bp Energy Outlook

2025 edition

This year's *Energy Outlook* is focused on two main scenarios: *Current Trajectory* and *Below 2°*. The scenarios are not predictions of what is likely to happen or what bp would like to happen. Rather they explore the possible implications of different judgements and assumptions concerning the nature of the energy transition. The scenarios are based on existing technologies and do not consider the possible impact of new or unknown technologies or applications.

The many uncertainties surrounding the possible speed and nature of the energy transition, as well as the many other factors shaping the energy system, mean the probability of either one of the scenarios materialising exactly as described is negligible.

Moreover, the two scenarios do not provide a comprehensive description of all possible outcomes. They do, however, span a wide range of possible outcomes and so might help to illustrate the key trends and uncertainties surrounding the possible development of energy markets out to 2050.

The *Outlook* is produced to inform bp's views of the risks and opportunities posed by the energy transition and is published to help share those views with bp's stakeholders and as a contribution to the wider debate about the factors shaping the future path of the global energy system.

But the *Outlook* is only one source among many when considering the prospects for global energy markets, and bp considers a wide range of other external scenarios, analysis and information when forming its long-term strategy.

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Introduction to *Energy Outlook 2025*

Welcome to the 2025 edition of bp's *Energy Outlook*

Welcome to the 2025 edition of the bp *Energy Outlook*.

The energy system sits at the heart of modern-day society, critical for the everyday needs of people and businesses around the globe, and adapting to changing political, technological, and environmental priorities.

That central role is why many of us choose to work within the industry.

It is also why the challenges and forces shaping the global energy system are forever changing.

And the past year has been no different.

Geopolitical tensions

Geopolitical tensions, which came to the fore with the war in Ukraine, escalated further with the conflicts in the Middle East and the increasing use of sanctions and tariffs.

Those tensions refocused attention on the importance of energy security. Increasing the priority on delivering secure and affordable energy is likely to affect countries in different ways.

For some, it may mean reducing dependency on imported fossil fuels, and accelerating the transition to greater electrification, powered by domestic low carbon energy. We may start to see the emergence of 'Electrostates'.

Others may increase the emphasis on domestically produced fossil fuels, and resist increasing their dependency on low-cost international supply chains for low carbon technologies.

Data centres

The seemingly exponential growth in data centres to support the increasing use of artificial intelligence (AI) applications provides an important new source of energy demand, especially in some markets such as the US where growth in power demand over the past decade had virtually stalled.

These changing political and technological factors come against a backdrop of another year of surprising strength in global energy demand: primary energy is estimated to have increased by 2% in 2024 – above the average for the past 10 years.

Energy efficiency

The strength in energy demand is the counterpart to another year of lacklustre gains in energy efficiency, the causes of which are still poorly understood.

I realize that shifting patterns in energy efficiency may seem a little arcane, but I would argue that the sustained weakness in efficiency gains over the past five years was one of the most important factors shaping global energy over this period. In particular, it underpinned the continued steady growth in fossil fuels despite the rapid growth in low carbon energy, led by solar and wind.

Carbon emissions

This year marks the 10th anniversary of the historic COP21 and the agreement of the Paris climate goals. Since then, carbon emissions from energy use and industry have risen every year (other than the Covid-induced dip in 2020). If CO_2 emissions remain around current levels for the next 10 years, the ability of the world to remain within a 2°C carbon budget would become increasing challenging and costly.

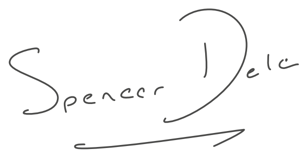
What should we make of all this?

Energy Outlook 2025

Readers of previous bp *Energy Outlooks* will not be surprised that this year's edition does not attempt to provide any definitive answers or recommendations. But it does present two scenarios – *Current Trajectory* and *Below 2°* – which can be used to explore some of the key uncertainties surrounding the future of the energy system stemming from differences in the speed and depth of the energy transition.

And this year's *Outlook* also develops three sensitivities, designed to illustrate the possible implications of some of the other recent issues shaping the energy system: increased geopolitical fragmentation, sustained weakness in energy efficiency, and a growing risk of a delayed and disorderly transition.

One of the benefits of publishing the *Energy Outlook* is that it contributes to the continuing debate and dialogue about the many issues affecting the energy system. I hope this year's *Outlook* is useful for everyone else grappling with these issues. Even more, I hope that you will let us know your views, how they differ to the analysis discussed in the *Outlook*, and how future *Outlooks* could be improved.



Spencer Dale
Chief economist

Recent developments and emerging trends

The *Energy Outlook* scenarios are informed by recent trends and developments in the global energy system.

Energy demand and efficiency

Global energy demand has continued to grow, averaging around 1% between 2019 and 2024, with all this growth coming from emerging economies, driven by increasing prosperity and growth.

The pace of improvement in energy efficiency – measured as the amount of total final energy consumed per unit of GDP – continues to be subpar, averaging just 1.5% per annum between 2019 and 2024, down from almost 2% p.a. in the previous 10 years. This weakness has underpinned the continued steady growth of fossil fuels despite rapid increases in low carbon energy.

Emissions

Carbon emissions have continued to increase, growing at an average rate of 0.6% per annum over the past five years (2019-2024). If CO_2 emissions remain close to recent levels, the carbon budget estimated by the Intergovernmental Panel on Climate Change (IPCC) to be consistent with a high probability of limiting global temperature rises to 2°C would be exhausted by the early 2040s.

Energy security

There has been a significant increase in geopolitical tensions and conflicts in recent years, including the wars in Ukraine and the Middle East, and the increasing use of trade sanctions and tariffs. These heightened tensions have led many countries to attach increased importance to their energy security.

Greater focus on energy security could give rise to a number of different and offsetting impacts on the energy system, including an increased preference for domestically produced rather than imported energy, and a desire to develop domestic or more diverse supply chains for low carbon technologies rather than rely on lowest-cost international providers.

These developments are likely to have differing effects on countries depending on the structure of their energy systems, leading to greater diversity in the energy pathways followed by different countries. Some energy importers may choose to increase the pace of electrification, powered by (domestic) low carbon energy, and so reduce their reliance on imported fossil fuels. In contrast, some energy producers may prefer to continue to use their domestic fossil fuels rather than increase their dependency on low carbon technologies, dominated by international supply chains.

Oil and natural gas

Growth in oil demand since 2019 has averaged 0.6Mb/d per year. All this growth has been due to increasing consumption in

emerging economies. China's oil demand, which accounted for around half of global oil demand growth over the past decade, looks set to plateau in the second half of the 2020s.

The pattern of oil demand growth is shifting, with its use as a feedstock in the petrochemical sector replacing road transport demand as the main source of future growth.

Growth in natural gas demand has been led by China, and to a lesser extent the Middle East and the US. The relative lack of domestic resources and availability of pipeline gas in China and other emerging Asian countries, combined with the continued loss of Russian pipeline gas exports to Europe, has further increased the importance of liquefied natural gas (LNG).

Based on LNG export facilities which are either under construction or have taken final investment decision (FID), global LNG exports are set to increase by more than half by 2035 relative to 2024, with the US and Middle East accounting for around two-thirds of that increase.

The growing demand from data centres to support the increasing adoption of generative artificial intelligence (AI) applications is already providing a significant boost to power demand in some markets and is set to grow rapidly in coming years. This impact is most pronounced in the US, which currently accounts for around a half of global data centre power demand in 2023, against a backdrop of almost flat power demand in the previous decade.

Low carbon energy

The International Energy Agency (IEA) estimate that investment in 'clean energy' has grown rapidly in recent years and is expected to reach around $2.2 trillion in 2025, up 70% since 2000[1].

This investment was heavily concentrated in developed economies and China, with far lower investment levels in other emerging economies, where financing costs pose a heavy burden.

Much of this investment has been deployed in electrification and in low carbon power generation, led by wind and solar power. Wind and solar power generation has doubled between 2019 and 2024, driven by solar. Growth in renewable power generation has been led by China which accounted for over half of the increase in wind and solar generation in the past five years.

Sales of electric vehicles (EVs) continue to increase rapidly, with China accounting for over half of global sales in recent years. Growth in the EU and the US – the other two major markets for EVs – has remained dependent on vehicle emissions regulations.

The rapid growth in both electricity demand and low carbon generation is putting increased pressure on network planning and power system operation. For example, in the US, the typical time from interconnection request to commercial operation has increased from under two years in the 2000s to nearly five years.

The development of less mature, higher cost low carbon energy vectors and technologies – including low carbon hydrogen, sustainable aviation fuel, and carbon capture use and storage – remain at a very early stage and heavily dependent on policy and regulatory support.

Despite growing concerns about the availability of critical minerals and the security of supply chains, investment growth slowed in 2024, and exploration activity was flat. The pressure on available supplies of copper look set to increase materially over the next 5-10 years.

[1] IEA investment in 'clean energy' includes investment in renewable power, energy efficiency and end use, low-emissions fuels, nuclear and other clean power, and grids and storage. See www.iea.org/reports/world-energy-investment-2025 for more information.

Key insights

The likelihood that either of the two scenarios used in this year's *Energy Outlook* will materialize exactly as described is negligible. Even so, the scenarios can be used to help develop some key insights about how the energy system might evolve over the next 25 years or so.

Those trends and features of the energy system that are common across both scenarios may have an increased likelihood of also occurring in a broader range of pathways which lie 'between' the two scenarios.

In contrast, those aspects of the energy system which differ materially across the two scenarios can be viewed as being more dependent on the speed of the energy transition.

Trends common across both scenarios

Growth in global energy demand is driven by emerging economies, outside of China. This increasing demand for energy is underpinned by rising prosperity and living standards in these economies and, to a lesser extent, the increasing size of their populations.

Growth in energy demand depends on actions to accelerate improvements in energy efficiency. Even relatively short-lived fluctuations in energy efficiency can have an important bearing on energy demand and carbon emissions.

The structure of energy demand changes, with the role of fossil fuels diminishing, given the increasing electrification of the energy system and the growing importance of low carbon energy, led by solar and wind. Electricity demand doubles over the *Outlook* in both scenarios.

Oil demand declines over the outlook but continues to play a significant role in the global energy system over at least the next 10-15 years.

The outlook for oil demand is shaped by two, counteracting forces: the diminishing role of oil in road transport as vehicles become more efficient and are increasingly electrified; offset by the more persistent use of oil as a feedstock in the petrochemicals sector, predominantly for the production of plastics.

The changing level and composition of oil demand puts increasing pressure on the refining system. Falls in oil demand are borne disproportionately by non-OPEC+ producers causing the share of OPEC+ oil production to rise over time[2].

Coal consumption falls, driven by declining use in power generation, especially in China.

Solar and wind grow rapidly, becoming the dominant source of power generation, supported by sustained competitiveness.

An increasing share of the global energy system shifts from the 'energy addition' phase of the energy transition, in which more of both low carbon energy and fossil fuels are used, to the 'energy substitution' phase, in which the rapid growth of low carbon energy crowds out the consumption of unabated fossil fuels.

Trends dependent on speed of energy transition

Whether the demand for natural gas – and LNG – increases or decreases over the next 25 years depends on the pace of the energy transition. Demand for both natural gas and imports of LNG increase in emerging economies as they grow and industrialize. But in accelerated transition pathways these increases are offset by shifts away from natural gas towards lower-carbon energy.

The use of biofuels and biomethane grow over the next 25 years. But the scale of that expansion is dependent on the extent of government policies and mandates supporting their use.

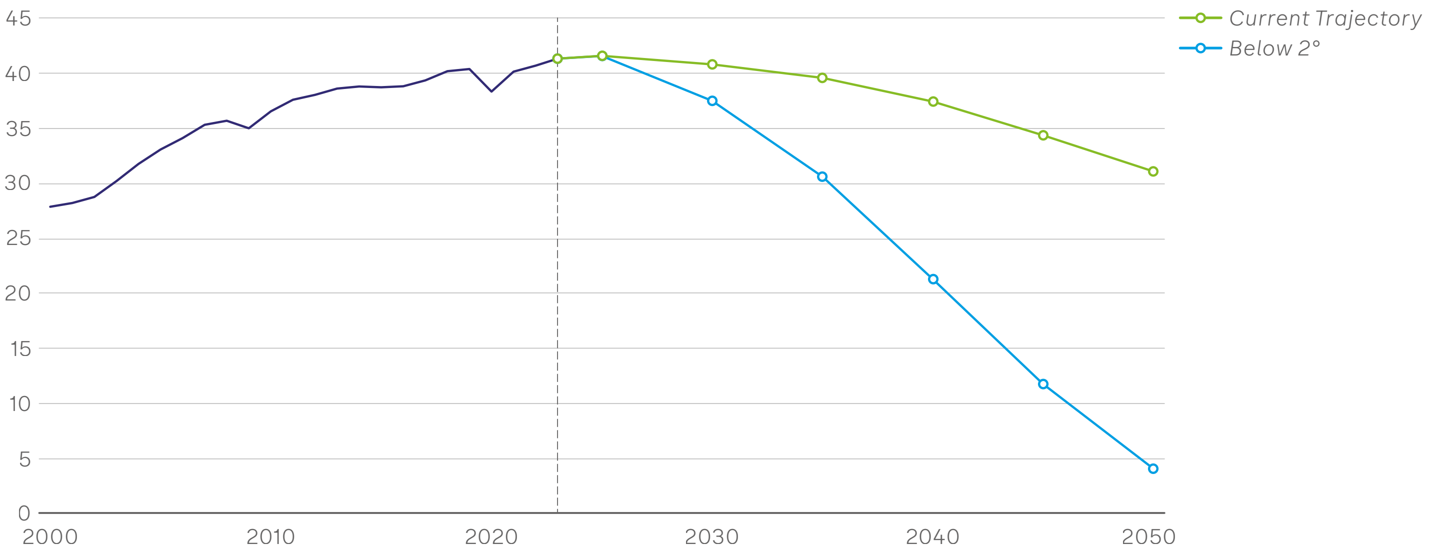
Low carbon hydrogen and carbon capture, use and storage (CCUS) are used to decarbonize sectors and activities in which emissions are hard-to-abate. But their relatively high cost mean that they only reach significant scale in deeper decarbonization pathways. Even then, their growth is concentrated in the second half of the outlook.

[2] OPEC+ refers to the coalition of 12 OPEC and 10 non-OPEC oil producing countries that have cooperated and aligned on petroleum production policy since 2016.

Overview

Two scenarios to explore the path of the energy transition out to 2050

Carbon emissions



Carbon emissions include CO_2 emissions from energy use, industrial processes, natural gas flaring, methane emissions from energy production and the incomplete combustion of traditional bioenergy.

bp's *Energy Outlook* 2025 uses two scenarios – *Current Trajectory* and *Below 2°* – to consider a range of possible outcomes for the global energy system out to 2050.

The scenarios explore the key uncertainties underpinning the global energy transition. They help us to understand which trends are more likely to occur under a range of different assumptions, and which are more sensitive to the speed and shape of the energy transition.

The scenarios consider carbon emissions from energy production and use, most non-energy related industrial processes, and natural gas flaring plus methane emissions from the production, transportation and distribution of fossil fuels, together with the incomplete combustion of traditional bioenergy (see pages 104-105 of the Annex for more details).

Current Trajectory scenario

Current Trajectory is designed to capture the broad pathway along which the global energy system is travelling. It places weight on climate and energy policies now in place and on recent trends and shifts in those policies. It also puts weight on global aims and pledges for future decarbonization, while recognizing the challenges associated with meeting some of those aims and pledges.

In *Current Trajectory*, CO_2 equivalent (CO_2e) emissions are roughly flat around their current levels throughout the remainder of this decade, before gradually declining over the 2030s and 2040s. Emissions fall by around a quarter from their 2023 level by 2050.

Below 2° scenario

Below 2° explores how different elements of the energy system might change in a pathway in which the world achieves much more substantial falls in emissions. In this scenario, net emissions decline by around 90% from their 2023 level by 2050. *Below 2°* assumes a significant tightening in climate policies alongside shifts in societal behaviour and preferences, which together support more rapid adoption of low carbon energy alongside faster gains in energy efficiency.

