the World Bank on a regular basis. The total of six indicators (see Box 3) for all countries in the world are based on more than 30 data sources in which governance is classified on the basis of a large number of respondents and various expert assessments. The scale of the ratings ranges from -2.5 to +2.5 and is derived based on statistical methods from the individual data collections (Kaufmann, Kraay, & Mastruzzi, 2010).

- The six different governance indicators are only partially independent of each other and are partially interdependent.
- Relatively strong correlations can be observed between the indicators Government Effectiveness (GE), Regulatory Quality (RQ), Rule of Law (RL) and Control of Corruption (CC).
- There are only comparatively weak correlations between the governance indicators Voice and Accountability (VA) and Political Stability and Absence of Violence/Terrorism (PV), and the other indicators.

Against this background and with a view to the questions addressed here, the analyses presented below refer to the governance indicator, Government Effectiveness (GE). Comparable analyses for the indicators Regulatory Quality (RQ), Rule of Law, and Control of Corruption lead to very similar results.

Structure and specification of the World Bank's Worldwide Governance Indicators (WGI)

A) The process by which governments are selected, monitored and replaced.

a. Voice and Accountability (VA) – capturing perceptions of the extent to which a country's citizens are able to participate in selecting their government, as well as freedom of expression, freedom of association, and a free media.

b. Political Stability and Absence of Violence/Terrorism (PV) – capturing perceptions of the likelihood that the government will be destabilized or overthrown by unconstitutional or violent means, including politically-motivated violence and terrorism.

B) The capacity of the government to effectively formulate and implement sound policies.

a. Government Effectiveness (GE) – capturing perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation and the credibility of the government's commitment to such policies.

b. Regulatory Quality (RQ) – capturing perceptions of the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development.

C) The respect of citizens and the state for the institutions that govern economic and social interactions among them.

a. Rule of Law (RL) – capturing perceptions of the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence.

b. Control of Corruption (CC) – capturing perceptions of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as "capture" of the state by elites and private interests.

Source: Kaufmann, Kraay, and Mastruzzi (2010).

Figure 8-1 shows an overview of the specific country ratings for the Government Effectiveness indicator. Higher ratings (GE greater than 0.5) are given primarily to OECD countries and China, while medium ratings (GE of -0.5 to 0.5) are given to most Latin American countries as well as India and some countries in the Middle East, Central Asia and Africa. Low ratings for government effectiveness (GE less than 1.5) are given to many states in Africa and some in the Middle East and Central Asia.

With a view to demographic, economic and energy factors, a differentiated picture emerges.[44]

- The countries with high government effectiveness ratings comprise approx. 32% of the world's population and 77% or 61% of global value added (at exchange rates or purchasing power parities). These countries account for 73% of global coal production, 62% of global oil production and 53% of total oil production.

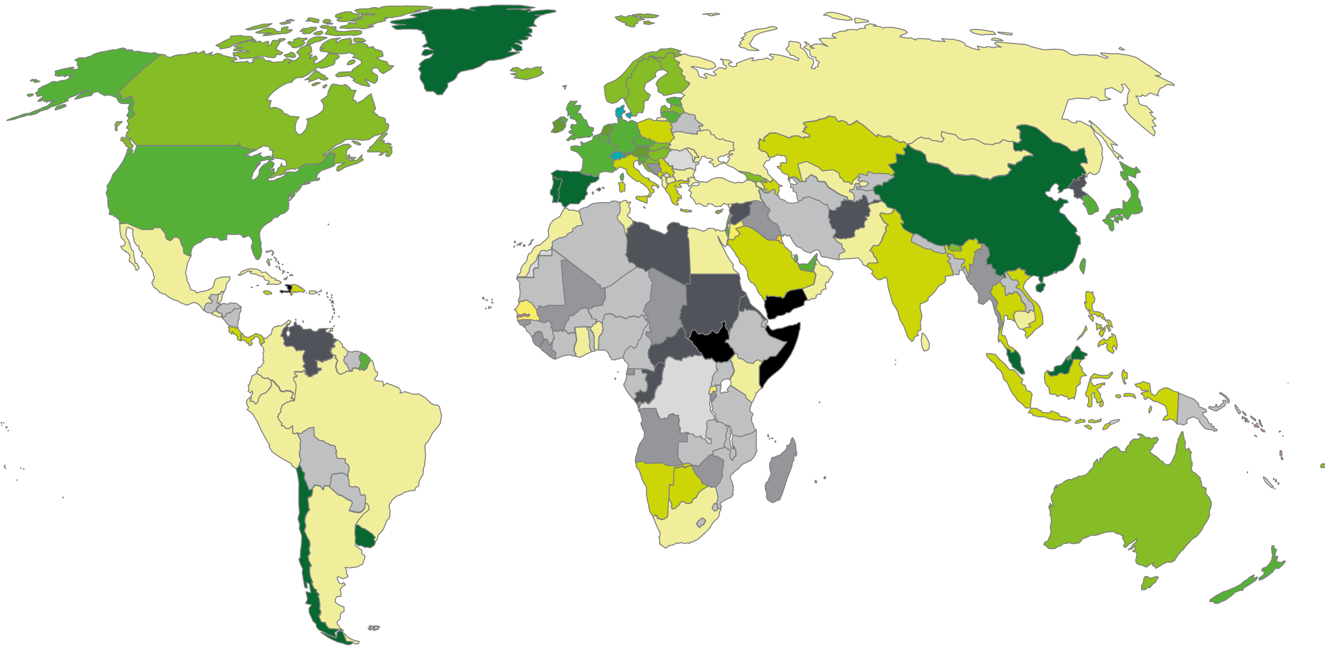
- The countries with a medium rating (-0.5 to +0.5) cover 48% of the world's population as well as 20% and 34% of global economic output (at exchange rates and purchasing power parities, respectively). The corresponding shares of fossil fuel production are 26% for coal, 31% for mineral oil, and 36% for natural gas.

- The countries with a low governance effectiveness score represent 20% of the global population and 3% and 6% of global value added (at exchange rates and purchasing power parities, respectively). The production shares for coal (1%), oil (7%), and natural gas (11%) are at a low level.

Overall and from an aggregated perspective, countries with high governance effectiveness have a particularly high share of total or per capita value added. The share of fossil energy production decreases with declining governance effectiveness. The differences for coal are significantly greater than for oil and natural gas. For countries with particularly low governance effectiveness, the share of global fossil fuel production plays only a minor role today.

[44] The data on population and gross domestic product were taken from the World Bank's World Development Indicator database (https://databank.worldbank.org/source/world-development-indicators), the energy data come from the IEA world energy statistics (https://www.iea.org/data-and-statistics/data-product/world-energy-statistics-and-balances#world-energy-statistics).

Fig. 8-1 – Government Effectiveness global governance indicator



Government effectiveness assessment

- worse than -2.0
- -1.5 to -2.0
- -1.0 to -1.5
- -0.5 to -1:0
- 0.0 to -0.5
- 0.0 to 0.5
- 0.5 to 1.0
- 1.0 to 1.5
- 1.5 to 2.0
- better than 2.0

Source: Oeko-Institut analysis based on Worldwide Governance Indicator database (https://databank.worldbank.org/source/worldwide-governance-indicators).