Implied temperature increases

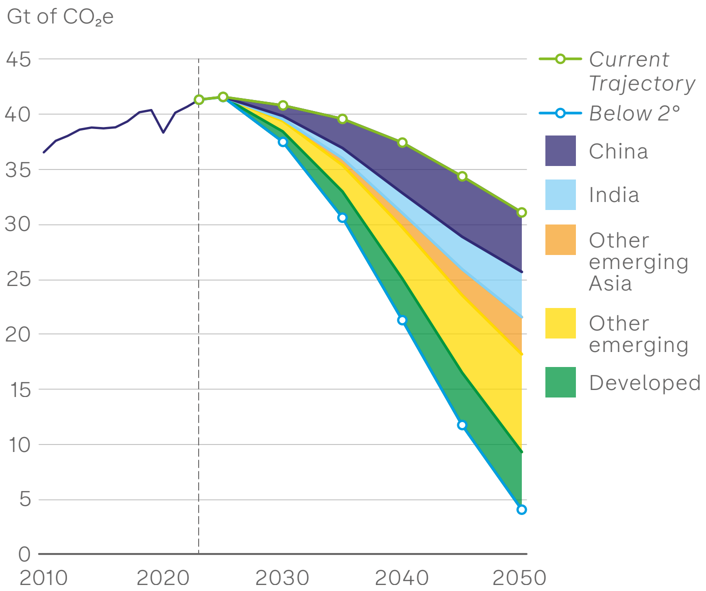
It is not possible to directly infer the increase in global average temperatures in 2100 implied by these scenarios, given they extend only to 2050 and do not model all forms of greenhouse gas emissions. However, it is possible to make indirect inferences by comparing cumulative carbon emissions for the period 2015-50 with the ranges of corresponding emissions in the scenarios included in the IPCC Sixth Assessment Report (see pages 104-105 in the Annex for more details).

Cumulative emissions in *Below 2°* are broadly in the middle of the range of those in the IPCC's 'C3' scenarios – that is, scenarios consistent with a greater than 67% probability of limiting average global temperature rises to 2°C (see Annex pages 104-105). On that basis, *Below 2°* might be considered broadly consistent with limiting the increase in the global average temperature to well below 2°C. In contrast, cumulative emissions in *Current Trajectory* are well above the range of C3 scenarios, suggesting it is not consistent with limiting the global average temperature rise to well below 2°C.

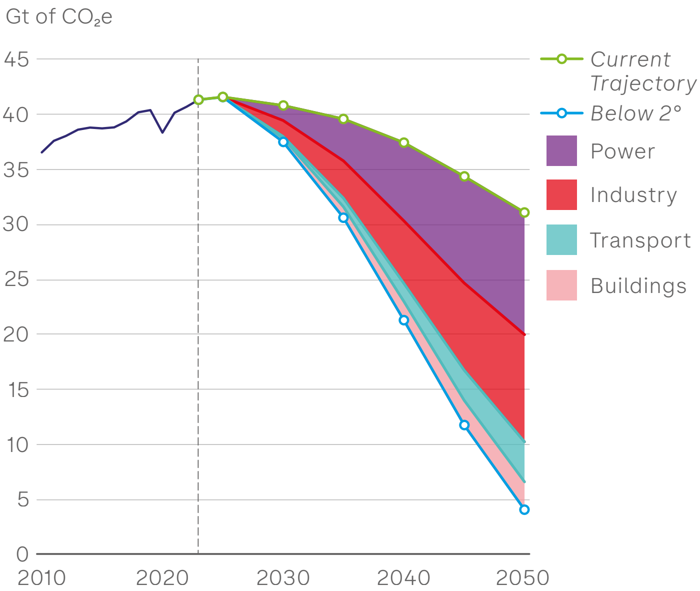
The following sections of this *Energy Outlook* explore these two scenarios in more detail. A final section – see pages 70-87 – considers some alternative sensitivities around these scenarios, including the possible effects of greater geopolitical fragmentation, and of persistently weaker improvements in energy efficiency.

Lower emissions in *Below 2°* are driven by faster decarbonization in emerging economies, and in the power and industrial sectors

Decomposition of differences in emissions by region *(Below 2° vs Current Trajectory)*



Decomposition of differences in emissions by use sector *(Below 2° vs Current Trajectory)*



The faster transition in *Below 2°* compared with *Current Trajectory* is driven largely by more rapid decarbonization in emerging economies, and, looking by energy use, by faster emissions reductions in electricity generation and industrial processes.

The scenarios can be used to explore which key additional shifts might help the world's energy system move from its current course to a faster and deeper decarbonization pathway.

Comparing the scenarios by geography

Viewed through a geographical lens, the faster decarbonization in *Below 2°* is driven overwhelmingly by more rapid emission reductions in emerging economies. By 2050, these countries account for around 80% of the difference in emissions between *Current Trajectory* and *Below 2°*.

Lower emissions in China make the largest single contribution to the gap between the two scenarios, accounting for around 30% of the difference in 2035, and 20% in 2050. Over the second half of the outlook, the contribution from other emerging Asian economies grows in importance, such that overall, emerging Asian countries (including China) account for almost half of the difference in emissions between the scenarios in both 2035 and 2050. In large part that reflects the rapid growth in energy needs of these countries: emerging Asian economies account for around three-quarters of global growth in primary energy in *Current Trajectory* between 2023 and 2050.

Comparing the scenarios by sector

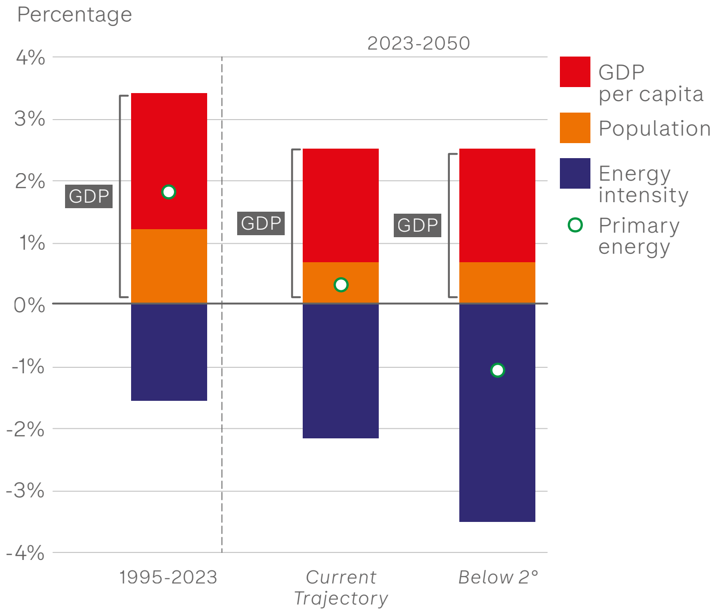
An alternative way to compare the two scenarios is to look at differences in emissions from the main sectors in which energy is used: buildings, industry, power and transport. Viewed through this lens, by far the biggest contributions to faster decarbonization in *Below 2°* come from the world's power and industrial sectors.

The global power sector accounts for around 40% of the difference in emissions between the two scenarios in both 2035 and 2050. That is largely due to slower decarbonization of electricity generation in emerging economies in *Current Trajectory*. The faster power sector decarbonization in emerging economies in *Below 2°* is largely due to more rapid adoption of wind and solar power: wind and solar account for around three-quarters of generation in emerging economies by 2050 in *Below 2°*, compared with around a half in *Current Trajectory*. The sustainability benefits of greater electrification depend on the extent to which the carbon intensity of that electricity is reduced.

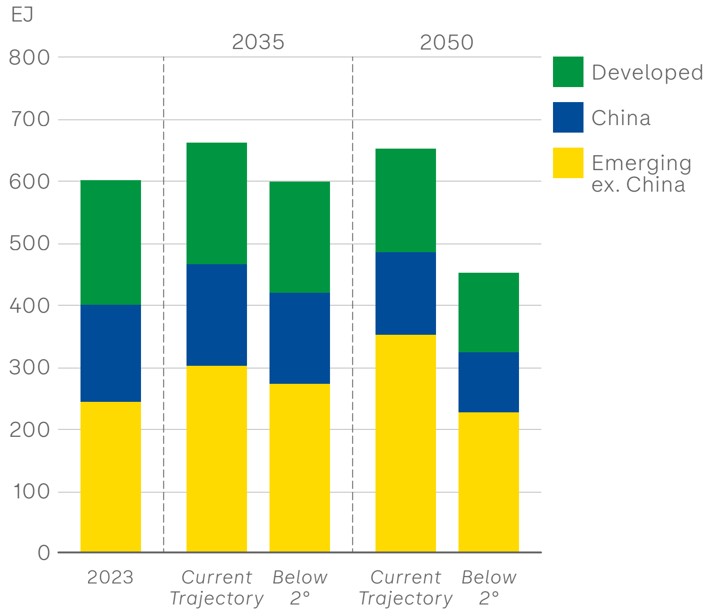
The industrial sector is the other main sector contributing to the difference in emissions between the two scenarios, accounting for around 35% of the gap between them. That reflects a range of factors including faster progress on improving industrial energy efficiency, greater levels of electrification, increased adoption of low carbon hydrogen and CCUS in harder-to-abate industries, as well as wider-economy measures that reduce the demand for manufactured goods and materials.

Growth in primary energy is driven by emerging economies, with its scale dependent on the path of energy efficiency

Average annual growth of primary energy demand



Primary energy by region



Growth in global primary energy is driven by increasing prosperity and rising populations in emerging economies. The scale and persistence of energy growth depends on the rate at which energy efficiency improves.

Global economic growth

Global GDP growth averages 2.5% per year over the outlook in the two scenarios, weaker than average global growth of 3.4% over the past 25 years. Slower GDP growth is mostly due to lower global population growth, although growth in GDP per capita is also a little weaker than in the past few decades.

The world economy nonetheless roughly doubles in size between 2023 and 2050. Global growth is heavily skewed towards emerging economies, which together account for 80% of the increase in world GDP over the outlook.

As in recent *Energy Outlooks*, the assumed trajectory for global GDP includes an estimate of the impact of climate change on growth. This impact includes the effects of both rising temperatures on economic activity and the upfront costs associated with mitigation and adaptation. Details of the approach and its limitations can be found in the Annex (see pages 102-103).

The impact of energy efficiency

The extent to which the doubling in global GDP by 2050 leads to increases in primary energy depends on the extent to which energy efficiency improves after a period of slower-than-usual gains over the past five years (see pages 78-81 for an exploration of the implications of different paths for energy efficiency). In *Current Trajectory*, energy efficiency improves by around 2% per year on average, whereas it rises by around 3.3% per year in *Below 2°*. The faster efficiency gains in *Below 2°* reflect more rapid displacement of thermal generation by renewables (reducing the energy losses associated with the conversion of thermal energy into electricity), together with greater efforts to improve system-wide energy efficiency to help accelerate decarbonization.

These faster gains in energy efficiency, together with somewhat slower GDP growth, mean that global primary energy grows more slowly than the average annual growth rate of 1.7% seen over the past 20 years. In *Current Trajectory*, total primary energy grows by 0.3% per year on average over the outlook, whereas it falls by around 1% per year on average in *Below 2°*.

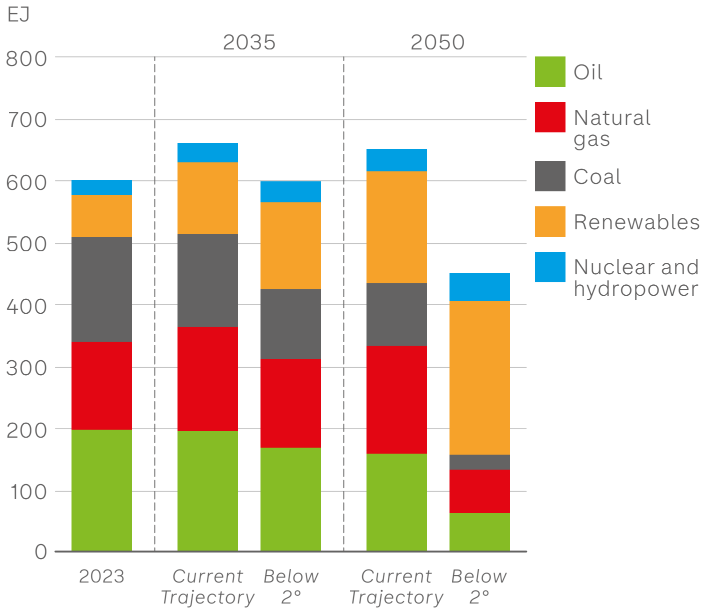
Growth in primary energy by region

In both scenarios, emerging economies (excluding China) are the main sources of increasing energy demand. Primary energy in those economies grows throughout the outlook in *Current Trajectory*, rising by almost a half by 2050. Within that, primary energy grows by around 70% in non-China Asian emerging economies, by 60% in Africa, and by around 30% in South America. In contrast, in *Below 2°* demand in emerging countries falls gradually over the second half of the outlook. But even in that scenario, their share of total global energy rises to 50% by 2050 from around 40% in 2023.

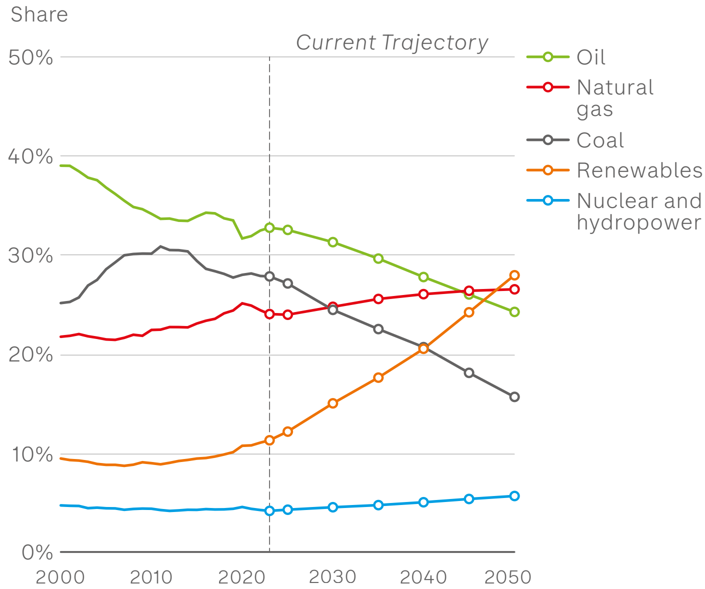
Energy demand growth in developed economies and in China is much weaker. Primary energy in developed economies continues the declines of the past two decades, falling by 15% in *Current Trajectory* and 40% in *Below 2°*. China's use of primary energy falls by more than 10% by 2050 in *Current Trajectory*, and by more than a third in *Below 2°*.

Renewables account for a growing share of primary energy

Primary energy by energy type



Primary energy fuel mix



The carbon intensity of primary energy gradually declines as renewable energy accounts for a growing share of the world's energy inputs.

Primary energy pathways in the two scenarios

The fastest growing source of primary energy in both scenarios is renewable energy, which includes wind and solar power, bioenergy and geothermal. The combined supply of energy from these sources rises more than two and a half-fold by 2050 in *Current Trajectory*, and three and a half-fold in *Below 2°*.

The counterpart to the increasing share of renewables in global energy is a decline in the shares of fossil fuels.

The biggest falls occur in the use of coal as its role in power generation declines (see pages 56-57).

Oil demand is broadly flat over the first half of the outlook in *Current Trajectory* but declines further out in both scenarios, driven primarily by lower use in road transport (see pages 30-33): oil demand ends the outlook around 15% lower than in 2023 in *Current Trajectory*, and 70% lower in *Below 2°*.

In contrast to the declines in oil and coal use, whether natural gas rises or falls over the outlook depends on the pace of decarbonization (see pages 40-41). In *Current Trajectory*, gas use increases through much of the outlook and by 2050 is around 20% above its 2023 level, whereas, in *Below 2°*, it is 55% lower driven by a faster shift towards electrification and increased use of renewables.

Primary energy shares in *Current Trajectory*

Despite the rapid growth in renewable energy, oil remains the single largest source of primary energy supply over most of the outlook in *Current Trajectory*. Oil provides 30% of global energy inputs in 2035, down only slightly from its current share. For the first time, the share of energy from natural gas surpasses that of coal around the end of the 2020s.