In the context of future natural gas production projects or their state support, however, the question of the highest possible governance capability arises primarily with regard to the available natural gas reserves and the necessary infrastructure. Against this background, a more in-depth analysis was carried out, focusing primarily on the critical aspects of natural gas production:

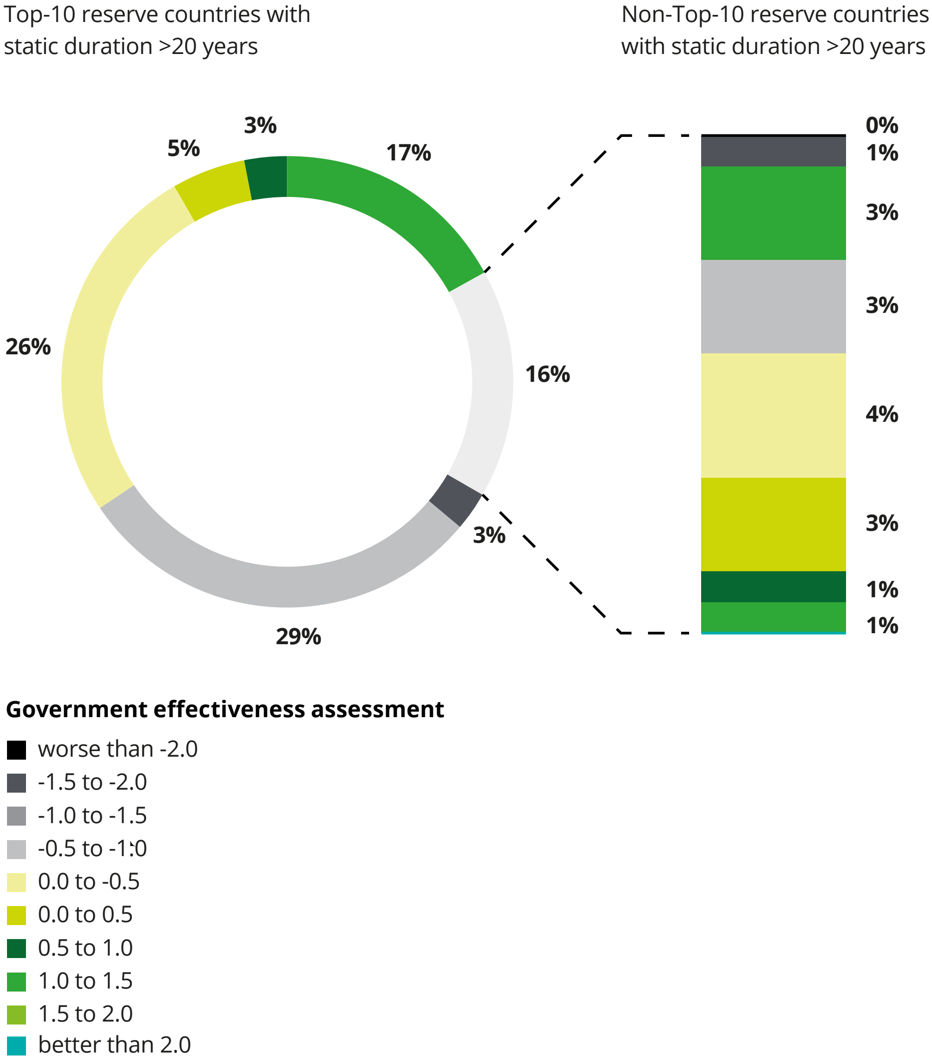
- Firstly, only the countries beyond the ten countries with the currently largest natural gas reserves or natural gas production volumes were considered. The background to this limitation is the assumption that the technical and economic framework conditions for these countries are such that government flanking measures are not likely to be relevant, especially in an international context.

- Secondly, only countries with natural gas reserves of more than 50bcm were considered; i.e., countries from which at least smaller contributions can be expected.

- Thirdly, only those countries were included for which the ratio between reserves and current production is more than 20 years (see Figure 8-2); i.e., natural gas production does not extend into the critical time window of global climate neutrality when viewed statically. This group of countries also includes those for which significant natural gas reserves are reported but production has not yet started or has started only on a very small scale. However, sensitivity analyses were carried out for this assumption.

In accordance with these assumptions, the individual countries were allocated from the perspective of governance effectiveness. The countries corresponding to the above limitations account for reserves of approx. 29tcm; i.e., about 16% of the total reserves. Without the criterion of static reserves, this value would increase to approx. 40tcm or 19% of total global reserves. The decisive restriction thus concerns the reserve wealth or the current production volumes of the largest natural gas producers.

Fig. 8-2 – Natural gas reserves with static duration of more than 20 years and governance assessment, 2021



Source: Oeko-Institut analysis based on Worldwide Governance Indicator database (https://databank.worldbank.org/source/worldwide-governance-indicators) and (BGR, 2023).

The following classifications result for the individual countries using the Governance Effectiveness indicator:

- Countries with high governance effectiveness (GE above +0.5) only have reserves of just under 4tcm (15% of the natural gas reserves examined) under the above restrictions.[45] However, none of these countries is ranked at the two highest levels (GE from +1.5 to +2.0 and above +2.0).

- Countries with medium governance effectiveness (GE from -0.5 to +0.5) have reserves of approx. 13tcm (45%).[46]

- Countries with low governance effectiveness comprise approx. 12tcm (42%) of the natural gas reserves included here. The two lowest classes (GE from -1.5 to -2.0 and below -2.0) account for a share of 8%,[47] and the next two classes (GE from -1.0 to -1.5 and -0.5 to -1.0) for a share of 34%.[48]

- Without the criterion of static reserve coverage, the share of countries with high governance effectiveness would increase significantly (15% to 24%, especially in the countries with the highest ratings). For countries with medium governance effectiveness, there would be only very small compartmental changes (decrease from 45% to 44%) and for the countries with low governance effectiveness, there would also be only a small change.

In the overall view, contributions to the development of natural gas reserves beyond the current main producers are low. However, the share of countries with low governance effectiveness beyond the current main natural gas countries is comparatively high. In view of the difficult balancing, distribution, and transformation issues that arise from the expansion of natural gas production and transport capacities under the constraints of an increasingly dynamic international climate policy, the governance capabilities of these countries must therefore be assessed as extremely challenging. This situation can significantly increase the challenge of lock-in effects or stranded assets on a large scale.

[45] This group of countries includes Brunei, Chile, Israel, Malaysia and Mauritius.

[46] Among these countries the following countries have an GE of 0.0 or higher: Azerbaijan, India, Kazakhstan, Namibia, Rwanda, Senegal, The Philippines, and Vietnam. Among the medium governance effectiveness countries are the following countries with a GE assessment below 0.0: Cuba, Egypt, Kuwait, Peru, Tunisia, Ukraine, Uzbekistan, Vietnam.

[47] This country group includes Afghanistan, Congo, Libya, Sudan, Syria, and Yemen.

[48] This country group includes Algeria, Angola, Cameroon, Iraq, Mozambique, and Myanmar.

Key results and takeaways

Managing the complex framework between security of supply considerations, existing business models of countries and companies, the search for new export fields, and a dynamically evolving international climate regime requires increasingly advanced governance capabilities, especially when significant investment in natural gas production and transport facilities is on the agenda.

The effectiveness and reliability of governance capacity is thus also a key parameter for international support for projects that may be associated with high lock-in effects or for which the probability of stranded assets is high. This issue is particularly relevant for projects that aim to significantly expand fossil energy exports.

In this context, governance indicators can provide an interesting and meaningful basis for evaluation across the whole range of evaluation criteria.

The combined analysis of reserve and governance indicators highlights that many of the countries for which an expansion of extraction and transport infrastructure could be interesting from a pure reserves and diversification perspective, face a very challenging situation in terms of governance capacity.

9. Implications for future natural gas exploration and production project

Global, EU, and German gas markets are facing major challenges in the context of the global energy transition. Natural gas demand is expected to lose momentum on the pathway towards climate neutrality, while current proven reserves appear sufficient to cover global needs in most scenarios consistent with the Paris Agreement. Against this backdrop, new investments in natural gas production projects are at risk to end up stranded, and any potential government support would raise several implications.

Global, EU, and German gas markets are facing major challenges. While some of these have been subject to political attention for some time, others arise directly from ongoing geopolitical tensions.

- The natural gas industry is facing fundamental changes in the context of the energy transition. To achieve climate commitments, greenhouse gas emissions from various economic activities, including the use of natural gas, must drastically decrease and eventually reach net zero. This will occur with different time horizons and trajectories across the globe. In Europe and other OECD countries, climate neutrality is already one of the guiding themes of political agendas. Far-reaching and robust instruments have already been implemented to achieve net-zero emissions from 2040 to 2050 and the peak of natural gas deployment may have already passed. This process could be delayed in other regions of the world, but remains inevitable to meeting global climate goals.

- The Russian attack on Ukraine and the resulting cut of large gas supplies from Russia (notably from the North Stream 1 and Yamal pipelines) have plunged global markets into turmoil, especially in Europe and Asia. The loss of about 1,400TWh of supply (140bcm) corresponds to more than 10% of internationally traded natural gas volumes and represents more than half of the pipeline deliveries to the EU. Since 2022, countermeasures affecting both the demand (including significant natural gas savings in all sectors) and the supply side (such as an increase in deliveries from Norway, expansion of LNG deliveries) have succeeded in stabilizing prices. Of greater importance is, however, the increased political pressure to diversify natural gas supplies, particularly for economies with high present-day natural gas import requirements. As a result, some governments have started to consider the option of reengaging public support for new natural gas projects, despite previous commitments to end international public financing of unabated fossil fuel projects made at COP26 in 2021.