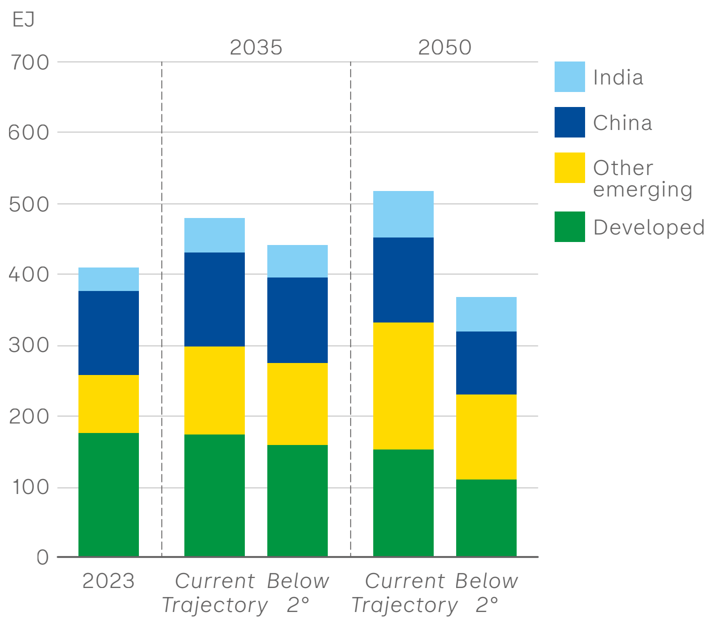
The share of renewables rises from around one-tenth of primary energy in 2023 to over 15% in 2035, supported by the growing electrification of the energy system and the increasing penetration of wind and solar power (see pages 54-57). The share of renewables in primary energy surpasses that of coal in the early 2040s, and of oil towards the end of that decade. By 2050, renewables and natural gas each provide around a quarter of the world's primary energy. The combined share of nuclear and hydropower is broadly flat at around 5% of primary energy.

Primary energy provides a measure of energy inputs – the raw energy sources fuelling the world. But the shares of fossil fuels in primary energy overstate their importance in terms of energy outputs – or useful energy. That reflects the energy losses involved in combusting fossil fuels, either when being used as a direct energy source or when being converted to an energy vector such as electricity or hydrogen.

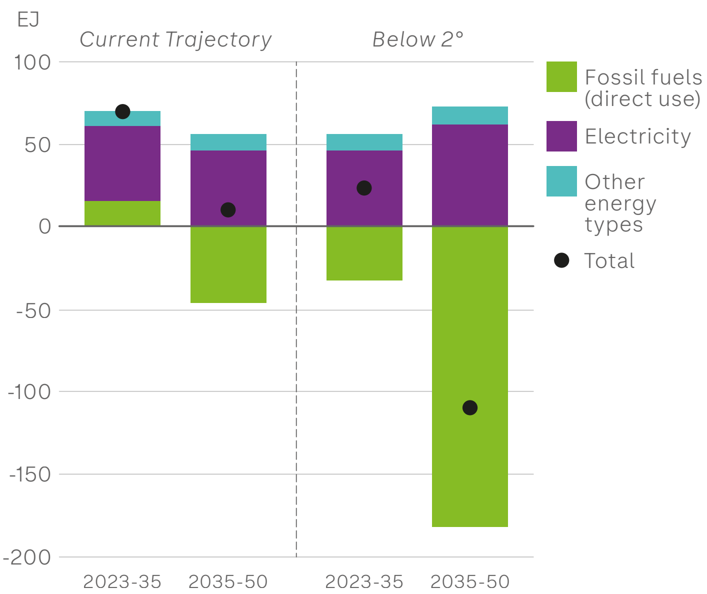
A better – but still imperfect – measure of energy outputs is provided by so-called 'total final consumption' of energy – see pages 22-23.

Total final consumption of energy peaks over the outlook as energy efficiency accelerates

Total final consumption by region



Change in total final consumption by energy type



Other energy types include hydrogen, hydrogen-derived fuels, bioenergy and heat.

Total final consumption (TFC) of energy – which provides a measure of energy demand at the final point of use – peaks during the outlook, as higher energy demand driven by increasing living standards and rising populations in emerging economies is offset by gains in energy efficiency.

Consumption of energy by region

TFC of energy rises by around 15% in the first half of the outlook in *Current Trajectory*, plateauing around that level thereafter. In contrast, in *Below 2°*, TFC starts to fall by the turn of this decade and by 2050 is more than 15% below its 2023 level.

In *Current Trajectory*, energy consumption growth over the first half of the outlook is entirely accounted for by higher demand in emerging economies, driven by rising prosperity and growing populations.

Energy consumption in emerging economies continues to rise over the second half of the outlook, particularly in India and other emerging Asian countries. But that growth is offset by declining energy consumption in developed economies and in China.

Falling Chinese energy consumption over the later part of the outlook period is a marked contrast to the pattern of recent decades: Chinese energy consumption has tripled since 2000, accounting for half of the total increase in global energy demand over that period.

In *Below 2°*, emerging economy energy consumption rises over the first half of the *Outlook*, albeit by less than in *Current Trajectory*. But accelerating gains in energy efficiency means final energy consumption in developed economies falls by around 10% by 2035. By 2050, energy demand in developed markets has fallen by more than a third from current levels, with Chinese energy consumption down by a quarter.

Energy consumption by energy vector

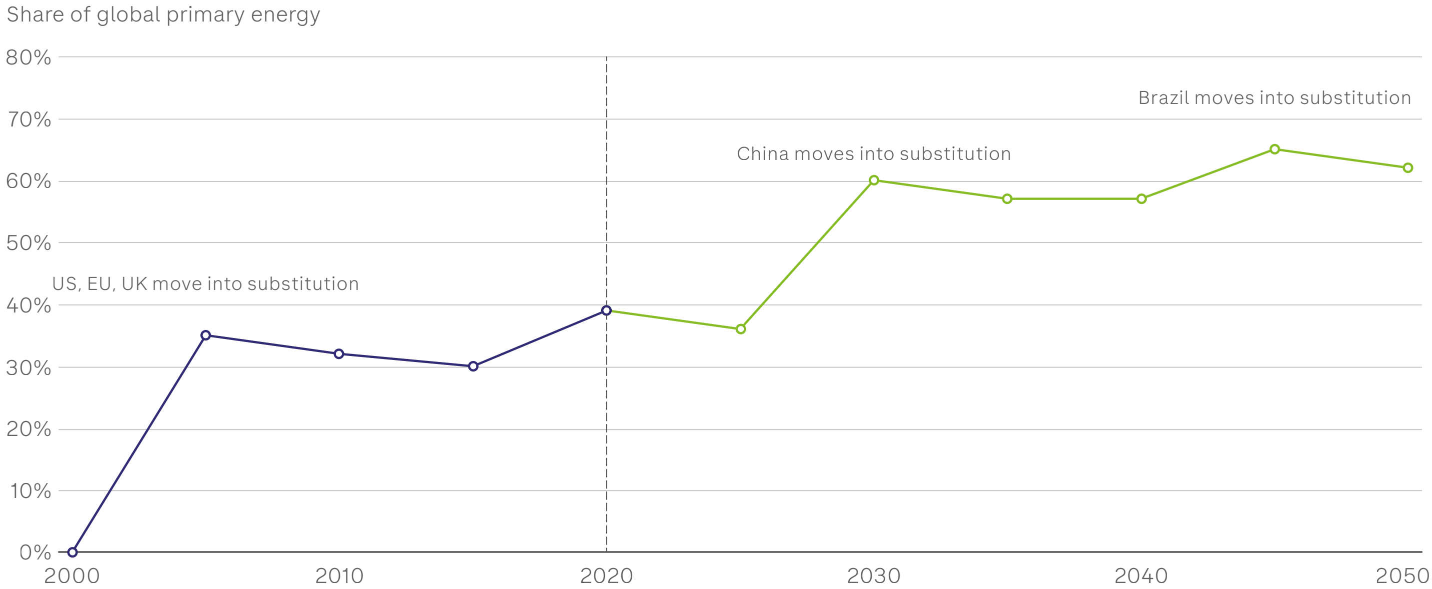
A key factor driving the acceleration in the efficiency of final energy use – and therefore in the slowing in the growth of TFC – is the increasing share of final energy uses which are electrified, as the efficiency of electric-based technologies such as electric motors and heat pumps are substantially higher than their fossil fuel-based equivalents. The share of electricity in final energy use increases from a little over 20% in 2023 to over a third by 2050 in *Current Trajectory*, and more than 50% in *Below 2°*.

Global electricity consumption rises by around 40% by 2035 in both scenarios, and by 85%-100% by 2050. The increase in consumption of electricity in *Below 2°* is only a little stronger than in *Current Trajectory* because more rapid electrification of the energy system is offset by faster progress of economy-wide energy efficiency measures.

The direct consumption of fossil fuels as a share of TFC declines from around two-thirds in 2023 to below 60% by 2035 in both scenarios. In *Current Trajectory* that share falls to around half of total energy use by 2050. Fossil fuel consumption declines much more rapidly in *Below 2°*, to only a quarter of final energy consumption by 2050.

A growing share of the world moves from energy addition to energy substitution

Primary energy of countries in 'energy substitution' in *Current Trajectory*



See Annex for details on the methodology for primary energy substitution.

An increasing number of regions and countries move from the 'energy addition' phase of the transition to 'energy substitution', as low carbon energy rises fast enough to reduce their use of unabated fossil fuels.

Energy addition to energy substitution

At a global level, the energy system is currently in the 'energy addition' phase of the energy transition. That means that while low carbon energy use is rising rapidly, it is not rising fast enough to meet the entire growth of total energy demand. The use of unabated fossil fuel is therefore also still increasing.

This 'energy addition' phase has occurred in previous structural energy transitions, for example when coal displaced traditional biomass (including wood) as the world's primary energy source, and later when oil became the dominant source of energy. In both cases the world continued to consume similar or growing amounts of the 'old' form of energy, albeit sometimes for new purposes, even as use of the new form of energy surged.

Although the global energy system as a whole is still in this addition phase, that is not the case for many countries and regions. Indeed, around 40% of global energy demand is now accounted for by regions and countries that have already moved into the 'energy substitution' phase of the transition. In these parts of the world, low carbon energy is already rising more rapidly than total energy demand, so that unabated fossil fuel use is falling. That is the case, for example, in both the EU and the US.

Rapidly growing deployment of renewables and an acceleration in electrification in the *Outlook* scenarios mean that more countries and regions move into this 'energy substitution' phase of the energy transition over the coming years[3].

In *Current Trajectory*, the share of global primary energy accounted for by countries and regions in the energy substitution phase of the transition rises to more than 60% of total global primary energy by 2050. That is a result of more of the world's emerging economies moving into the energy substitution phase, as their deployment of renewables accelerates and the electrification of their economies gathers pace, allowing their use of unabated fossil fuel to decline. This includes, for example, China around 2030 and Brazil in the 2040s. That shift happens even more rapidly in *Below 2°*, so that all regions enter the substitution phase during the outlook period.

[3] In countries and regions in which overall energy demand – and both unabated fossil fuels and low carbon energy – are falling, we define 'energy substitution' to be occurring if fossil fuel energy is falling more rapidly than low carbon energy. See Annex page 94 for more details.

The impact of AI on the global energy system

Increasing use of artificial intelligence (AI) is boosting the electricity demand of data centres. AI may have much more widespread impacts on the energy system over time, however, affecting both energy supply and also economy-wide energy demand.

Energy demands of AI

Growing power demand from data centres, driven in large part by rising use of AI, is likely to provide a material boost to electricity demand, albeit to differing degrees in different regions and countries.

In *Current Trajectory*, growth in data centres' use of electricity accounts for around a tenth of global power demand growth out to 2035. But that impact differs substantially across regions: for example, rising data centre demand accounts for 40% of overall US power demand growth over the next decade (see pages 52-53).

Any such projections of the power demand of data centres are highly uncertain, however. In part their demand will depend on the evolution and rate of adoption of AI. But it will also depend crucially on the energy efficiency of data centres, which has risen dramatically over recent years: digital data traffic rose more than 25-fold between 2010 and 2024, but the energy use of data centres rose only two-fold over that period.

While some of the drivers of those past efficiency improvements – for example the widespread shifts from on-premises data centres to the cloud – may not have much further to run, other innovations, including continuing advances in chip design and AI programming, are likely to drive more improvements in the energy efficiency of data centres in the coming years.

Impacts of AI on the energy sector

The demand for electricity of data centres is only one narrow aspect of the likely impacts of AI on the global energy sector, however. AI may over time have significant impacts on the supply of energy, too.

AI is already being widely used in the oil and gas industry, for example improving and accelerating exploration through better analysis of geological structures. It is also being used to plan and design new oil and gas wells, improving the subsequent operation and efficiency of those facilities.

AI also has the potential to accelerate innovation in low carbon energy, for example through the development of new materials for solar panels or carbon capture, of new battery chemistries, or through improving the design and efficiency of low carbon hydrogen systems. More radically, continued advances in AI could unlock major technological breakthroughs in low carbon energy supply, such as through the development of new advanced biofuels, or even of usable nuclear fusion.

Accelerating use of AI could also improve the efficiency with which energy systems are operated. It has the potential to enable more efficient planning and operation of electricity grids, helping to forecast demand spikes and optimize battery storage deployment. It could help to make grids 'smarter', enabling more efficient aggregation of large quantities of small assets such as EVs, rooftop solar and smart thermostats. And it is already being used in both fossil fuel facilities and power systems to better predict faults or failures, improving safety and reducing downtime or the need for additional backup capacity.

Wider impacts of AI on the global economy and the energy system

Such effects of AI on energy supply are, however, only energy sector-specific examples of the wider potential impacts of the technology on the global economy, with broader-still implications for the energy system.

AI could materially boost the growth of the global economy if it leads to faster productivity growth. That could occur in a wide range of ways, including the automation of an increasing range of tasks, more efficient use of physical assets, and the acceleration of innovation and new discoveries. There is currently an extremely wide range of estimates of the likely size of these effects. One recent OECD survey[4] reported estimates varying from only moderate impacts – boosting the level of US GDP by only around 1% over the next decade – to effects as large as an additional 2.5 percentage points per year on productivity growth in the US.

AI-driven improvements in productivity growth could have very significant implications for energy demand. The average of the estimates from the OECD survey – higher productivity growth of around 1.2% per year – would, if manifested at a global level, boost total energy demand by around 15% by 2035, assuming that global energy efficiency continued to improve at around its past average rate. That is twenty times as large as the increase in data centres' power demand in *Current Trajectory*.

It is probably unrealistic to assume that the energy efficiency of the global economy would itself be unaffected by major advances in AI, however. AI could help to optimize manufacturing processes and accelerate the development of more energy-efficient products, leading to substantial improvements in industrial efficiency. In the transport sector, AI may be used to better manage traffic and optimize routes, and it could also bring about substantial reductions in the use of energy for heating and cooling in buildings. Recent IEA analysis[5] suggests that wide application of AI to improve economy-wide energy efficiency could have very substantial impacts on global energy demand.

Assumptions about the effects of AI in *Current Trajectory* and *Below 2°*

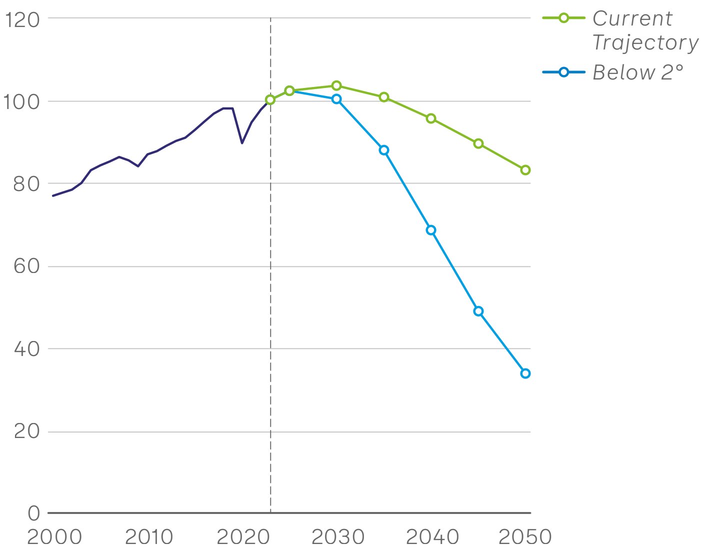
Current Trajectory and *Below 2°* both assume only a moderate boost to productivity and GDP growth from the use of AI over the outlook. Moreover, the scenarios do not explicitly incorporate significant AI-driven technological breakthroughs in energy supply. But given the rapid pace of developments in the design and use of AI applications, any estimates of these AI effects are, at present, enormously uncertain, and their impacts could be far larger. The uncertainties around their eventual size dwarf those solely around the future power needs of data centres.

[4] Miracle or Myth? Assessing the macroeconomic productivity gains from Artificial Intelligence, OECD Artificial Intelligence Papers, 22 November 2024.
[5] Energy and AI – Analysis, IEA, April 2025.