These changes raise considerable uncertainties for the decades ahead. The future demand pathway will be critical to assessing supply needs and the potential implications for new natural gas projects. Furthermore, a decline in demand may hamper the viability of investments in supply and transport infrastructure. The question of whether, when, and how Russian natural gas supplies will return to global markets creates even more ambiguity. Against this background, episodes of sharp declines in natural gas prices and temporary supply shortages cannot be ruled out, at least in the medium term. Considerable risks consequently arise for capital-intensive exploration and production projects with an operating lifetime of up to 30 years. For transport and storage infrastructure projects, these risks also exist, but likely with less grave consequences.

Our modeling of future natural gas consumption in the EU and Germany shows a significant decrease in demand in the decades ahead (central scenario). This applies to all time horizons (up to 2030 and beyond) and to all sectors.

- By 2030, we expect a decrease of more than a quarter in natural gas demand in both the EU and in Germany and, by 2040, in the range of one-half to two-thirds (both compared with the reference year, built on 2018 historical data). By 2050, natural gas consumption only comprises approx. 4% of total primary energy supply in the EU (about 750TWh) and about 1% in Germany (about 50TWh). This outlook is supported by the strong climate policy instruments already in place or to be implemented in the EU and Germany (emission trading schemes for the power sector, energy-intensive industries, buildings, and road transport, as well as a variety of powerful technology- and sector-specific mechanisms). A sensitivity analysis of a delayed renewable energy deployment does not reveal a reversal in the natural gas demand pathways; with less than 75% of the REPowerEU's renewable capacity deployment targets achieved in 2030, natural gas consumption is higher, compared with its counterpart in the central scenario, but still approx. 15% lower than in 2018 in the EU and 10% lower in Germany.

- The phase-out of natural gas is faster in Germany compared with the EU. This is in line with more ambitious German climate targets compared with other EU member states, including the achievement of climate neutrality by 2045, complemented by strong climate and energy policies.

- The building sector (residential, tertiary, and district heating) is making a major contribution to the decrease in natural gas consumption throughout our outlook, particularly by 2030 when it accounts for more than half of the decrease in Germany and the EU. While the building sector was the largest consumer of natural gas in 2018, it presents competitive decarbonization options such as thermal retrofits and heat pump deployment. By 2050, natural gas plays only a marginal role in buildings, mostly in district heating.

- From 2030 onwards, decarbonization efforts gain momentum in other sectors. Alongside falling clean technology costs, tighter climate regulations (such as carbon pricing) are making it increasingly viable to move away from fossil-fuel dependent production. In industry, natural gas is replaced by process electrification and clean (and increasingly green) hydrogen-based solutions for industrial heat. By 2050, however, a small amount of natural gas will still be needed for industrial consumption in the EU as a feedstock for chemicals manufacturing, and to produce high-temperature heat combined with CCS. The power sector sees a tremendous increase in renewable energy deployment; wind and solar power represent more than half of net electricity generation in the EU from 2030 onwards. By 2050, gas-fired backup capacities, which can technically run on clean hydrogen, still remain operational to ensure the reliability of the power system during peak hours.

These results are in line with recent energy outlooks, confirming a consensus on decreasing natural gas demand in the EU and Germany by 2050. These studies present varying views on the future of energy systems, the macroeconomic and policy context (including the level of climate ambition) and technological assumptions. In Germany, this leads to some uncertainty in the 2020s, but all the trajectories reviewed show a drastic decrease in natural gas demand from 2030 onwards. At the EU level, mainstream climate-aligned scenarios show at least a broad 75% decrease in natural gas consumption by 2050. Our trajectories fall within the range of this benchmark.

A more differentiated picture emerges from a global perspective. An analysis of 30 recent key energy system outlooks reveals that the development of global demand for natural gas is closely related to the assumed stringency of global climate policy. The scenarios in which global warming is kept to well below 2°C present a cumulative global demand for natural gas of less than 1,000,000TWh from 2020 to 2050. On the other hand, outlooks with a cumulative global demand in excess of 1,500,000TWh clearly lead to global warming above 2°C, unless CDR (carbon dioxide removal) options are extensively deployed from a very early stage, a technological and industrial challenge. In the latter case, a 2°C world could still be met even with cumulative natural gas consumption of 2,000,000TWh, while global warming reaches at least 2.6°C in scenarios presenting comparable natural gas consumption pathways but without strong CDR deployment.

Behind global trends, considerably different patterns emerge across various world regions.

- If they are to meet the 1.5°C target, democratic industrialized countries reduce their natural gas consumption by 20% to 40% as soon as 2030 over 2020 levels, with a strong phase-down by mid-century. In a 2°C world, natural gas use does not increase any further from around 2030 onwards and significantly declines thereafter, to at least 60% by 2050 over 2020 levels. The early and extended use of CDR options could postpone this pathway by about a decade. Any other developments in natural gas use would result in global warming well above the Paris Agreement targets.

- For the Rest of the World, projections show a different picture. Under a 1.5°C-compatible development pathway, natural gas demand stabilizes at current levels and significantly decreases from 2035 onwards, falling 40%-50% over 2020 levels by 2050. To limit global warming to around 2°C, natural gas use could increase by up to 40% by 2035, but would then need to decline to 20%-40% over current levels by mid-century. A very early deployment of CDR could allow these pathways to be postponed by about a decade. All other trajectories of natural gas consumption show global warming well above 2°C by the end of this century.

The different scenarios reviewed all describe how energy systems will transform by 2050, under various assumptions, including the macroeconomic outlook, the availability and costs of new technologies, and different levels of climate ambition. Nevertheless, the trajectories present common patterns.

- The bulk of scenarios project a decrease in the share of natural gas in global primary energy supply for 2050 over 2020 levels. In all scenarios compatible with a 2°C target, the relative role of natural gas in the energy mix significantly declines by 2050 relative to 2020.

- The transition pathways also broadly diverge from the energy system transformation paradigm that prevailed up to 2020. Previously, in relative terms to total primary energy supply, carbon-intensive energy carriers were replaced in rather equal measure by carbon-free energy carriers and natural gas. In the reviewed scenarios of future energy transition, there is a demonstrable shift towards carbon-free energy carriers, which take on a predominant role.

Emission reduction through CCS or CO_2 removal from the atmosphere can play an important role for ambitious climate protection strategies in the long run. However, the early and extensive deployment of CCS and CDR to delay the phase-down of natural gas appears a highly uncertain strategy, given their foreseeable technical, infrastructural, and economic framework conditions that seem insufficiently mature for such a large-scale deployment in the short run.

CDR solutions can certainly play an important role in achieving the energy transition in the long term, for instance, to reduce the environmental footprint of hard-to-abate activities, to supply carbon feedstock to the chemical industry, or to offset residual emissions. However, despite efforts over the past ten years, there is little reason to believe that a major political, economic, or technological breakthrough is imminent. Hence, CCS technologies do not seem sufficiently mature to be deployed within this decade on a scale that could enable the use of natural gas to be extended while complying with climate commitments.

At the global level, current natural gas reserves (excluding new discoveries) are at least twice as high as cumulative global natural gas consumption by 2050 under trajectories compliant with keeping global warming under a 1.5°C pathway. If all currently known natural gas reserves were to be completely burned and the resulting CO_2 were released into the atmosphere, the result would most likely cause an increase in the global mean temperature of 1.5°C or more above pre-industrial levels.

The greater challenge is the high concentration of both natural gas reserves and current production in a few countries. Except for Russia, Algeria, and Norway, none of the top ten reserve and production countries is within substantial pipeline reach of Germany and the EU. In the short term, additional imports can only arise from the LNG route, due to the supply constraints in Norway and North Africa, both already connected to the EU via pipeline. The LNG market is dominated by three suppliers: the US, Qatar, and Australia (with global market shares of about 20% each). Despite political interest in diversification, this concentration can hardly be lowered in view of the location of reserves and the infrastructure contraints, at least in the short term. Although the expansion of the European LNG supply segment will reduce the previous dependence on Russian gas, it will likely only marginally improve EU reliance on a limited set of countries. Besides, the development of new supply regions, which have relatively limited reserves and are largely unable to rely on already developed production and transport infrastructure for natural gas exports, is therefore not expected to ultimately make a significant contribution to security of supply in the short, medium, and long term.

Against this background, several fundamental questions arise about international support measures for new natural gas production projects[49] located outside the EU and targeting the German and EU markets:

- Is the contribution of such projects relevant for security of supply? From a purely EU and German perspective, and thus in the context of a strongly orchestrated climate protection paradigm and ultimately natural gas phase-out in the long term, the relevance of these projects is questionable. Beyond the short-term measures to compensate for the loss of natural gas supplies from Russia as part of REPowerEU, the contribution of new gas development projects to the diversification of international natural gas supplies appears limited, at least in the short term, due to the concentration of reserves and existing infrastructure. Furthermore, the foreseeable significant decline in German and EU demand is likely to reduce security of supply concerns and political pressure to diversify in the medium and long run.

- With an operational life that typically spans several decades, do these projects comply with the Paris Agreement? Our modeling at German and EU level and our survey of the global studies reveal that, to meet climate targets, many consuming regions (including China) are likely to have already reached their peak demand or are likely to do so in the next 10 to 15 years, before a significant phase-down. This suggests a high risk of stranded assets for newly developed projects that are primarily aimed at exporting natural gas. This applies particularly to newly or small-scale producing regions, where production and shipping infrastructure must be created or greatly expanded. This, in turns, raises the broader question on how to foster growth opportunities in developing and emerging markets to ensure a fair global energy transition.

- Against this backdrop, government support from EU countries would raise questions about consistency with climate and development goals. It would blur the strong commitments made by EU countries to promote the global energy transition. It could also encourage beneficiary countries to embark on a development trajectory that would be either unsustainable or incompatible with curbing global emissions.

Notwithstanding these fundamental concerns, our analysis suggests two important implications for any potential policy support from EU countries for new natural gas production and export projects, and for major expansions of existing infrastructure:

- Factor the risk of stranded assets into project design. If new investments in natural gas are pursued, they could incorporate ex ante plans, with accountable roadmaps, on how major parts of the facilities can later be repurposed into assets that support a country's energy transition, for example towards clean hydrogen and its derivatives. The adoption of best available technologies should be another prerequisite.

- Limit lock-in effects by promoting agile business models and high governance standards. For instance, business models that mainly rely on long-term contracts commit projects to operating over a fixed time horizon, while destination clauses freeze exports to the same destinations. Both gas-producing and gas-buying countries have therefore an incentive to prolong the use of gas-based technologies, even if alternative cleaner and competitive solutions become readily available. To promote flexible business models, governments could refrain from supporting projects based solely on long-term contracts and/or that include destination clauses. Improving governance standards will also be key to ensuring the timely transformation of assets and business models on the road to carbon neutrality. Otherwise, long-term financial and climate risks may outweigh potential medium-term benefits.

[49] Similar issues arise for natural gas export infrastructure (LNG liquefaction terminals). For import infrastructure, however, they are much less relevant given the much lower capital commitments.

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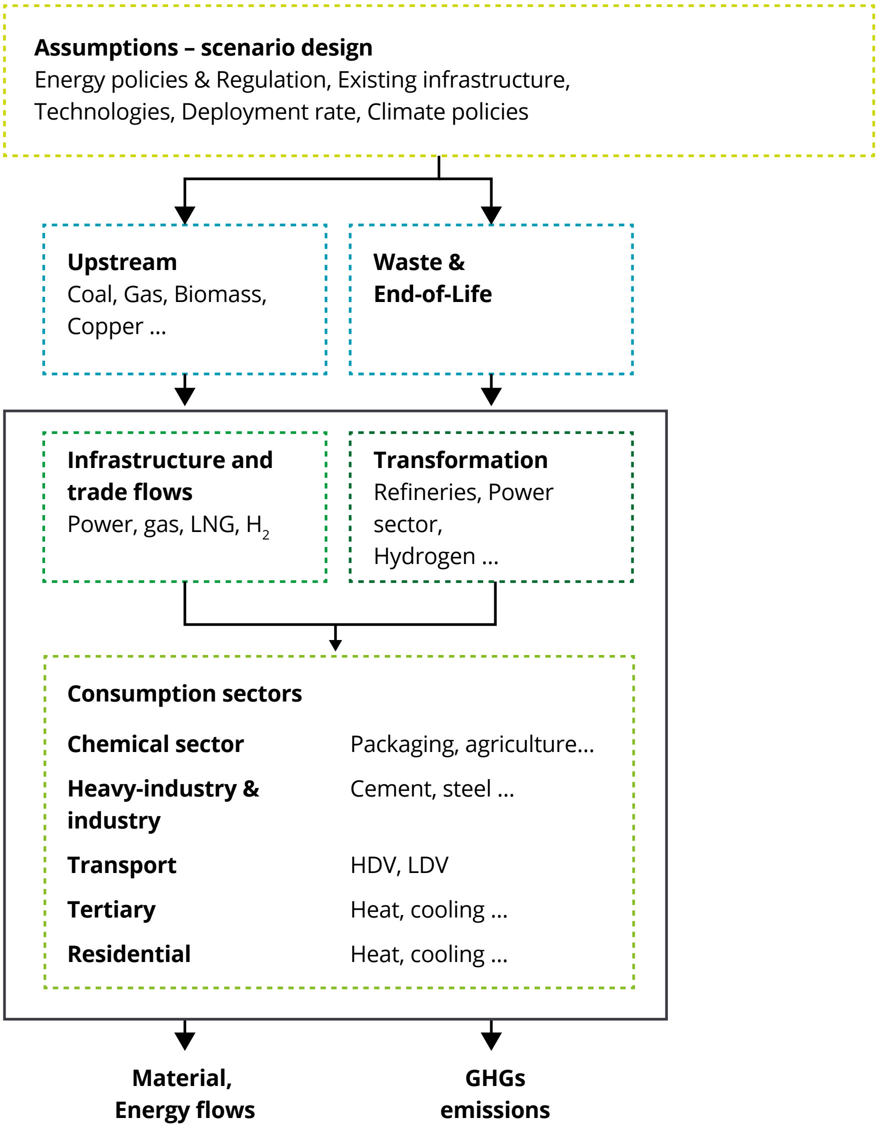
Glossary

BAT	Best available technologies
CBAM	Carbon Border Adjustment Mechanism
CCS	Carbon Capture and Storage
CCFD	Carbon Contract for Difference
CDR	Carbon Dioxide Removal
CNG	Carbon Contract for Difference
CO_{2eq}	CO_2-equivalent
CRD	Carbon Removals Certification
DAC	Direct Air Capture
DACCS	Direct Air Carbon Capture and Storage
EU	European Union
EU ETS	EU Emissions Trading System
EUA	EU Allowances
GDP	Gross Domestic Product
ILUC	Indirect Land Use Change
LNG	Liquified Natural Gas
LULUCF	Land Use, Land Use Change and Forestry
NGFS	Network of Central Banks and Supervisors for Greening the Financial System
RED	Renewable Energy Directive

Appendix 1.
Technical presentation of DARE

The Deloitte's Applied Research on Energy (DARE) model provides a detailed view of the joint evolution of the main energy-consuming and energy-producing sectors in Europe. It is a bottom-up linear system optimization approach, featuring highly detailed and data-driven pathways towards climate neutrality with 5- to 10-year increments. The optimization relies on exogenous data-driven demand trajectories for end-use consuming activities in various economic sectors (such as cement or paper consumption, residential heating, passenger car road travel). It is also based on an extensive dataset of techno-economic parameters depicting the costs and characteristics of the relevant energy and commodity production processes. Based on these inputs, the model identifies the cost-efficient mix of technologies to meet the demand scenario, subject to various technical, economic and environmental constraints (for instance operational specificities, deployment rates, resource constraints, emissions ceiling, carbon pricing). It distinguishes energy and material flows throughout transformation processes (see Figure A.1-1). The model represents the energy system of all EU countries, the United Kingdom, Switzerland, and Norway in an interconnected manner, to enable exchanges between the neighboring countries.

Fig. A.1-1 – Simplified representation of the energy system modeled in DARE



Source: Deloitte analysis.

DARE adopts a 'brownfield' optimization approach in which, based on the composition of the energy system and production capacities in a reference year, the model optimizes the energy and economic developments over the entire period under consideration. The model is calibrated on a based historical year (currently 2018), accounting for existing infrastructure and energy flows at this time, and the subsequent periods simulated at a 5-to-10-year intervals until 2050. The optimization is done at once for whole 32-year period assuming perfect foresight. Depending on the specificities of each technology or constraint, the relevant time scale is considered. While most of the characteristics are defined at the annual level, electricity supply and demand patterns are assessed on an hourly basis during representative periods. Due to the complexity of the model, hourly weather conditions influencing wind- and solar-power generation are based on an 8-week representative sample of a year. This methodology allows to account for the short-term variability of electricity demand and renewable energy supply, but not designed to fully capture seasonal variations, which also impact energy storage requirements.