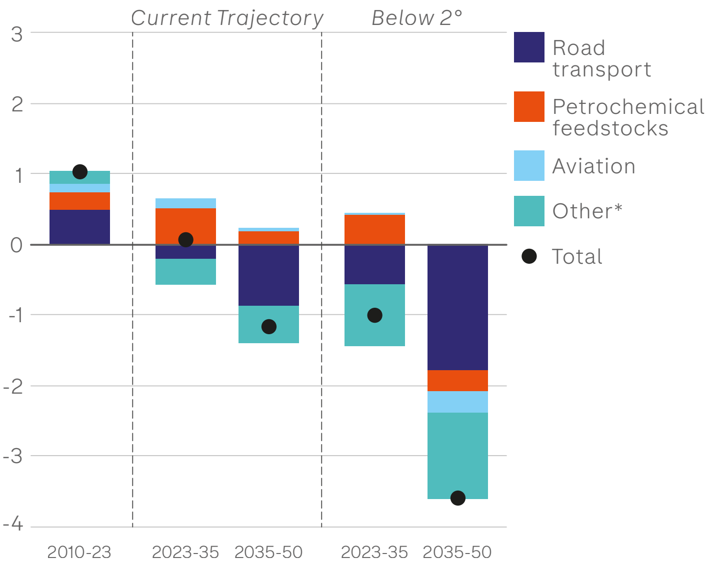
Energy demand

Oil continues to play a major role in the global economy

Oil demand



Average annual oil demand growth by sector



*Includes other feedstocks, industry, rail, marine and residential / commercial use.

Global oil demand broadly plateaus over the remainder of this decade, before declining further out, led by falling use in road transport.

Oil continues to play a critical role in the global energy system over the first half of the outlook, with the world consuming between 85-100Mb/d of oil in 2035 in the two scenarios.

Oil in *Current Trajectory*

In *Current Trajectory*, oil consumption continues to grow over the rest of this decade, albeit at a declining rate, before edging back to around its current level by 2035. Demand is supported by increasing use in India and other emerging Asian countries as their economies continue to grow rapidly, partially offset by continuing declines in developed markets. In marked contrast to the past decade during which China accounted for around half of all global oil demand growth, China's oil consumption is slightly lower by 2035 in *Current Trajectory*.

Beyond 2035, oil demand in *Current Trajectory* declines, falling to a little below 85Mb/d by 2050. This fall is concentrated in developed economies and China, with oil consumption in 2050 in most other regions of the world broadly unchanged from their 2035 levels.

Oil in *Below 2°*

In *Below 2°* the falls in oil demand occur sooner and with greater intensity, with oil demand falling to a little above 85Mb/d by 2035 and to a little below 35Mb/d by 2050. The declines in oil consumption are broadly based across geographies, led in the first half of the outlook by the developed world and China, but with demand falls in other emerging economies accelerating beyond 2035.

Sources of oil demand

The two most important uses of oil shaping the outlook for oil demand are the diminishing role of oil in road transport as vehicles become more efficient and are increasingly electrified, counteracted by the more persistent use of oil as a feedstock in the petrochemicals sector led by the continuing demand for plastics. These two uses are considered in more detail on pages 32-33 and pages 34-35 respectively.

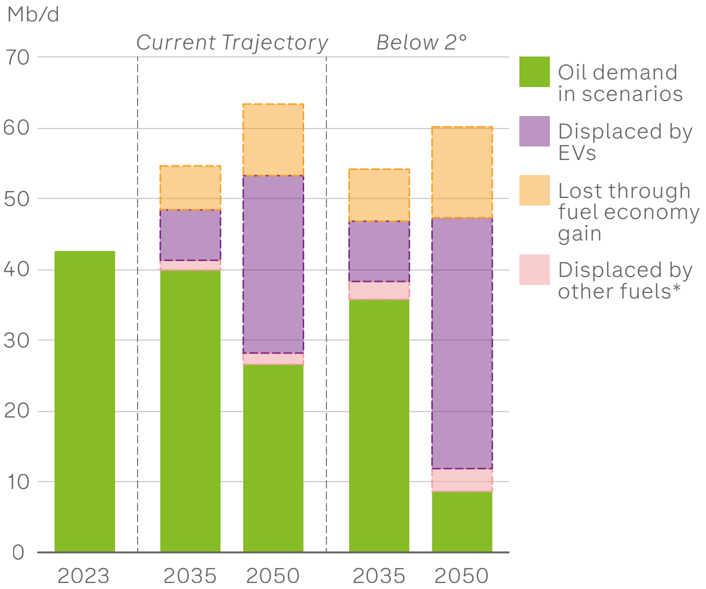
Outside of these two sources of demand, oil consumption in *Current Trajectory* is boosted by rising consumption of jet fuel as increasing global economic activity and growing prosperity in developing economies spur greater demand for air travel. Oil use in aviation also increases over the rest of this decade in *Below 2°* but subsequently declines as an increasing share of aviation demand is met by sustainable aviation fuel (SAF) derived from biofuels and hydrogen.

The use of oil in marine transport increases slightly over the first half of the outlook in *Current Trajectory* before gradually falling as the use of bunker fuel is replaced by alternative marine fuels, led by LNG, liquid biofuels, and biomethane.

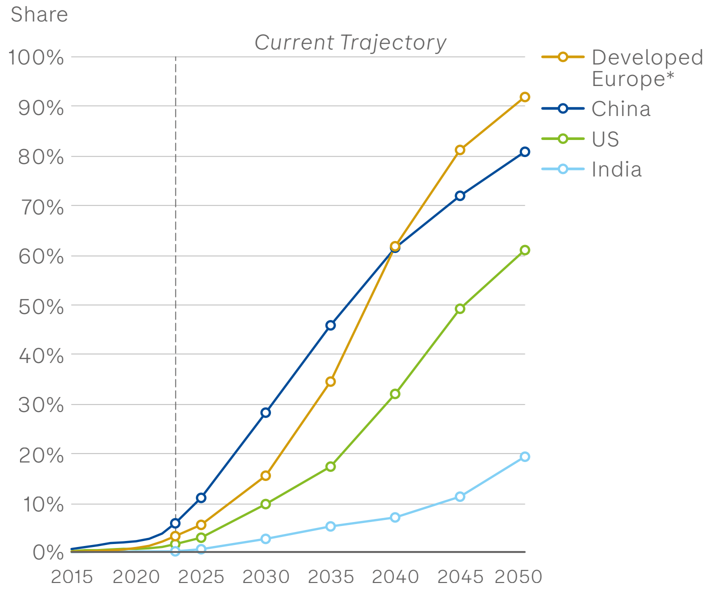
More generally, the remaining use of oil as an energy source, largely in industry and buildings, gradually declines over the outlook in both scenarios as these sectors increasingly electrify and improve their energy efficiency.

Oil use in road transport declines as increasing vehicle efficiency and electrification offsets growing transport demand in emerging economies

Factors impacting oil demand in road transport



Electricity's share of car and truck kilometres travelled



*Other fuels include biofuels, natural gas and hydrogen.

*Includes the EU, Iceland, Norway, Switzerland and the UK.

Oil used in road transport declines over the outlook, as the impact of increasing demand for road transportation is more than offset by improving vehicle efficiency and the switch to electric vehicles.

Opposing forces

The use of oil in road transportation is the largest source of oil demand, accounting for around 40% of oil consumption in 2023. The future use of oil in road transport reflects the outcome of two opposing forces: increasing prosperity and improving living standards in emerging economies leading to a growing demand for road transportation; but the impact of this increased road transportation on oil use being offset by road vehicles becoming more efficient and by an increasing switch to electric vehicles, primarily in developed economies and China.

Oil in road transport

In *Current Trajectory*, the expanding demand from road transportation would, other things equal, cause oil use to increase by around 12Mb/d by 2035. But the impact of this increase in underlying demand is broadly offset by a combination of improving efficiency of internal combustion engine (ICE) vehicles and an increasing electrification of road transport.

Beyond 2035 in *Current Trajectory*, underlying transport demand continues to increase, but the accelerating adoption of electric vehicles, together with continuing efficiency improvements of the ICE vehicle fleet, more than offset the implication of this demand increase for oil use. The use of oil in road transport in *Current Trajectory* falls to a little over 25Mb/d by 2050, compared with close to 40Mb/d in 2023 and 2035.

The same opposing trends are apparent in *Below 2°*, but the downwards impact from the increasing electrification of road vehicles is greater, especially in the second half of the outlook. Oil use in road transport falls to around 35Mb/d by 2035 and to less than 10Mb/d by 2050.

Key markets

The increasing penetration of electric vehicles over the outlook is driven initially by a combination of tightening vehicle CO_2 emission standards and direct policy support, later reinforced by economic factors as the price of electric vehicles falls relative to ICE vehicles and approaches price parity in some vehicle segments and regions.

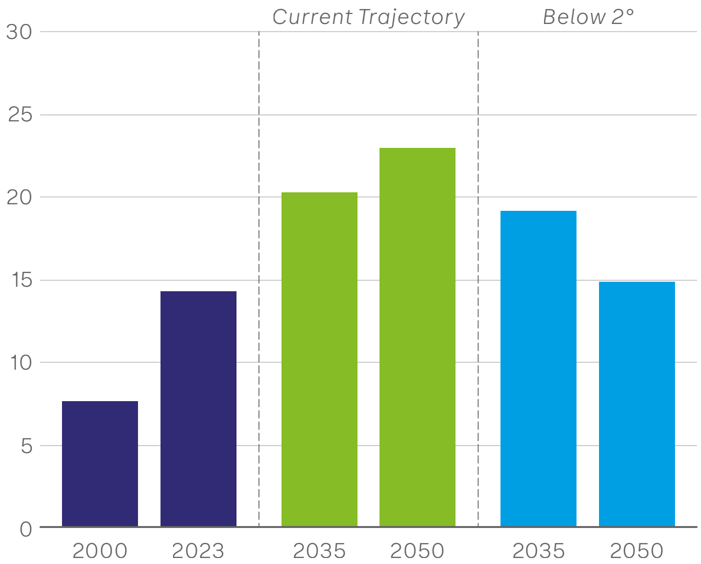
In *Current Trajectory*, the number of electric passenger cars and trucks increases from around 40 million in 2023 to 480 million in 2035 and 1.4 billion in 2050. The corresponding numbers for *Below 2°* are 560 million and 2.1 billion.

The increasing importance of electric vehicles in road transport is dominated by three key markets: China, Europe, and the US. In *Current Trajectory*, China's current leadership in the adoption of electric vehicles continues over the next 15 years or so, with electricity fuelling around 45% of vehicle kilometres in China in 2035, compared with around 35% across developed European economies and less than 20% in the US.

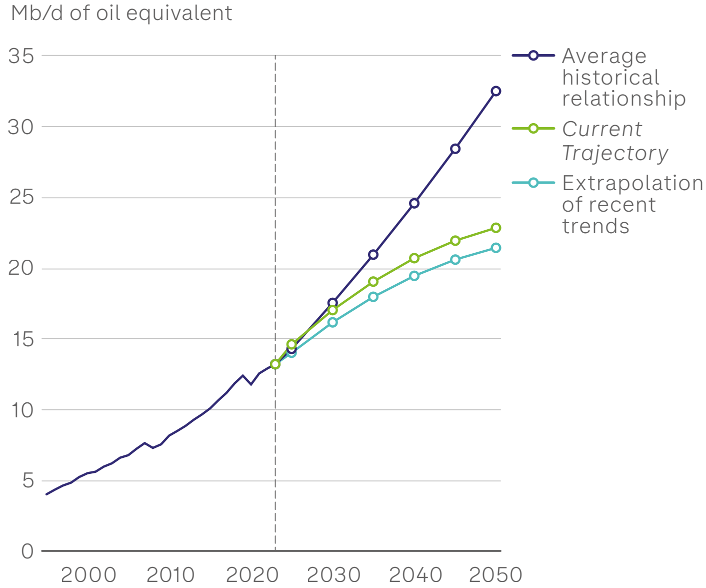
Further ahead, however, the increasing restrictions on the sale of new internal combustion engine cars in both the EU and other parts of developed Europe in the second half of the 2030s mean that by 2050, more than 90% of vehicle kilometres are powered by electricity in Europe, compared with 80% in China and 60% in the US.

The use of oil as a petrochemicals feedstock becomes an increasingly important component of oil demand

Demand for oil for petrochemical feedstocks



Feedstock demand for plastics production



The 'average historical relationship' uses a fixed income elasticity (1995-2023). The 'extrapolation of recent trends' uses the trend income elasticities over the same period.

The most resilient component of oil demand is the use of oil as a feedstock in the petrochemicals sector, underpinned by continuing demand for plastics as the world economy expands and by the limited scope for efficiency improvements or substitution when oil is used as a feedstock rather than as an energy source.

Growing importance of oil as a feedstock

The use of oil as a feedstock has almost doubled since 2000, increasing from less than 8Mb/d to over 14Mb/d by 2023, accounting for around a quarter of the growth in total oil demand over this period. This growth was underpinned by the increasing production of plastics, which more than doubled over the same period, and which accounts for around 70% of the growth in the use of oil in petrochemicals since 2000.

In *Current Trajectory*, the use of oil by the petrochemicals sector increases further over the first half of the outlook, reaching around 20Mb/d by 2035. This increase is led by China and the Middle East, reflecting the growing concentration of petrochemical production capacity in these regions.

Beyond 2035, the growth of oil as a petrochemicals feedstock slows, as global economic growth moderates and the responsiveness of the demand for plastic to economic growth declines. Even so, the use of oil as a feedstock rises to around 23Mb/d by 2050, with its share in overall oil demand increasing from around 15% in 2023 to 20% in 2035 and to close to 30% in 2050.

Greater sustainability

The greater regulations and incentives to reduce, reuse and recycle plastic goods in *Below 2°* means the increased use of oil in petrochemicals is more limited. Oil used as a feedstock increases to a little below 20Mb/d by 2035 but falls back in the second half of the outlook, such that by 2050 it is back close to current levels. But the more pronounced falls in other components of oil demand (see pages 30-31) means that by 2050 petrochemical demand accounts for around 45% of total oil demand.

Economic growth and plastics demand

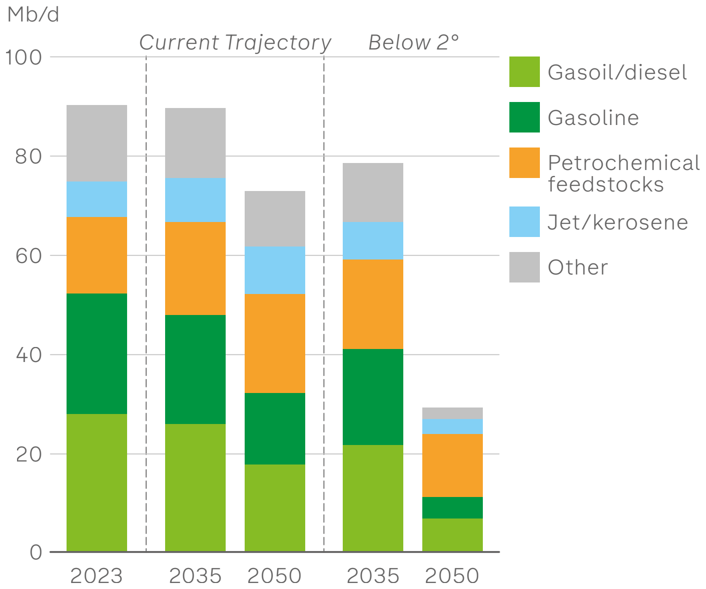
The use of oil as a feedstock is highly dependent on the growth in the demand for plastic goods. Over the past 30 years or so, the demand for plastics has become less responsive to increases in economic activity, as the global pattern of economic demand has shifted away from goods towards services, and as society has used plastic goods in more sustainable ways.

The future relationship between economic growth and the use of plastics has an important bearing on overall oil demand.

In *Current Trajectory*, holding all other aspects of the scenario constant, the difference between assuming that the average relationship between economic growth and plastic demands seen over the past 30 years holds into the future, as opposed to assuming that it continues to decline at a similar rate to the past, can lead to a difference in feedstock demand of as much as 10Mb/d of oil equivalent by 2050, the large majority of which would be from oil.

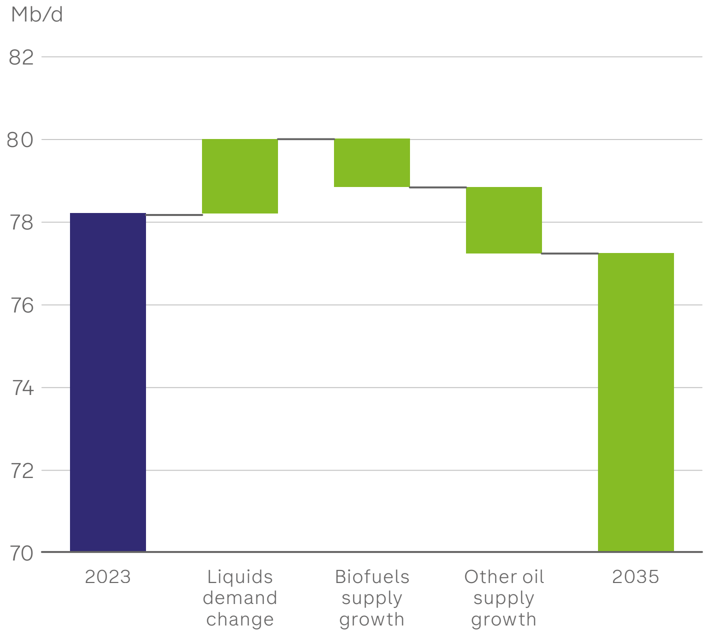
The changing level and composition of oil demand puts increasing pressure on refineries

Product demand



Product demand includes NGLs but excludes biofuels and ethane.
Petrochemical feedstocks refers to LPG and naphtha.

Refined product demand in *Current Trajectory* (2023–2035)



Other oil supply includes upstream NGLs and condensate, and gas and coal to liquids.

The changing level, mix and geographical composition of refined product demand, together with increasing use of non-refined alternatives, leads to increasing pressure on refinery utilization and rationalization.

Key trends shaping refining

The outlook for refining is shaped by three key trends:

- The overall demand for refined product, which declines over the outlook;
- The changing pattern of oil use, with falling demand for road fuels counteracted by more persistent demand for petrochemical feedstocks and jet fuel;
- The shifting geographical composition of product demand, with demand falling more in the developed world than in emerging Asia and the Middle East.

Current Trajectory

In *Current Trajectory*, overall demand for refined product is broadly unchanged out to 2035. Gasoline and diesel demand decline as their use in road transport wanes, but this is offset by the increasing demand for petrochemical feedstocks and jet fuel.

The US and Europe experience the largest falls in gasoline and diesel, whereas the increases in demand for petrochemical feedstocks are concentrated in China and the Middle East.

These trends gather pace beyond 2035 in *Current Trajectory*. Falls in gasoline and diesel demand accelerate, only partially offset by muted growth in jet fuel and petrochemical feedstocks. The global demand for refined products falls to a little over 70Mb/d by 2050, compared with close to 90Mb/d in 2023 and 2035. As in the first part of the outlook, the lion's share of this reduced demand occurs in developed economies, leading to continuing challenges to the utilization and viability of refineries in those economies.

Below 2°

The falls in gasoline and diesel demand are more pronounced in *Below 2°*, with each falling by around 5Mb/d by 2035 and by a further 15Mb/d by 2050. The use of oil in petrochemicals continues to grow over the first half of the outlook but then falls back as the world limits its use of plastic goods. By 2050, petrochemical feedstock demand is close to its current level (see pages 34-35).

The falls in product demand are more broadly based across the globe than in *Current Trajectory*, with developed economies continuing to see the largest reductions, but with material declines also in China, other parts of emerging Asia, and the Middle East.

The speed and nature of the adjustment in the refinery sector to the increasing economic pressures in both scenarios depends on the extent to which domestic refineries are perceived as providing wider benefits to the local economy, such as a source of employment or enhancing energy security.

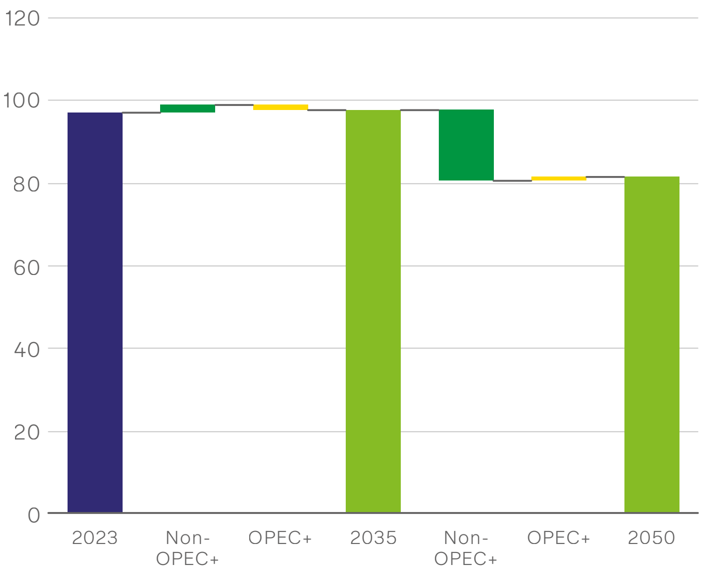
Non-refined alternatives

In addition to the changing levels and composition of product demand, the pressure on refineries is compounded by the growing use of non-refined alternatives, particularly natural gas liquids (NGLs) and biofuels.

For example, in *Current Trajectory*, the small increase in the demand for total liquid fuels out to 2035 is more than met by increasing supplies of NGLs and biofuels, such that the demand for refined products falls.

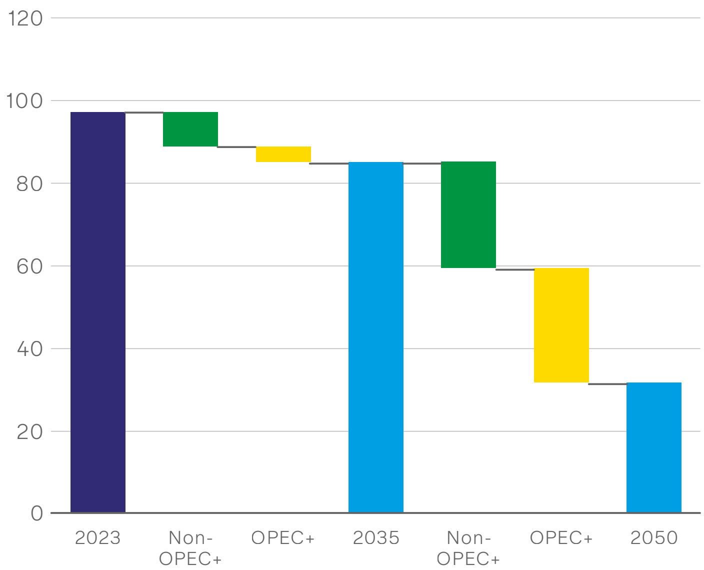
The pattern of global oil supplies changes as US tight oil peaks and oil demand declines

Oil supply in *Current Trajectory* (2023-2050)



Supply refers to upstream crude, NGL, and condensate production. This excludes coal- and gas-to-liquids, and refinery gains.

Oil supply in *Below 2°* (2023-2050)



Supply refers to upstream crude, NGL, and condensate production. This excludes coal- and gas-to-liquids, and refinery gains.

The composition of global oil production changes over time, as US tight oil plateaus and declines in global oil demand fall disproportionately on non-OPEC+ producers.

Forces shaping oil production

The outlook for global oil production is shaped by two key forces. First, by changes in the pattern of non-OPEC+ supplies, as US tight oil – which has been the single largest source of global supply growth over the past 10 years or so – plateaus and subsequently declines. And second, by increasing competition for market share by OPEC+ producers as global oil demand falls.

In *Current Trajectory*, global oil production is little changed over the first half of the outlook. In contrast to the rapid growth seen over the past 10-15 years, US onshore production is broadly flat over this period at around 15Mb/d. Brazil and Guyana record the largest increases, with their production reaching around 5Mb/d and 2Mb/d respectively by 2035.

The combination of broadly flat oil demand out to 2035, together with continuing gains in overall non-OPEC+ supplies, means there is little scope for OPEC+ to increase their output over the first half of the outlook.

OPEC+ compete for market share

Falling oil demand in the second half of the outlook in *Current Trajectory* leads OPEC+ to seek to increase its share of overall production, in order to maintain output levels, while also balancing the implications of that greater competition for oil prices.

The greater cost competitiveness of OPEC+ oil producers means all the fall in global demand out to 2050 in *Current Trajectory* is borne by non-OPEC+ producers, led by the US, Brazil and Guyana. US onshore production falls to around 10Mb/d by 2050. The market share of OPEC+ increases from close to 50% in 2023 and 2035 to around 60% by 2050.

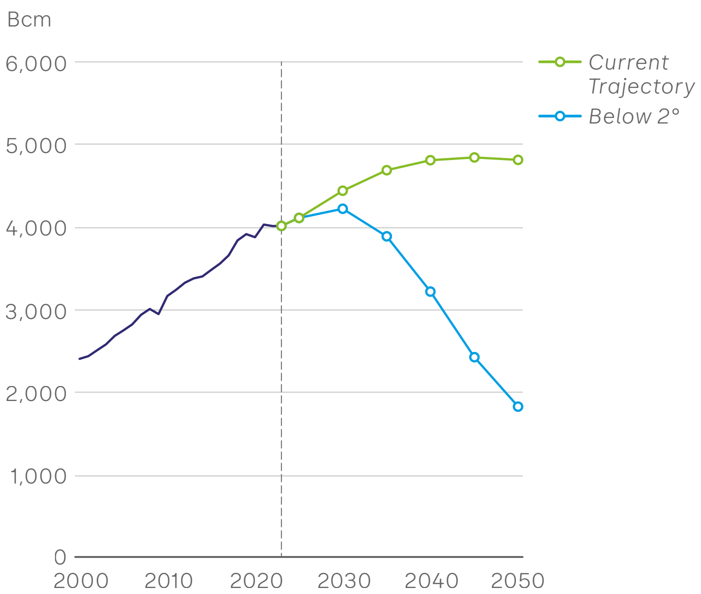
Non-OPEC+ production falls most

The earlier and deeper falls in oil demand in *Below 2°* cause OPEC+ to compete more actively to maintain its production levels and expand its market share. As a result, the falls in oil demand out to 2035 are almost entirely concentrated in non-OPEC+ production, led by marked falls in onshore US output. Brazil and Guyana register some increase in production, but the more competitive environment means the scale of the expansions are more limited than in *Current Trajectory*.

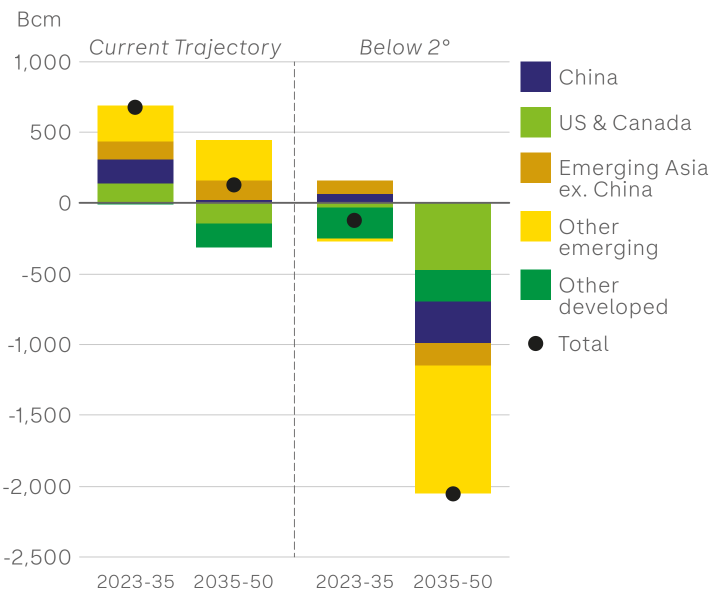
The accelerating falls in oil demand post-2035 in *Below 2°* lead to more broadly-based falls in both non-OPEC+ and OPEC+ production. Even so, the greater cost competitiveness of OPEC+ producers means non-OPEC+ production accounts for over half of the total fall in oil supplies out to 2050, with the market share of OPEC+ producers increasing to 55% by 2035 and to over 60% by 2050.

The outlook for gas demand depends on the speed of the energy transition

Natural gas demand



Change in natural gas demand by region



The outlook for natural gas is shaped by two opposing forces: increasing demand in emerging economies as they rapidly grow and industrialize, offset by a shift away from natural gas as the world increasingly electrifies and decarbonizes. The relative strength of these two forces – and hence the outlook for natural gas – depends on the pace of the energy transition.

Growth driven by emerging economies

In *Current Trajectory*, natural gas demand increases to around 4,700Bcm by 2035, close to 20% higher than in 2023. Over 80% of this growth stems from emerging economies, led by China, India and other emerging Asian economies, as well as the Middle East. The most important source of demand growth in emerging economies comes from the industrial sector, especially the chemical sector and light industry. That higher industrial demand is broadly matched by the combined impact of increasing use of natural gas in buildings and the power sector.

Gas demand in most developed markets falls

In the developed world, natural gas demand outside of the US is broadly flat or falling over the first half of the outlook in *Current Trajectory* as declining use in buildings is partially offset by increases in power and transport. The main exception is the US where domestic US gas demand grows by almost 15% by 2035, with most of that gas being used to support increasing power generation (see pages 44-45).

Global gas consumption broadly plateaus over the final 10 years of the outlook in *Current Trajectory*. The use of natural gas in much of the emerging world continues to increase, led by emerging Asian economies (other than China). But this growth is increasingly offset by falling demand in developed markets, as the use of natural gas in buildings and industry is crowded out by growing electrification, and gas loses share to wind and solar in power markets.

In contrast to the first half of the outlook in *Current Trajectory*, in which China is the single largest source of demand growth, China's use of natural gas broadly plateaus after 2035.

Gas demand falls in fast transition

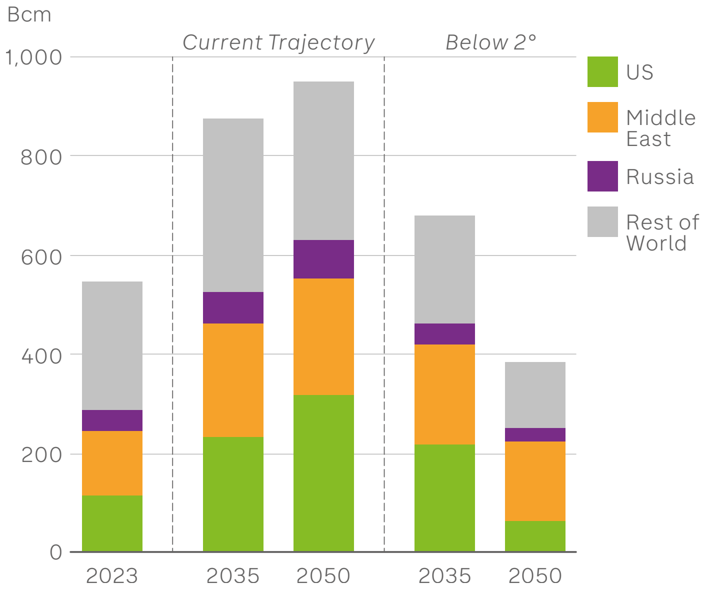
In contrast, natural gas demand in *Below 2°* peaks by the end of this decade, such that by 2035 it is back close to current levels and by 2050 is around 50% lower.

The use of natural gas in emerging economies continues to grow through the first half of the outlook, but this is offset by falling demand in developed markets. This fall in gas demand in developed markets is driven by the increasing electrification of buildings and industry, together with the impact of natural gas losing share in the power sector. Gas demand in developed markets peaks by the end of this decade in *Below 2°*.

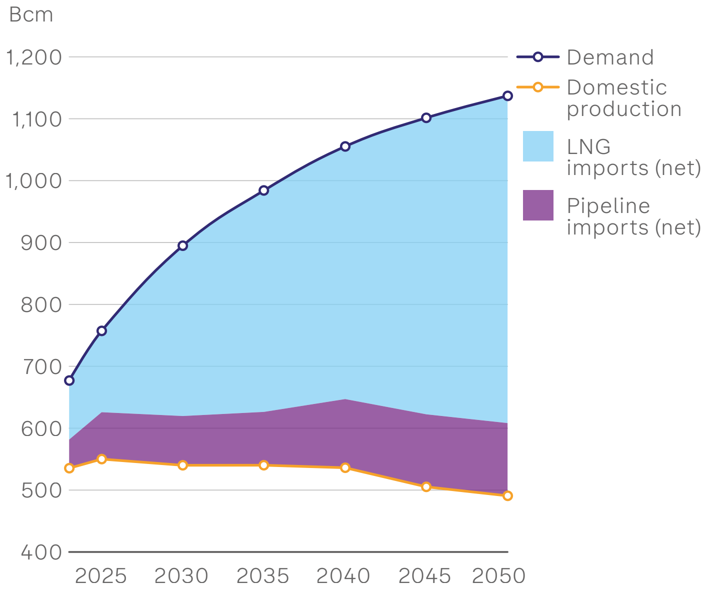
The falls in natural gas demand become more broadly based in the second half of the outlook in *Below 2°*, with the use of natural gas in emerging economies also declining. The greater government support and pressure for decarbonization means that by 2050, almost 60% of the remaining use of natural gas is combined with carbon capture.