The DARE model offers a comprehensive view of the entire energy value chain (see Figure A1-1). DARE takes into consideration the commodities from the primary energy supply (such as coal, oil, gas, wind) to the end-use energy-consuming activities (such as commodity demands, heating, transport). The use of primary energy sources is shaped by access conditions (such as costs, resource constraints, temporality). The model can arbitrate between numerous technologies and transformation processes (such as hydroelectric dams, refineries, electrolyzers, iron and steel manufacturing) while distinguishing primary and secondary energy carriers (such as methane, electricity, hydrogen). The power sector reflects local and national specificities (including existing facilities, commissioned projects, announced decommissioning trajectories). Energy storage options (for instance batteries, pumped hydro storage) and international exchanges (that is power interconnections) are also modelled to optimize the endogenous matching with final energy consumption (for instance in buildings, industry or transport).

Greenhouse gas emissions are accounted for throughout production processes. The modeled CO_2 value chain includes CO_2 capture on various industrial processes, power production (via gas power plants connected to CCS) and direct air capture (DAC). The captured CO_2 can be stored or used as a feedstock in industrial processes (such as e-fuel or chemicals production), in compliance with EU regulation on carbon capture and usage.[50]

Technical and economic constraints guarantee the consistency of the trajectories gleaned. For example, at each stage, the equilibrium between energy supply and demand should be obtained, resource constraints should be met, relevant technological deployment rates should be followed, and key environmental regulations (including emission reduction targets) should be achieved.

Tab. A.1-1 – Technological scope of the DARE model

Primary energy supply	Energy transformation	Final energy supply	End-use sector
Coal	Electricity production	Electricity	Industry
Oil	Electrolysis	Hydrogen	Residential
Gas	Methane reforming	Coal	Tertiary
Biomass	Methane pyrolysis	Natural gas	Transport (road, aviation, maritime)
Solar energy	Gasification	Oil	
Wind power	Gas-to-liquids	Biomass	
Hydropower	Biorefinery	Liquid biofuels	
Uranium	E-refinery	E-fuels	
Representation of CCS routes (industrial carbon capture or DAC, CO_2 transport, use and storage)			

Source: Deloitte analysis.

[50] https://energy.ec.europa.eu/system/files/2023-02/C_2023_1086_1_EN_ACT_part1_v5.pdf.

Key equations

The modeling assumes perfect foresight and derives in a single loop the technology mix which would achieve climate ambitions at least-cost. Notably, second-best technological options can be selected in one sector to relax constraints on resources that might have a higher economic value in another. Equation (1) provides a simplified version of the objective function:

(1)

$$C^{Total} = \sum_{y=2018}^{2050} \frac{(C_y^{industry} + C_y^{transport} + C_y^{buildings} + C_y^{upstream})}{(1+dr)^y}$$

where C^{Total} is the total cost of the energy system over the whole period, and $C_y^{industry}$, $C_y^{transport}$, $C_y^{buildings}$, $C_y^{upstream}$ and $C_y^{network}$ are the costs of industry, transport, buildings and upstream activities (primary energy and feedstock production) in year y.

The objective function is the Net Present Cost over the period for all countries modeled. Future costs are discounted at a rate (dr) to account for the time value of money. Capital and operational costs are differentiated. CAPEX (capital expenditures) are annualized and include investment costs, financing costs contingency costs, and owner costs (when applicable). Annuities are calculated following Equation (2):

(2)

$$C_y^{Investment} = \frac{i \times (1+i)^N}{(1+i)^N - 1} \times CAPEX$$

with $C_y^{Investment}$ the annualized investment cost for a given investment, i the Weighted Average Cost of Capital (WACC) for this type of investment and N is the economic lifetime of the investment.

The model delivers the cost-efficient technology mix to meet an exogenous end-demand trajectory (for instance in industrial production, buildings, heating). In each end-use sector, a supply/demand equilibrium constraint ensures that the solution is technically and economically consistent. Demand for intermediate products and energy sources (such as electricity, hydrogen) are endogenously calculated.

Equation (3) illustrates this constraint in the case of industrial products:

(3)

$$ED_{y,c}^{Product} + ID_{y,c}^{Product} = \sum_T P_{y,c}^T + \sum_T BP_{y,c}^T + \sum_C I_{y,c}^C$$

$ED_{y,c}^{Product}$ stands for exogenous product demand (such as the demand for methanol as an end-product for the production of derivative chemicals such as adhesives, paints, sealants or lubricants) in year y and country c, while $ID_{y,c}^{Product}$ represents endogenous product demand as intermediate consumption from other industrial processes (for instance methanol used as a feedstock to produce of ethylene or aromatics). The total demand can be met by domestic supply – either directly via different production pathways $P_{y,c}^T$ corresponds to the output from technology T in country c and year y) or as a by-product of other processes ($BP_{y,c}^T$) – or imported from other European countries ($I_{y,c}^C$, counted negative if the country is a net exporter).

In the power sector, supply/demand equilibrium is computed on an hourly basis to capture the short term-variability of demand, renewable energy supply, and the resulting short-term storage needs. The power market equilibrium condition is given in Equation (4) where $D_{y,c,h}^{Transport,power}$, $D_{y,c,h}^{Industry,power}$, $D_{y,c,h}^{Buildings,power}$ are the power demand in year y, country c and hour h in the corresponding sectors.

(4)

$$D_{y,c,h}^{Transport,power} + D_{y,c,h}^{Industry,power} + D_{y,c,h}^{Buildings,power} = \sum_T G_{y,c,h}^{T} + \sum_S U_{y,c,h}^{S} + \sum_C I_{y,c,h}^{C}$$

At each hour h, demand must be met by the combination of supply from the country's power plants ($G^{T}_{y,c,h}$ presents the power generation of technology T at hour h in country c and year y), storage management net output ($U^{S}_{y,c,h}$ with a positive flow when electricity is released and a negative flovw when stored), and electricity net imports from neighboring countries ($I^{C}_{y,c,h}$ counted positive if the country is importing and negative if the country is exporting electricity).

Technology deployments are limited by several constraints, such as technology availability, deployment rates, asset renewal rates, or access to bioresources as depicted in Equation (5).

(5)

$$D_{y,c}^{Transport,biofeed} + D_{y,c}^{Industry,biofeed} + D_{y,c}^{Power,biofeed} + D_{y,c}^{Buildings,biofeed} \leq A_{y,c}^{biofeed}$$

$D^{Transport,biofeed}_{y,c}$, $D^{Industry,biofeed}_{y,c}$, $D^{Power,biofeed}_{y,c}$ and $D^{Buildings,biofeed}_{y,c}$ respectively stand for the demand for feedstock biofeed in year y and country c in the transport, industry, power and buildings sectors. Demand should be lower than the availability of the feedstock in the year y and country c ($A^{biofeed}_{y,c}$).

GHG emissions and carbon management across the different sectors are tracked rigorously in the model. The scope of the climate constraint is given by Equation (6).

(6)

$$E_y^{Transport} + E_y^{Industry} + E_y^{Power} + E_y^{Buildings} - DAC_y^{S} - LTS_y^{b} \leq E_y^{Max}$$

$E^{Transport}_{y}$, $E^{Industry}_{y}$, E^{Power}_{y}, $E^{Buildings}_{y}$ are respectively the direct emissions in the transport, industry, power, and buildings sectors over the year (y). Carbon removal is modelled in two ways: DAC^{S}_{y} is the amount of CO_2 captured via direct air capture in year y, whileLTS^{b}_{y} represents the amount of biogenic carbon sequestered for the long-term either in the ground (via BECCS) or in chemical products (following a cradle-to-gate approach). On the other hand, E^{Max}_{y} is the carbon budget for the EU economy in year y set in compliance with EU regulation.

Appendix 2. Methodology for global projections analysis

The following sections describe the methodology applied to develop a consistent database of different scenario-based projections for the transition of global energy systems (Global Scenarios of Transforming Energy Systems Database, or short: Global-ScenSe-DB). The database comprises energy- and CO_2-emission-related data as a panel dataset, at least for the time period 2015–2020 to 2050-2100 in 5-to-10-year steps. The dataset is harmonized in its definitions for different parameters. Moreover, it allows the data on different regional disaggregation levels to be examined using a harmonization procedure to account for different regional coverage and definitions.