LNG trade is underpinned by gas demand in emerging Asia

LNG exports by region



Natural gas demand and supply in emerging Asian economies in *Current Trajectory*



Emerging Asian economies include China, India and other emerging Asia.

Trade in LNG increases rapidly through the rest of this decade, but prospects for LNG trade post-2030 are dependent on the pace of the energy transition.

US and Middle East emerge as major LNG export hubs

In *Current Trajectory*, LNG exports increase by over 60% by 2035. Most of this demand growth is met by the US and the Middle East, who emerge as the dominant supply hubs for global LNG, accounting for over 50% of LNG exports by 2035.

LNG trade continues to increase in the second half of the outlook in *Current Trajectory*, albeit at a slower pace, as global natural gas consumption plateaus (see pages 40-41). The US more than accounts for the growth in global LNG exports post-2035, helped by the continuing competitiveness of its natural gas resources.

Russian LNG

Russian LNG exports continue to be constrained by international sanctions over the first part of the outlook. However, as the impacts of international sanctions decline in *Current Trajectory*, the continuing growth in global LNG demand allows Russian exports to expand, reaching around 80Bcm by 2050, up from 45Bcm in 2023.

LNG trade falls in fast transition

Although LNG trade increases robustly through the rest of this decade in *Below 2°*, it then declines through the 2030s and 2040s as the pace of the energy transition accelerates, causing global gas demand to decline (see pages 40-41). By 2050, LNG exports are around 25% below their 2023 level. Between 2023 and 2050, US exports fall proportionately more than those from the Middle East, reflecting the closer proximity of the Middle East to the most resilient LNG markets in emerging Asian economies.

LNG exports underpinned by demand in emerging Asian

The sustained growth of LNG demand in *Current Trajectory* is underpinned by increasing gas consumption in emerging Asian economies which together account for over half of the increase in global gas demand over the outlook.

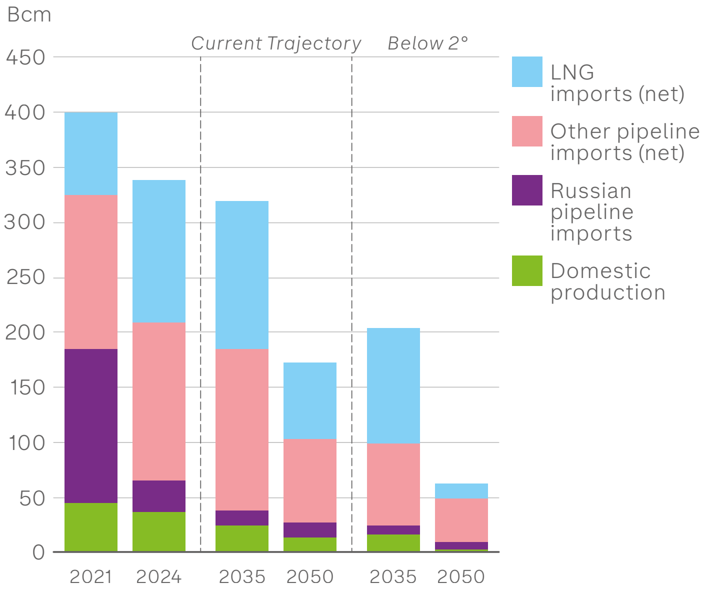
Gas production in these emerging Asian economies is broadly flat over the first half of the outlook, before edging lower in the 2040s.

Moreover, access to additional pipeline gas for these economies is limited, except for China which sees some increase in imports of piped gas in the late 2030s as the Power of Siberia 2 comes on stream.

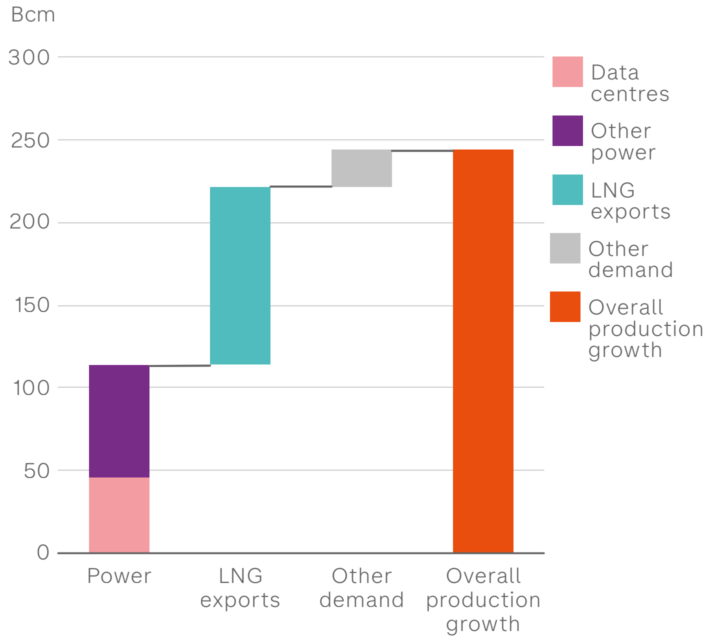
As a result, almost the entire growth in gas demand in emerging Asian economies in *Current Trajectory* is met by increasing LNG imports. The increase in these economies' imports of LNG more than account for the entire growth in global LNG demand.

Natural gas markets are impacted by both geopolitical factors and new sources of demand

EU natural gas demand by source



Sectoral contributions to US natural gas production growth* (2024-2035)



*Assuming that the power generation fuel mix is constant across all sectors.

The outlooks for natural gas in different regions and countries depend on a range of factors. In the EU, imports of natural gas continue to be impacted by geopolitical factors. And in the US, the increase in US gas production over the first half of the outlook is driven by the expansion of LNG exports and rising electricity demand.

Meeting EU gas demand

The EU is heavily dependent on imports of natural gas, importing around 90% of the gas it consumed in 2024. In 2021, prior to the war in Ukraine, the EU imported almost a third (140Bcm) of the gas it consumed via pipelines from Russia. By 2024, pipeline imports from Russia had declined to around 30Bcm. The EU responded to that loss by reducing its overall consumption of gas and increasing its imports of LNG.

Increased role for LNG imports

In *Current Trajectory*, pipeline imports from Russia fall further, to around 15Bcm, as the EU seeks to reduce its dependency on Russian energy. This loss of gas supplies is compounded by declining domestic gas production. Total EU gas consumption in 2035 is little changed from 2024, with the additional shortfall in supply met by a combination of increases in pipeline gas from outside of Russia and an expansion of LNG imports. LNG imports account for 40% of EU gas demand in 2035 in *Current Trajectory*, only a little above their share in 2024, but more than double their share prior to the war in Ukraine.

EU gas consumption falls by around 45% in the second half of the outlook in *Current Trajectory*. Even though European production continues to decline, the fall in EU gas demand allows it to reduce its imports of LNG to below levels seen prior to the war in Ukraine.

EU gas consumption declines earlier and more quickly in *Below 2°*, such that by 2035 it is 40% below 2024 levels and 80% lower by 2050. This weaker demand outlook means EU imports of LNG in 2035 are below 2024 levels and fall further in the second half of the outlook.

US production of natural gas

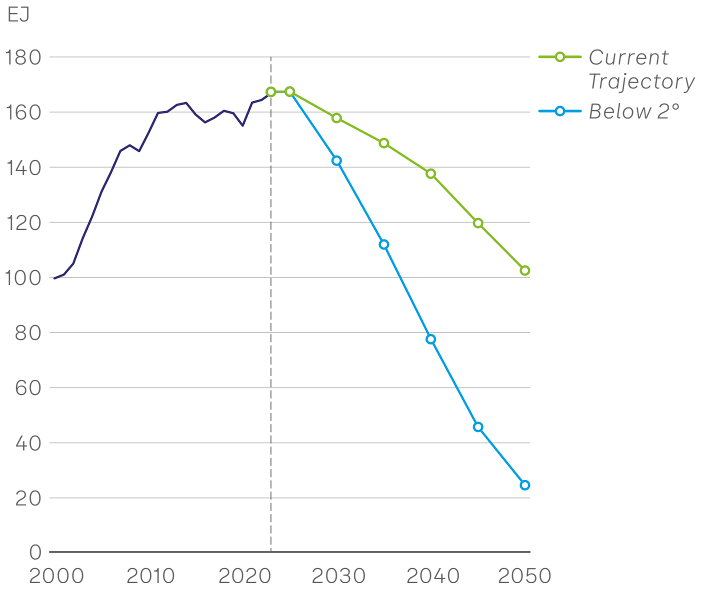
US natural gas production increases by around 240Bcm over the first half of the outlook in *Current Trajectory*.

Around half of that increased production is used to meet the acceleration in US power demand. The growing needs of data centres account for around 40% of the increase in US power, with the remainder reflecting broadly-based increases in power demand.

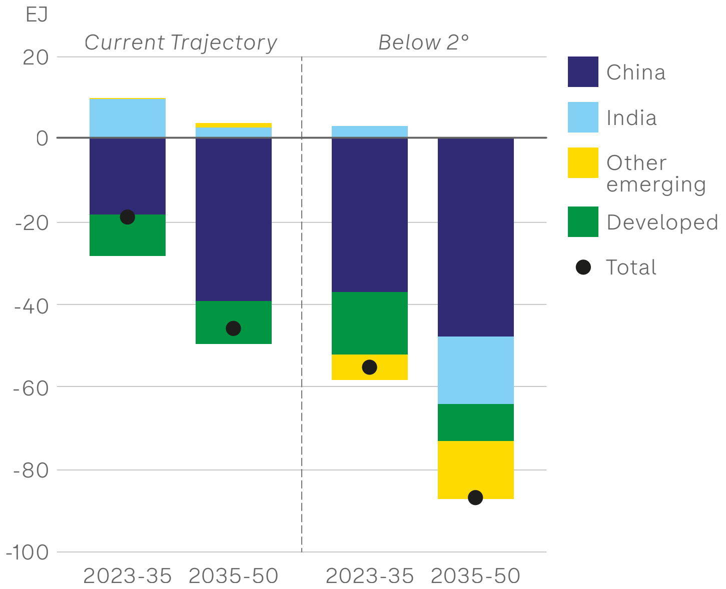
The other major driver of the increase in US gas production over the next 10 years in *Current Trajectory* is the need for additional feedgas to support the growth of US LNG exports, which double over this period (see pages 42-43). As a result, US LNG exports account for almost 20% of US gas production by 2035, compared with a little over 10% in 2024 and less than 1% in 2010.

The role of coal in the global energy system declines, led by China

Coal demand



Change in coal demand by region



Global coal consumption peaks in the second half of this decade before declining through the rest of the outlook, led by falling use of coal in power generation in China and, to a lesser extent, in developed markets.

Falls in coal demand led by China

In *Current Trajectory*, global coal consumption begins to slowly decline from the late 2020s, falling by a little over 5% by 2035.

Most of this fall stems from the declining use of coal in China, which falls by around 20% over this period. Around 60% of this fall occurs in the Chinese power sector, as the share of coal in power generation declines markedly – from 55% to 30% – crowded out by increasing solar and wind generation. Coal use in China's industrial sector also falls as production of steel and cement declines.

The use of coal also falls in developed economies, declining by almost 40% by 2035 in *Current Trajectory*. As in China, this drop is concentrated in the power sector, as coal is increasingly displaced by solar and wind power.

India's demand more resilient

The fall in overall coal consumption out to 2035 is ameliorated by increasing coal demand in India, which expands by over 40%. This growth is underpinned by the role of coal in supporting the rapid growth of Indian power generation and, to a lesser extent, industrial output.

The pace of decline in coal consumption accelerates post-2035 in *Current Trajectory*, with demand down by a further 30% by 2050. As in the first half of the outlook, this fall is dominated by declining use in China and, to a lesser extent, in developed economies.

The fall in coal consumption in *Below 2°* is more pronounced, with demand down by around 85% over the outlook. As in *Current Trajectory*, the largest falls in coal demand are in China, as it transitions to other sources of energy. Outside of China, the declines in coal use are more broadly based across both developed and emerging economies, reflecting both the increasing electrification of energy systems and the growing dominance of wind and solar power generation.

Role of coal in energy system declines

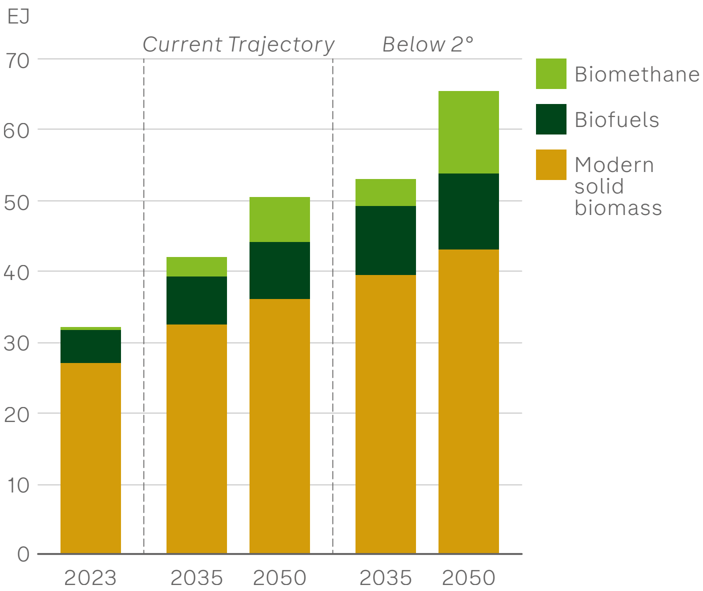
By 2050, coal consumption accounts for around 15% of primary energy in *Current Trajectory* and 5% in *Below 2°*, down from almost 30% in 2023 (see pages 20-21).

China also leads fall in global coal production

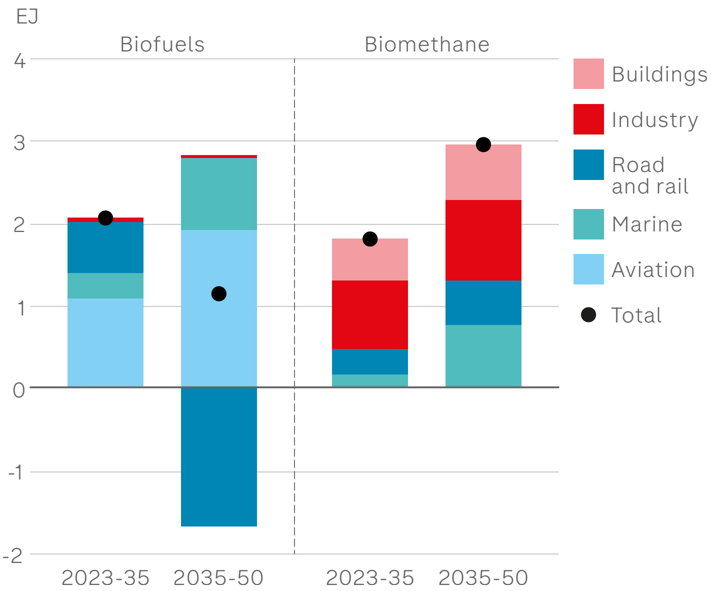
The dominant role of China in driving the falls in global coal demand are mirrored on the supply side, with China accounting for around 85% of the reduction in global coal production by 2050 in *Current Trajectory*. By 2050, China accounts for around 30% of global coal production in *Current Trajectory*, down from over 50% in 2023, with India and other emerging Asian nations overtaking China as the major global centres of coal production.

The role of modern bioenergy increases, underpinned by policies supporting its use

Modern bioenergy demand



Change in biofuels and biomethane demand in *Current Trajectory*



Demand shown is total final consumption - it excludes biomethane used for power.

The use of modern bioenergy – modern solid biomass, biofuels, and biomethane – increases over the outlook, underpinned by policies incentivizing its use.

In *Current Trajectory*, modern bioenergy increases by around 30% (10EJ) out to 2035 and by a further 20% (8EJ) by 2050. As a result, the share of modern bioenergy in primary energy increases from 5% in 2023 to 8% by 2050.

Solid biomass

The most important source of growth is solid biomass (such as wood pellets, and forest and agriculture residues) which grows by around a third over the outlook in *Current Trajectory*. Solid biomass is used mainly in the industrial sector as a low-emissions alternative to coal and natural gas to fuel high-temperature heat processes, especially in cement production and in the food and paper industries, as well as in the power sector as an alternative to traditional thermal power.

Biofuels

The use of biofuels, derived largely from first-generation feedstocks, accounted for around 15% of modern bioenergy in 2023, with almost all of that consumed within road transport, underpinned by blending mandates for liquid fuels.

Biofuels demand increases by around 45% by 2035 in *Current Trajectory*. Some of this increase stems from the growing use of biofuels in road transport, supported by higher blending mandates in some emerging economies. But the growth of biofuels in road transport is constrained by the relatively flat outlook for liquid road fuels overall (see pages 32-33).

Instead, the biggest source of growth in biofuels out to 2035 in *Current Trajectory* is in the aviation sector, underpinned by increasing mandates and incentives for the use of SAF, especially in the EU. Biofuels also play an expanding role in marine transportation helping to meet regulatory requirements to reduce carbon emissions.

The declining use of liquid fuels in road transport in the second half of the outlook in *Current Trajectory*, as road vehicles are increasingly electrified (see pages 32-33), also causes the use of biofuels in road transport to fall. As a result, all the growth in biofuels in the latter half of the outlook stems from increasing use in the aviation sector – where it provides around a third of all aviation fuels by 2050 – and, to a lesser extent, in the marine sector.

Biomethane

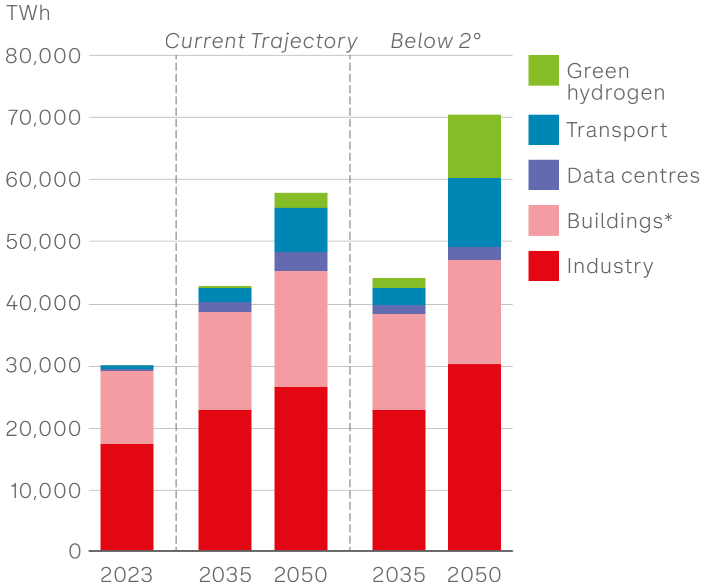
Biomethane grows rapidly in *Current Trajectory*, albeit from a low base, increasing by around 15% per year out to 2035, before slowing to around 6% per year between 2035 and 2050. The growing use of biomethane is underpinned by regulations designed to reduce methane emissions from agricultural waste and landfills, incentivizing productive use of those emissions. As biomethane is used as a direct substitute for natural gas, its increasing demand is broadly based across all three end-use sectors – industry, buildings and transport. By 2050, biomethane reaches nearly 4% of global natural gas in primary energy.

The growth of modern bioenergy is even more pronounced in *Below 2°*, underpinned by growing levels of regulatory and policy support. The use of modern bioenergy doubles by 2050, with around half of that growth stemming from biomethane and biofuels.

Power sector

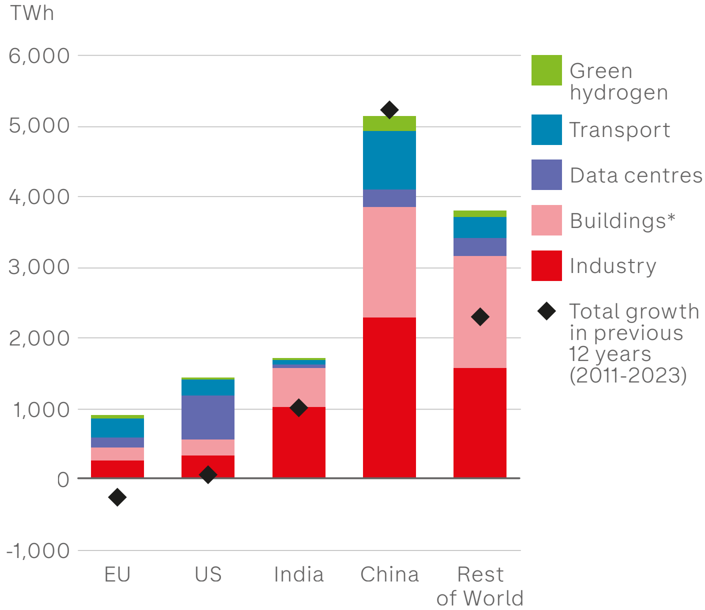
Electricity use grows rapidly, as emerging economies' demand rises and all sectors electrify

Electricity use by sector



*Includes electricity used to produce heat for heat networks.

Change in electricity demand in *Current Trajectory* (2023-2035)



*Includes electricity used to produce heat for heat networks.

Electricity demand rises rapidly throughout the outlook, driven by rising prosperity and growing populations in emerging economies, and by increasing electrification across all sectors.

Global electricity demand grows rapidly over the coming decade in *Current Trajectory*, rising to over 40,000TWh by 2035, more than 40% above the level in 2023. That is driven primarily by rising demand in the industrial and buildings sectors, which together comprise around 95% of current electricity use, and account for three-quarters of the increase in demand out to 2035.

New sources of power demand

Those existing sources of demand are supplemented in particular by two newer sources of power use: the increasing electrification of transport and the growing power needs of data centres. Higher data centre demand accounts for a tenth of the total increase in global power demand out to 2035, somewhat below the contribution from transport.

Electricity demand continues to grow strongly in the second half of the outlook in *Current Trajectory*, reaching almost twice its 2023 level by 2050. Industrial and buildings demand both continue to rise, but the largest single contributor to rising power demand between 2035 and 2050 is a tripling in electricity use in the transport sector (see pages 32-33). The production of green hydrogen also begins to make a material contribution to demand, accounting for a little under 5% of total electricity use by 2050.

Demand from green hydrogen

Power demand rises at a similar rate out to 2035 in *Below 2°*, before accelerating more rapidly over the second half of the outlook. Industry and transport both electrify more rapidly than in *Current Trajectory*, together accounting for around 60% of the higher level of demand in 2050. But the biggest single contributor to higher electricity demand than in *Current Trajectory* comes from much higher production of green hydrogen, which alone accounts for almost 15% of total power used by 2050 (see pages 64-65).

Regional pattern of growth

Most of the growth in power demand over the coming decade in *Current Trajectory* occurs in China and in other emerging economies. China's electricity demand rises by around 5,000TWh between 2023 and 2035, accounting for 40% of the global increase in generation. Power demand in India also increases significantly, growing by more than 1,500TWh – an increase of around 85% relative to 2023. Together, China, India and other emerging economies account for more than three-quarters of the total increase in electricity demand between 2023 and 2035 in *Current Trajectory*.

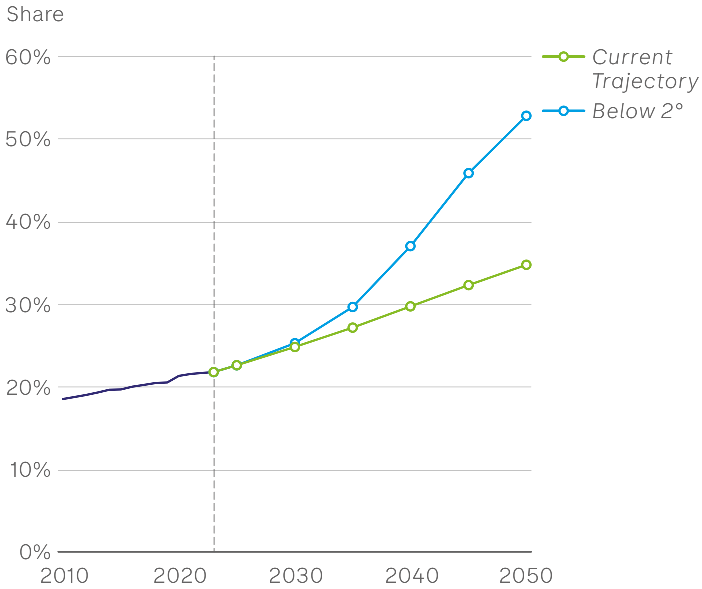
After more than 15 years of broadly flat demand, power consumption also rises in developed economies, albeit by much less than in emerging economies, as electrification of industry, buildings and transport gathers pace.

US data centres

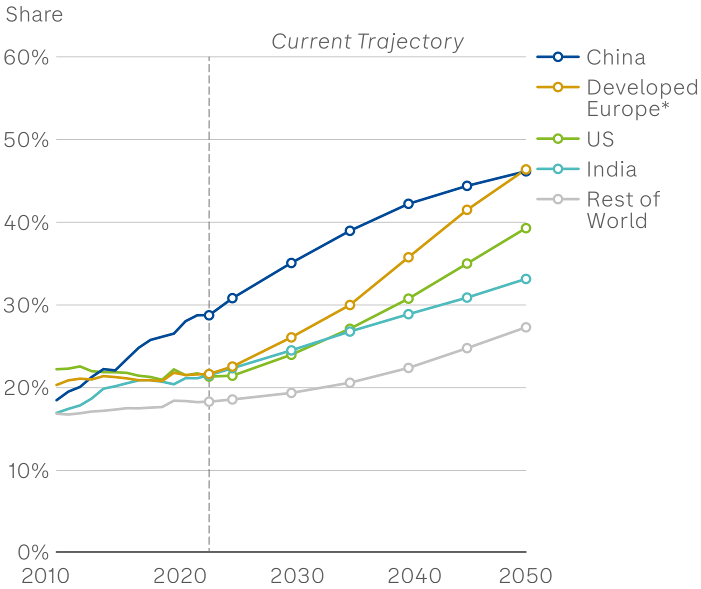
In the US, growing power demand from data centres plays a much more significant role than at a global level, accounting for around 40% of the total increase in electricity demand between 2023 and 2035 in *Current Trajectory*.

The global energy system continues to electrify

Electricity's share of total final consumption



Electricity's share of total final consumption by region



*Includes the EU, Iceland, Norway, Switzerland and the UK.

The share of the world's final energy use that is electrified continues to rise, led by China but with the EU and other countries catching up later in the outlook.

Electricity use by sector

The importance of electricity in global final energy use continues to rise over the coming decade in *Current Trajectory*, accounting for roughly two-thirds of the growth in TFC. That is led by the buildings sector, as the use of electrical appliances rises in emerging economies and heat pumps for space heating are more widely adopted, and by the industrial sector, as more processes are electrified. Electricity's share in road transport also grows but remains less than 10% of the sector's total energy consumption in 2035.

Electricity's share of TFC continues to rise over the second half of the outlook in *Current Trajectory*, reaching around a third of global energy consumption by 2050. The sharpest increase occurs in road transport, as the composition of the global vehicle parc shifts more materially towards electric vehicles: by the end of the outlook, electricity accounts for almost 30% of energy consumption in road transport.

Electrification occurs at a much faster pace in *Below 2°*, reflecting greater policy support and incentives to decarbonize, with the share of electricity in TFC rising to over 50% by 2050. The greatest scope for electrification is in the buildings sector, where the share reaches almost 80%, with the additional growth relative to *Current Trajectory* driven by more rapid adoption of heat pumps and a greater phaseout of inefficient traditional biomass in emerging economies.

Electrification in different regions in *Current Trajectory*

The steady rise in electricity's share of energy consumption masks different trends across countries and regions.

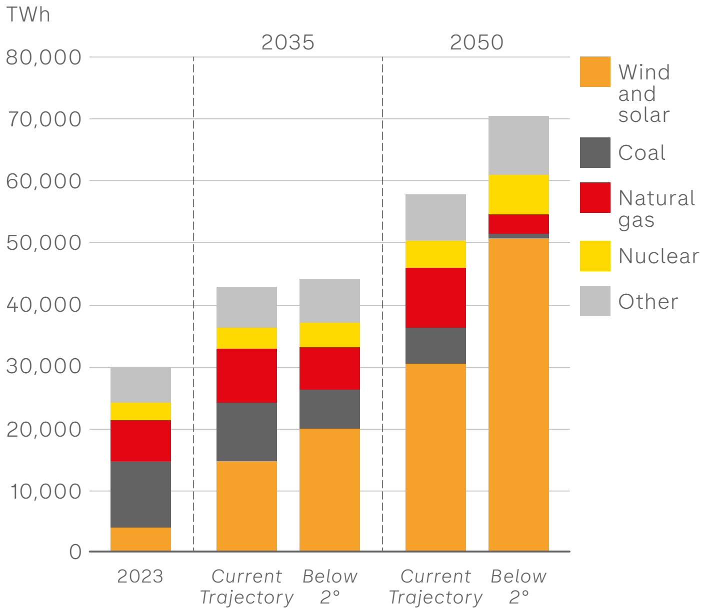
China begins the outlook with a significantly higher electrification share than many other countries, reflecting both the country's desire to limit fossil fuel imports, and also the high share of manufacturing in the Chinese economy, which tends to be much more electrified than, for example, the transport sector. The share of electricity in China's energy consumption continues to rise, increasing from 29% in 2023 to almost 40% by 2035.

The US, Europe and India's pace of electrification has lagged that of China in the past, with electricity's share in consumption in 2023 a little above 20% in all three. Those shares all rise over the coming decade, but more slowly than in China, such that the difference in the degree of electrification between China and these economies widens further.

Over the second half of the outlook, however, the pace of electrification in Europe picks up more rapidly, to reach levels similar to that in China, at around 45% of total consumption, by 2050. That is driven by very rapid electrification of European road transport, with the share of electricity rising from a little over 10% in 2035 to more than two-thirds by 2050. Electrification also accelerates in the US, but more slowly, with its share of TFC rising to a little below 40% by the end of the outlook.

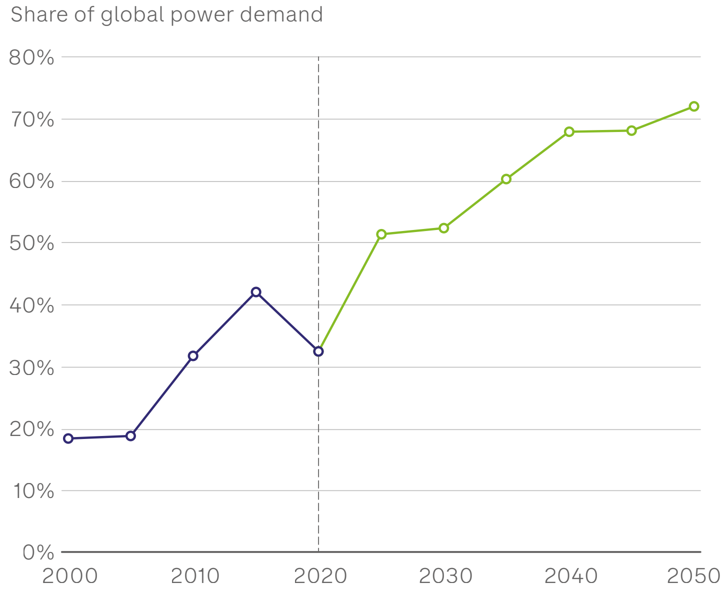
Growing electricity demand is mostly met by rapid increases in wind and solar power

Electricity generation by source



Other includes bioenergy, hydro, geothermal, oil and hydrogen fired power generation.

Power demand of countries in 'power sector substitution' in *Current Trajectory*



Data points correspond to five-year averages centred on each year shown. See Annex for details on the methodology for power substitution.

Rising electricity demand is largely met by rapid growth of wind and solar power as countries continue to decarbonize their power sectors.

Wind and solar generation

Rapid growth in wind and solar power generation meets over 80% of the increase in electricity demand out to 2035 in *Current Trajectory*, with half of that occurring in China. Solar generation continues to grow more rapidly than wind power, reflecting faster declines in costs, shorter deployment timelines and greater policy support. This large expansion in wind and solar means that power systems need to enhance their resilience to increasing generation from variable sources. Delivering this resilience will require a range of measures including increased flexible generation and energy storage, greater demand-side responsiveness, more advanced grid technologies and enhanced interconnections. See pages 58-59 of *Energy Outlook* 2024 for more discussion of these issues.

Low carbon power generation is further boosted by steady growth in hydropower, which rises by around 25% by 2035, and by some renewed growth in nuclear generation (see pages 58-59). Generation from geothermal rises but remains a very small proportion of total power generation.