Table A.2-1 shows the classifications of key international scenarios included in the Global-ScenSe-DB. It provides information on the respective issuing organization, the underlying study, scenario names, and classification of the respective scenarios.

Tab. A.2-2 – Classification of key international scenarios included in the Global-ScenSe-DB

Organization	Study	Scenarios	Post 24 February 2022 view	Policy reactions	Speed and level of technology change	Use of CDR	Regional variation	Climate ambitions and innovation
NGFS: Network of Central Banks and Supervisor for Greening the Financial System	NGFS Climate Scenarios prepared by Integrated Modeling Community (IAM) also working on the IPCC scenarios: PIK, PNNL, IIASA Report: NGFS (2022a) Dataset: NGFS (2022b)	Current Policies	no	none- current policies	slow	low	low	only currently implemented policies are preserved
		Nationally Determined Contributions	no	NDCs	slow	low-medium	medium	includes all NDC pledged policies even if not yet implemented
		Delayed Transition	no	delayed	first slow, then fast	low-medium	high	new climate policies are not introduced before 2030; strong role for carbon prices
		Below 2°C	no	immediate and smooth	moderate	medium-high use	low	gradual increase of climate policy stringency
		Divergent Net-Zero	no	immediate but divergent	fast; more stringent for transport and buildings than Net Zero 2050	low-medium	medium	net-zero by 2050 but with higher costs due to divergent policies introduced across sectors and a quicker phase-out of fossil fuels
		Net Zero 2050	no	immediate and smooth	Fast and deep	medium-high	medium	limit global warming to 1.5 °C through stringent climate policies
IEA	World Energy Outlook 2022 Report and dataset: IEA (2022b)	Stated Policies	yes	None - current policies	slow	low	high	none
		Announced Pledges	yes	NDCs	moderate	medium-low	high	NCDs + net-zero emission targets met in full and on time
		Net-Zero Emissions by 2050	yes	First advanced economies then others	fast and deep change	medium-high	low	achieve net-zero CO_2 emissions by 2050

Tab. A.2-1 – Classification of key international scenarios included in the Global-ScenSe-DB

Organization	Study	Scenarios	Post 24 February 2022 view	Policy reactions	Speed and level of technology change	Use of CDR	Regional variation	Climate ambitions and innovation
BP	BP Energy Outlook 2023 edition Report: BP (2023a), Dataset: BP (2023b)	New Momentum	yes	Focus on local energy supply	slow	low	low	none; CO_2 emissions 30% below 2019 levels by 2050
		Accelerated	yes	Not specified	slow	medium-low	low	CO_2 emissions 75% below 2019 levels by 2050
		Net-Zero	yes	Delayed coal phase-out	moderate	medium-high	low	CO_2 emissions 95% below 2019 levels by 2050
Equinor	Energy Perspectives 2022 Report: Equinor (2022a) Dataset: Equinor (2022b)	Walls	yes	delayed and divergent	slow	low	medium	none
		Bridges	yes	immediate and smooth	fast	medium-high	low	50% probability of no more than a 1.5°C temperature rise
Shell	Energy Security Scenarios Report: Shell (2023a) Dataset: Shell (2023b)	Archipelagos	yes	delayed and divergent	slow	low	high	no explicit ambitions; emission levels decline after 2040
		Sky 2050	yes	immediate but divergent	first slow, then fast	medium-high	high	net-zero emissions by 2050 and global warming limited to 1.5°C

Tab. A.2-1 – Classification of key international scenarios included in the Global-ScenSe-DB

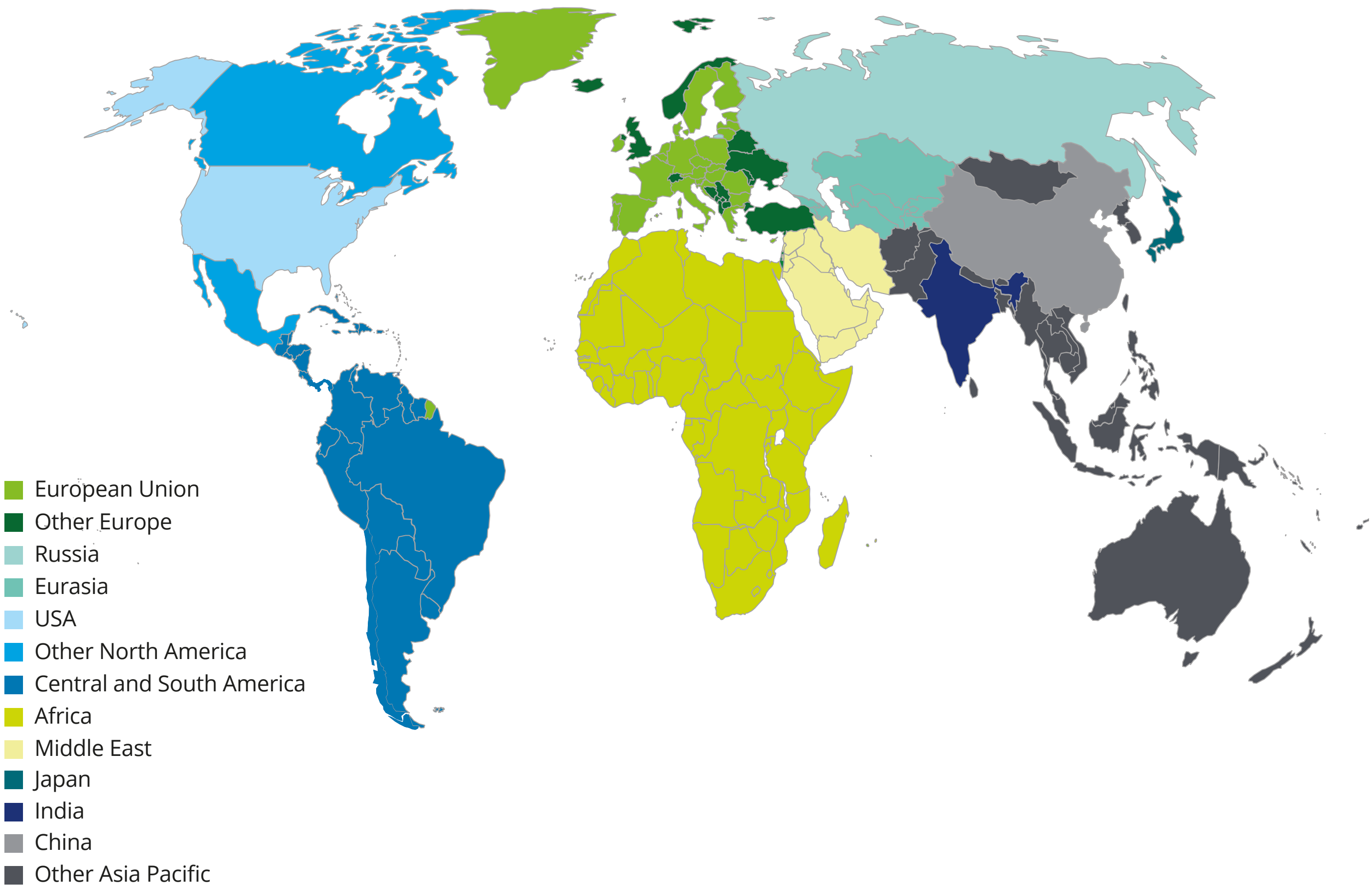
Organization	Study	Scenarios	Post 24 February 2022 view	Policy reactions	Speed and level of technology change	Use of CDR	Regional variation	Climate ambitions and innovation
ExxonMobil	2022 Outlook for Energy Report: Exxon-Mobil (2022) Dataset: ExxonMobil (2023)	Projection (no own name)	no	none – current policies	slow	ambitious compared to planned capacities, low compa-red to IPCC scenarios	high	none
EIA	International Energy Out-look 2021 Report: EIA (2021a) Dataset: EIA (2021b)	ref2021	no	none – current policies	slow	N/A	high	none
Teske et al. 2019	Achieving the Paris Climate Agreement Goals Report and dataset: Teske et al. (2019)	2°	no	delayed	moderate	low-medium	high	2°
		1.5°	no	immediate	fast change	medium-high	medium	1.5°
		Reference	no	none	slow	low	high	5°C; based on current policy scenario from WEO 2017

Appendix 2.1: Regional disaggregation

Regional disaggregation employed in the Global-ScenSe-DB is available for the regions depicted in Figure A.2-1. Typically, data from global projections is available with different regional breakdown. Therefore, all sources are harmonized to the same set of regions and countries. The methodology follows the same logic (see Table A.2-2):

- Larger regions are made up of smaller original regions/countries added together
- Smaller final regions are scaled down based on reference data
- Upscaling of data is possible based on the respective reference data
- Reference data for down- and upscaling can be defined and tested for different approaches

Fig. A.2-1 – Regional disaggregation available in the Global-ScenSe-DB



Note: Regional disaggregation is structured as follows:
Region: Europe; sub-regions: European Union (EU-27), Other Europe
Region: Eurasia: subregions: Russia
Region: America, sub-regions: North America: sub-sub-region: USA; Central and South American, sub-sub-region: Brazil
Region: Africa
Region: Middle East
Region: Asia Pacific, sub-regions: India, China, Japan

Source: Oeko-Institut analysis based on Global-ScenSe-DB.

Tab. A.2-2 – Corresprondance of regional groupings between initial dataset and Global ScenSe-DB

Dataset (organization)	Global-ScenSe-DB region	Original region	Comment
IEA	**Europe**	**Europe**	
	EU27	EU27	
	Rest of Europe	Rest of Europe	
	Eurasia	**Eurasia**	
	Russia	Russia	
	America	**America**	
	North America	North America	
	USA	USA	
	Central and South America	Central and South America	
	Brazil	Brazil	
	Africa	**Africa**	
	Middle East	**Middle East**	
	Asia Pacific	**Asia Pacific**	
	China	China	
	India	India	
	Japan	Japan	
	World	**World**	

Tab. A.2-2 – Corresprondance of regional groupings between initial dataset and Global ScenSe-DB

Dataset (organization)	Global-ScenSe-DB region	Original region	Comment
BP	**Europe**	**Europe**	
	EU27	European Union members	
	Rest of Europe		Difference of: "Europe" – "European Union members"
	Eurasia	**Commonwealth of Independent States (CIS)**	Multiply by adjusted share (to attain the CIS regional contribution to the Eurasia region)
	Russia	Russia	
	America		Sum of: "North America" + "South and Central America"
	North America	North America	
	USA	USA	
	Central and South America	Central and South America	
	Brazil	Brazil	
	Africa	**Africa**	
	Middle East	**Middle East**	Multiply by adjusted share
	Asia Pacific	**Asia Pacific**	
	China	China	
	India	India	
	Japan	Asia Pacific	Multiply by adjusted share
	World	**World**	

Tab. A.2-2 – Corresprondance of regional groupings between initial dataset and Global ScenSe-DB

Dataset (organization)	Global-ScenSe-DB region	Original region	Comment
	Europe	**Europe**	"European Union" + "Other Europe"
	EU27	European Union	Multiply by percentage adjusted share
	Rest of Europe	Other Europe	Difference of: "Europe" – "European Union members"
	Eurasia		Included in Rest of World
	Russia		Included in Rest of World
	America		"North America" + "Other Americas"
	North America	North America	
	USA	North America	Multiply by adjusted share
	Central and South America	Other America	
Equinor	Brazil	Other America	Multiply by adjusted share
	Africa	**Africa**	
	Middle East	**Middle East**	Multiply by adjusted share
	Asia Pacific		"China" + "India" + "Industrial Asia Pacific"
	China	China	
	India	India	
	Japan	Industrial Asia Pacific	Multiply by adjusted share
	World		"European Union" + "Other Europe" + "North America" + "Other Americas" + "Africa" + "China" + "India" + "Industrial Asia Pacific" + "Rest of World"

Tab. A.2-2 – Corresprondance of regional groupings between initial dataset and Global ScenSe-DB

Dataset (organization)	Global-ScenSe-DB region	Original region	Comment
Shell	**Europe**		"EU" + "(Europe West Other + Rest of Europe East Other)"
	EU27	EU	Multiply by percentage adjusted share
	Rest of Europe	Europe West Other + Rest of Europe East Other)	
	Eurasia	**Eurasia**	Multiply by adjusted share
	Russia	Europe East Other	Multiply by adjusted share
	America		"North America" + "Central and South America"
	North America	North America	
	USA	North America	Multiply by adjusted share
	Central and South America	Central and South America	
	Brazil	Brazil	Multiply by adjusted share
	Africa	**Africa**	
	Middle East	**Middle East**	Multiply by adjusted share
	Asia Pacific		"South Asia" + "East Asia" + "SE Asia" + "Central Asia" + "Oceania"
	China	East Asia	Multiply by adjusted share
	India	South Asia	Multiply by adjusted share
	Japan	East Asia	Multiply by adjusted share
	World	**World**	"Europe" + "Eurasia" + "America" + "Middle East" + "Africa" + "Asia Pacific" + "Rest of World"

Tab. A.2-2 – Corresprondance of regional groupings between initial dataset and Global ScenSe-DB

Dataset (organization)	Global-ScenSe-DB region	Original region	Comment
ExxonMobil	**Europe**	**Europe**	Multiply by adjusted share
	EU27	Europe	Multiply by adjusted share
	Rest of Europe	Europe	Multiply by adjusted share
	Eurasia	**Russia/Caspian**	Multiply by adjusted share
	Russia	Russia/Caspian	Multiply by adjusted share
	America		"North America" + "Other Americas"
	North America	North America	
	USA	North America	Multiply by adjusted share
	Central and South America	Latin America	
	Brazil	Latin America	Multiply by adjusted share
	Africa	**Africa**	
	Middle East	**Middle East**	Multiply by adjusted share
	Asia Pacific	**Asia Pacific**	
	China	Asia Pacific	Multiply by adjusted share
	India	Asia Pacific	Multiply by adjusted share
	Japan	Asia Pacific	Multiply by adjusted share
	World		"Europe" + "Russia/Caspian" + "America" + "Middle East" + "Africa" + "Asia Pacific" + "Rest of World"

Tab. A.2-2 – Corresprondance of regional groupings between initial dataset and Global ScenSe-DB

Dataset (organization)	Global-ScenSe-DB region	Original region	Comment
	Europe	**OECD Europe**	Multiply by adjusted share
	EU27	OECD Europe	Multiply by adjusted share
	Rest of Europe		"Europe" – "EU27"
	Eurasia	**Other non-OECD Europe and Eurasia**	Multiply by adjusted share
	Russia	EIA_Russia	
	America		"North America" + "Central and South America"
	North America		"United States" + "Canada" + the adjusted share of "Mexico and other OECD Americas"
	USA	United States	
EIA	Central and South America	Mexico and other OECD Americas	"Mexico and other OECD Americas" + Non-OECD Americas" - adjusted share of "Mexico and other OECD Americas"
	Brazil	Brazil	Multiply by adjusted share
	Africa	**Africa**	
	Middle East	**Middle East**	Multiply by adjusted share
	Asia Pacific	**Asia Pacific**	OECD Asia + Non-OECD Asia
	China	China	
	India	India	
	Japan	Japan	
	World	**World**	"Europe" + "Eurasia" + "America" + "Middle East" + "Africa" + "Asia Pacific" + "Rest of World"

Tab. A.2-2 – Corresprondance of regional groupings between initial dataset and Global ScenSe-DB

Dataset (organization)	Global-ScenSe-DB region	Original region	Comment
Teske et al. 2019	**Europe**	**OECD Europe**	
	EU27	OECD Europe	Multiply by adjusted share
	Rest of Europe		"Europe" – "EU27"
	Eurasia	**Eastern Europe/Eurasia**	Multiply by adjusted share
	Russia	Eastern Europe/Eurasia	Multiply by adjusted share
	America		"North America" + "Latin America"
	North America	North America	
	USA	United States	Multiply by adjusted share
	Central and South America	Latin America	
	Brazil	Latin America	Multiply by adjusted share
	Africa	**Africa**	
	Middle East	**Middle East**	
	Asia Pacific	**Asia Pacific**	"World"- "Europe"- America" – "Africa" – "Middle East"- "Eurasia"
	China	Asia Pacific	Multiply by adjusted share
	India	India	
	Japan	Asia Pacific	Multiply by adjusted share
	World	**World**	

Tab. A.2-2 – Corresprondance of regional groupings between initial dataset and Global ScenSe-DB

Dataset (organization)	Global-ScenSe-DB region	Original region	Comment
IIASA	**Europe**	**Eastern Europe + Western Europe**	“Eastern Europe” + “Western Europe”
	EU27	Western Europe + share of Europe Eastern	“Western Europe” + adjusted share of “Eastern Europe”
	Rest of Europe	Former Soviet Union	Multiply by adjusted share
	Eurasia	**Former Soviet Union**	Multiply by adjusted share
	Russia	Eastern Europe/Eurasia	Multiply by adjusted share
	America		“North America” + “Latin America and the Caribbean”
	North America	North America	Multiply by adjusted share
	USA	North America	Multiply by adjusted share
	Central and South America	Latin America and the Caribbean	Multiply by adjusted share
	Brazil	Latin America and the Caribbean	Multiply by adjusted share
	Africa	**Africa**	
	Middle East	**Middle East and North Africa**	
	Asia Pacific	**Asia Pacific**	“Rest Centrally Planned Asia” + “China” + “Other Pacific Asia” + “South Asia” + “Pacific OECD”
	China	China	
	India	South Asia	Multiply by adjusted share
	Japan	Pacific OECD	Multiply by adjusted share
	World	**World**	“Europe” + “Eurasia” + “America” + “Middle East” + “Africa” + “Asia Pacific”

Tab. A.2-2 – Corresprondance of regional groupings between initial dataset and Global ScenSe-DB

Dataset (organization)	Global-ScenSe-DB region	Original region	Comment
	Europe		"Europe Non EU" + "European Free Trade Association" + "European Eastern"
	EU27	Western Europe + share of Europe Eastern	"Western Europe" + adjusted share of "Eastern Europe"
	Rest of Europe	Former Soviet Union	Multiply by adjusted share
	Eurasia	**Former Soviet Union**	Multiply by adjusted share
	Russia	Eastern Europe/Eurasia	Multiply by adjusted share
	America		"North America" + "Latin America and the Caribbean"
	North America		"USA" + "Canada" + "Mexico"
	USA	USA	
	Central and South America		"Brazil" + "Central America and Carib-bean" + "Northern South America" + "Southern South America" + "Colom-bia" + "Argentina"
PNNL	Brazil	Brazil	
	Africa	**Africa**	"Eastern Africa" + "Northern Africa" + "Western Africa" + "Southern Africa" + "South Africa"
	Middle East	**Middle East**	
	Asia Pacific	**Asia Pacific**	"China" + "India" + "Japan" + "South Asia" + "Australia and New Zealand" + "Indonesia" + "Pakistan" + "Southeast Asia" + "South Korea" + "Taiwan"
	China	China	
	India	India	
	Japan	Japan	
	World	**World**	"Europe" + "Eurasia" + "America" + "Middle East" + "Africa" + "Asia Pacific"

Tab. A.2-2 – Corresprondance of regional groupings between initial dataset and Global ScenSe-DB

Dataset (organization)	Global-ScenSe-DB region	Original region	Comment
PIK	**Europe**		"EU27" + "Rest of Europe"
	EU27	Northern Europe	
	Rest of Europe	Northern Europe	
	Eurasia	**Countries from the Reforming Economies of the Former Soviet Union**	Multiply by adjusted share
	Russia	Countries from the Reforming Economies of the Former Soviet Union	Multiply by adjusted share
	America		"North America" + "Central and South America"
	North America		"USA" + "Canada" + "Mexico"
	USA	USA	
	Central and South America	Latin America	Multiply by adjusted share
	Brazil	Latin America	Multiply by adjusted share
	Africa	**Africa**	"Sub-saharan Africa" + "North Africa"
	Middle East	**Middle East**	Multiply by adjusted share
	Asia Pacific	**Asia Pacific**	
	China	China	
	India	India	
	Japan	Japan	
	World	**World**	"Europe" + "Eurasia" + "America" + "Middle East" + "Africa" + "Asia Pacific"

Scaling is based on different reference data for different parameters. Table A.2-3 summarizes the reference data used for different parameters. Two main sources are used:

- for data on primary energy supply for different carriers: World Energy Statistics (IEA, 2019)
- for data on CO_2 emissions: GHG emissions from fuel combustion (OECD, 2023)

Tab. A.2-3 – Specification of reference data used for regional disaggregation for different parameters

Parameter	Data set
PES Coal	Coal and coal products (IEA, 2019)
PES Oil	Primary and secondary oil (IEA, 2019)
PES Gas	Natural gas (IEA, 2019)
PES Wind	Renewables (IEA, 2019)
PES Solar	Renewables (IEA, 2019)
PES Hydro	Renewables (IEA, 2019)
PES Biomass	Renewables (IEA, 2019)
PES other renewables	Renewables (IEA, 2019)
PES Nuclear	Nuclear (IEA, 2019)
PES others	Renewables (IEA, 2019)
PES Total	Total (IEA, 2019)
CO_2 emitted gross	CO_2 (OECD, 2023)
CO_2 emitted net	CO_2 (OECD, 2023)
CO_2 captured	CO_2 (OECD, 2023)
CO_2 stored	CO_2 (OECD, 2023)

Source: Oeko-Institut

Appendix 2.2: Primary energy supply

In order to be able to compare values on primary energy supply between different datasets, data points need to be used on the same basis in various ways. We describe the different dimensions and the steps taken to make data points comparable below.

Unit conversion: All energy units are converted to PJ using the respective conversion factors.

There are two different methodologies for calculating primary energy supply: partial substitution method and physical energy content method:

- The partial substitution method calculates primary energy supply based on the primary energy that would have been necessary to generate the same amount of electricity via conventional generation from fossil fuels. Hence a specific efficiency factor representing a typical or average conventional generation unit is employed. The primary energy equivalent of the above sources of electricity generation constitutes the amount of energy that would be necessary to generate an identical amount of electricity in conventional thermal power plants. Because it is hard to find a good fit for a conventional generation unit as a typical substitute, many organizations, including IEA (2023e) have stopped using this method.

- In the physical content method, the physical content of the primary energy source itself is used as primary energy equivalent. This method yields an efficiency of 100% for many RES-E technologies like PV, wind, and hydro. For nuclear it depends on the definition of primary energy equivalent. If it refers to the heat generated by the reactor it would also be 100%. However, the electric efficiency of nuclear power plants is known to be around 33%. Therefore, primary energy equivalent for nuclear is calculated based on these efficiency values relative to the electricity produced. This method is employed by IEA (2023e) and many other organizations.

- We follow the physical energy content method to be in line with the methodology employed by IEA. Hence the values from other sources using other methods were converted. The respective parameters that where converted are listed in Table A.2-4.

- In order to allow a comparison of shares of different energy sources in total primary energy supply, the values for total primary energy supply were also recalculated based on the sums of primary energy supply by source.

Tab. A.2-4 – Recalculations of primary energy supply by dataset and primary energy source

Name of dataset	Primary energy source	Recalculation procedure
IEA 2022	all	None; this is the reference dataset
BP	wind, solar PV, hydro, nuclear	Recalculated from partial substitution method to physical content method; efficiency factor for the former method provided here: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/methodology-for-converting-non-fossil-fuel-primary-energy.pdf
Euqinor	none	
Shell	none	
ExxonMobil	none	
EIA	none	Efficiency factor of 33% is assumed
Teske et al. 2009	none	
IIASA	none	Efficiency factor of 33% is assumed
PNNL	none	Efficiency factor of 33% is assumed
PIK	none	Efficiency factor of 33% is assumed

Source: Oeko-Institut

There is divergence already in the historical data points; e.g., for PES solar for the year 2020 between BP, IIASA, PIK, PNNL and others like IEA. The divergence can have several origins, including different scopes. IEA also includes solar thermal as solar, as well as different treatment in terms of primary energy input for RES-E, and in particular geothermal and solar thermal (see above).

- In order to bring the values to a common basis for comparison, values for major energy source categories are scaled based on historical data points (see Table A.2-5).
- This procedure is applied in the evaluation section of the database. Hence, the original unscaled values remain in the dataset of the database.

Tab. A.2-5 – Recalculations of primary energy supply by dataset and primary energy source

Dataset	Year	Parameters
BP	2015	PES Coal
Euqinor	2020	PES Gas
Shell	2020	PES Oil
ExxonMobil	2020	PES Solar
EIA	2020	PES Biomass
Teske et al. 2009	2015	PES Hydro
IIASA	2015	
PNNL	2015	
PIK	2015	

Source: Oeko-Institut

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