Decline in coal generation

The main counterpart to the rising share of low carbon generation over the coming decade is a marked decline in the share of coal power, which falls from around 35% of global generation in 2023 to a little above 20% in 2035, driven primarily by declining coal use in China (see pages 46-47).

In contrast, the level of natural gas-powered generation rises by around 30% between 2023 and 2035, such that its share of total global generation falls only slightly. A third of that increase in gas-powered generation is in the US, with most of the rest in emerging economies.

Power generation post-2035

These trends largely continue over the second half of the outlook in *Current Trajectory*, with wind and solar power reaching over half of total global electricity generation by 2050. That reflects accelerating deployment across a range of emerging economies as financing challenges and infrastructure limitations ease. Natural gas generation rises further over the second half of the outlook, with that growth entirely accounted for by (non-China) emerging economies.

In *Below 2°*, coal is displaced much more rapidly than in *Current Trajectory* and natural gas generation declines from the early 2030s onwards. These declines are primarily driven by even more rapid deployment of wind and solar power, which accounts for 70% of global generation by 2050.

Power sector addition to substitution

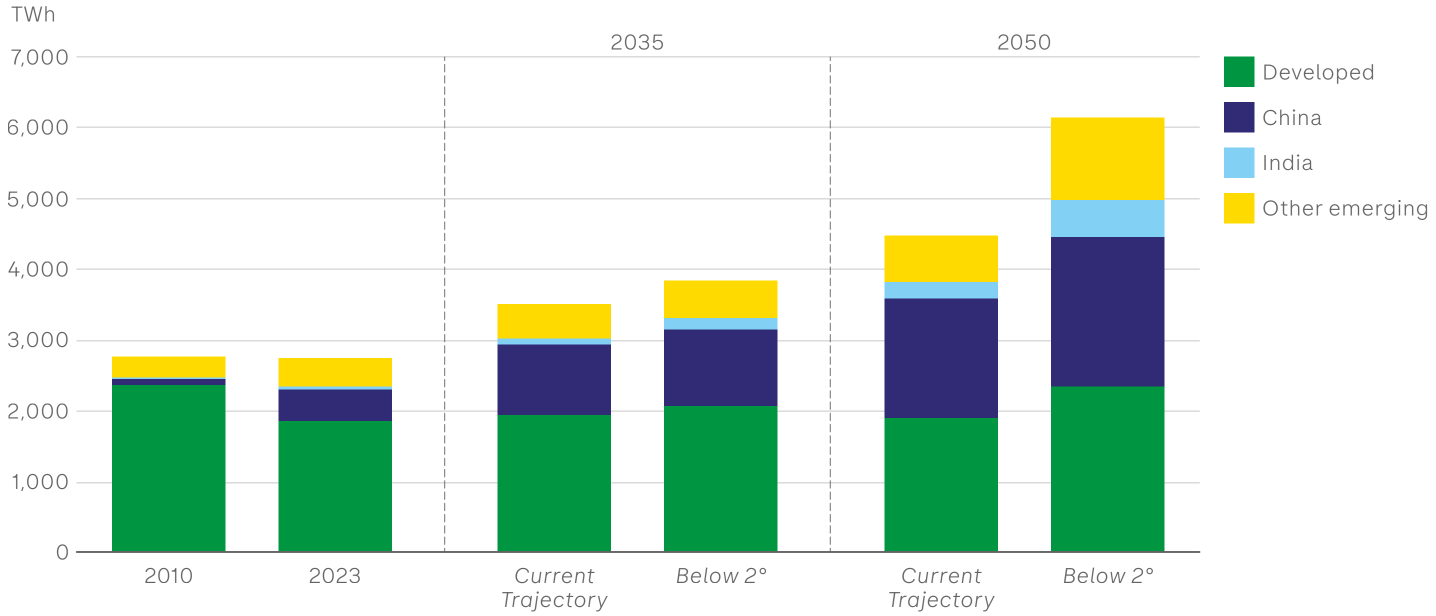
An increasing number of countries are moving into 'power sector substitution', with rapid deployment of solar and wind power meaning that fossil-based generation is declining. That is already the case for regions accounting for around 40% of global electricity demand.

In *Current Trajectory* that share rises to around 60% of global power demand by 2035, as countries including China increase renewables generation sufficiently rapidly to more than meet their additional power needs.

By 2050, around 70% of global power demand is in countries or regions that are in this 'substitution' phase. That shift happens even more rapidly in *Below 2°*, so that all regions enter the substitution phase before 2050.

Nuclear power generation helps to meet growing demand for firm, low carbon electricity

Nuclear electricity generation by region



Nuclear power generation rises throughout the outlook, as countries seek non-variable, low carbon electricity that enhances their energy security and supports climate goals.

Nuclear power in *Current Trajectory*

Nuclear power generation has risen only a little over the past two decades, such that its share of global electricity generation has fallen from over 15% in 2000 to below 10% in 2023. Over the coming decade, however, nuclear generation begins to rise in *Current Trajectory*, growing by almost 30% by 2035, boosted by countries' desire to produce firm, low carbon power that enhances their energy security needs and supports their climate goals. Given the rapid growth in electricity demand, however, nuclear power's share of total generation nonetheless declines slightly, to around 8% in 2035.

Growth in nuclear generation out to 2035 in *Current Trajectory* is dominated by additional capacity coming online in China, which accounts for around 70% of growth in global nuclear generation. As a result, China surpasses the US as the world's largest producer of nuclear power in the early 2030s. China's nuclear expansion continues to be underpinned by long-term planning, streamlined state financing and an established delivery model, which together enable relatively cost-effective deployment.

The remainder of the growth in global nuclear generation over the coming decade in *Current Trajectory* takes place through new capacity coming online in India and a range of other emerging economies, together with some further restarts of plants in Japan. US nuclear generation is flat over the coming decade, sustained by lifetime extensions of most existing reactors and some limited restarts.

Nuclear generation rises at a similar pace over the second half of the outlook in *Current Trajectory*, with that growth continuing to be dominated by China. By 2050, China accounts for around 40% of global nuclear generation, compared with around 15% in 2023. Nuclear power's share of global power generation is broadly stable over the second half of the outlook.

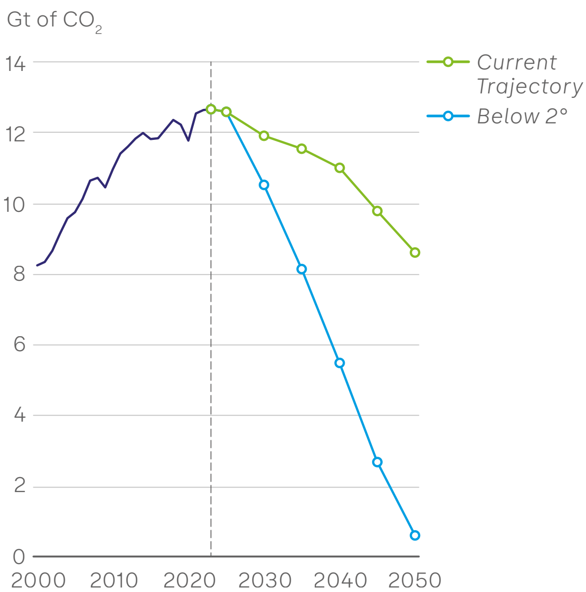
Nuclear power in *Below 2°*

Nuclear generation grows more rapidly in *Below 2°*, reflecting the greater pressure and support to decarbonize power systems in many economies. Given the lengthy lead times required to develop new nuclear plants, much of this growth is concentrated in the second half of the outlook. By 2050 generation has more than doubled from its 2023 level, although its share of total power does not rise above 10%.

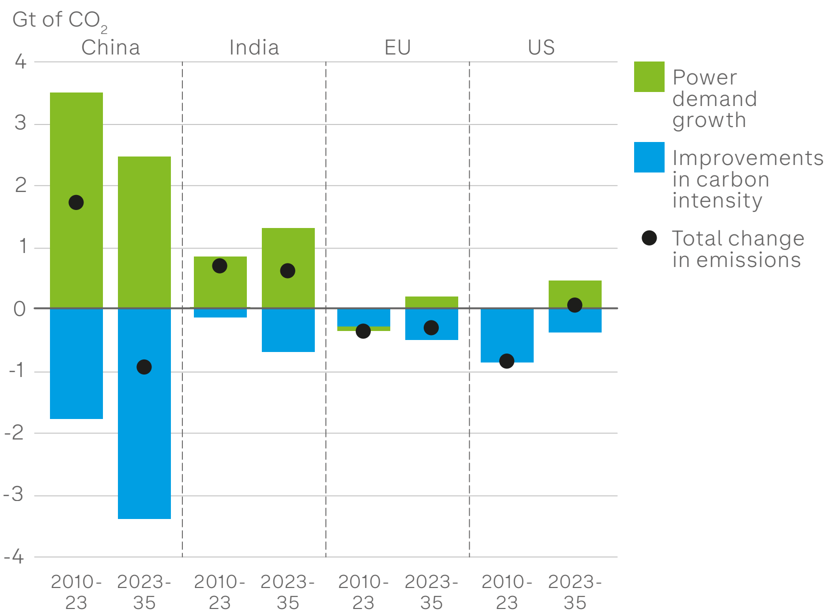
The importance of nuclear power in both scenarios is limited by its relatively high cost compared to other low carbon energy sources, especially wind and solar. Moreover, the capital-intensive nature of nuclear energy means that it is most suited to being operated near continuously as baseload generation. As such, it may be challenging for nuclear to provide the more flexible generation that many grids could require as a complement to rapidly growing wind and solar power.

Emissions from the global power sector fall despite rising electricity demand

Power sector emissions



Decomposition of the changes in power sector emissions in *Current Trajectory*



Global power sector emissions are reported net of removals from all carbon capture and storage (CCS) technologies.

Global power sector emissions fall over the outlook despite growing electricity demand, as wind and solar generation replace coal power.

Power sector emissions in the two scenarios

Emissions from electricity generation currently account for around a third of total global energy system emissions. That share has been broadly flat throughout this century, with power system emissions rising by more than 50% since 2000, roughly in line with energy system emissions as a whole.

That past trend of rising emissions from electricity generation reverses around the start of the outlook period in *Current Trajectory*, despite further rises in power demand. This is enabled by rapid deployment of low carbon electricity outpacing total power demand growth. In other words, the global power system in aggregate moves from 'energy addition' to 'energy substitution' over the coming years (see pages 56-57).

Global power system emissions decline by around a third over the outlook in *Current Trajectory*, even as electricity generation rises by over 90%. The average carbon intensity of electricity generation falls by around two-thirds between 2023 and 2050, driven by the sharply rising share of wind and solar generation and the falling role of coal generation (see pages 56-57).

The fall in power systems emissions is larger still in *Below 2°*, despite even stronger electricity demand growth. Emissions from the sector fall to below 1GtCO_2, a drop of around 95%, representing near total decarbonization of the world's power systems.

Analysing the path of power sector emissions in *Current Trajectory*

The difficulty of decarbonizing power sector emissions depends on the growth in electricity demand.

Chinese and Indian power demand both increase strongly out to 2035 in *Current Trajectory*. And both begin the outlook period with relatively carbon-heavy generation mixes.

Despite that, China's power system emissions fall over the coming decade in *Current Trajectory*, as wind and solar generation rapidly replace coal so that the average carbon intensity of generation falls by almost a half.

India's carbon intensity also declines as renewables deployment rises, but not by enough to offset the 85% growth in power demand. As a result, Indian power sector emissions rise by 600MtCO_2, or around 40%.

Power demand returns to growth in the US and the EU over the next decade, rising by around 30% in each case. In the EU decarbonization of the sector accelerates, such that power sector emissions fall by more than half despite rising generation. The pace of falls in the carbon intensity of US generation slows somewhat, but is still sufficient to offset rising power demand, leading to broadly flat power sector emissions there.

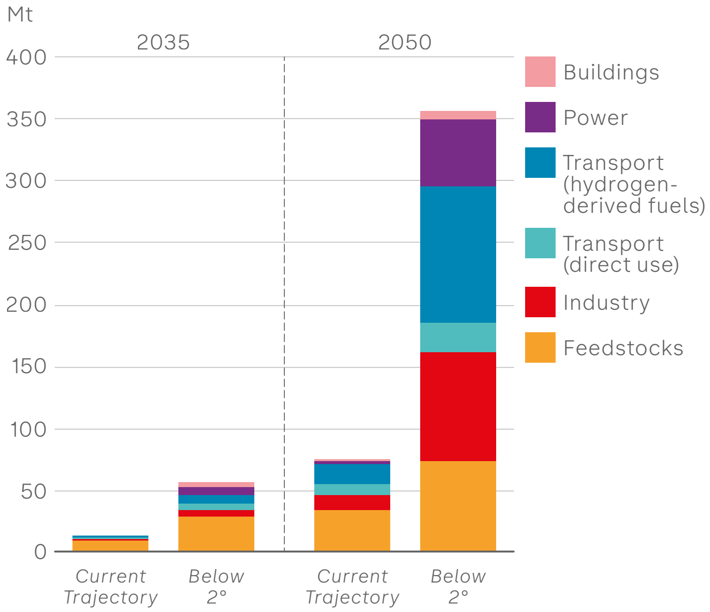
Over the second half of the outlook in *Current Trajectory*, emissions from power generation fall in China, the EU and the US, partly due to slowing power demand growth as efficiency gains accelerate.

India, in contrast, sees a further 65% rise in power demand over this period. Despite that growth, emissions plateau and then begin to decline in the final years of the outlook, enabled by wind and solar power rising to half of total generation by 2050.

Low carbon hydrogen and carbon mitigation and removals

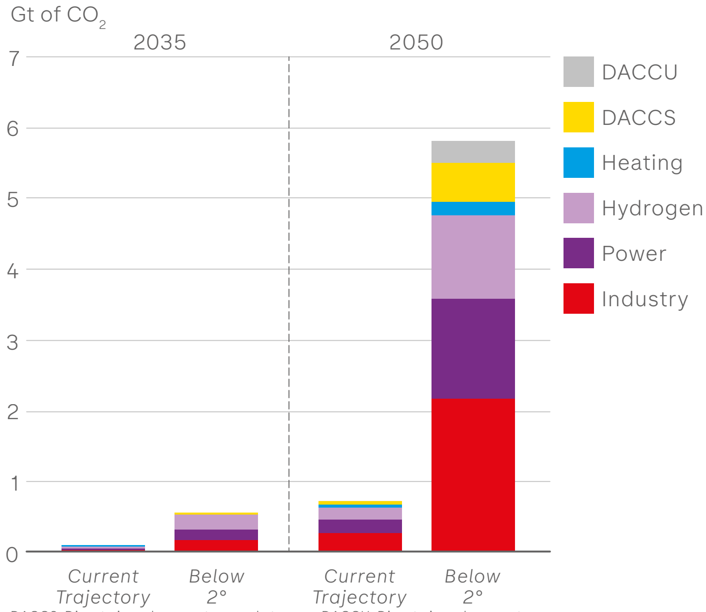
Low carbon hydrogen and CCUS play important roles supporting deep decarbonization pathways

Low carbon hydrogen demand by sector



Transport (hydrogen-derived fuels) includes hydrogen used to produce methanol, ammonia, and synthetic fuels consumed in the transport sector.

Carbon capture, use and storage by sector



DACCS: Direct air carbon capture and storage. DACCU: Direct air carbon capture and use. This includes use as a source of carbon neutral CO_2 for hydrogen-derived fuels such as synthetic jet fuel. Emissions captured from natural gas processing and bioethanol production are not included.

Low carbon hydrogen and CCUS are used to decarbonize hard-to-abate processes and sectors. But their relatively high cost mean that they only reach significant scale in more rapid transition pathways, in which deeper decarbonization options are supported. Even in those types of pathways, much of that expansion occurs in the second half of the outlook.

Low carbon hydrogen

In *Current Trajectory*, the use of low carbon hydrogen rises gradually to a little under 15Mt by 2035, from less than 1Mt in 2023. It is mainly deployed as a low carbon alternative to hydrogen derived from fossil fuels – so called 'grey hydrogen' – which is used in the production of ammonia and methanol and in refining. But the higher cost of low carbon hydrogen and limited policy support mean that it has only displaced around 10% of grey hydrogen in 2035.

By 2050, demand for low carbon hydrogen reaches 75Mt per year in *Current Trajectory*. Around half of that demand is replacing the use of grey hydrogen as feedstock, with another third used in the transport sector, to produce hydrogen-derived fuels such as ammonia and methanol for marine transport and for direct use in heavy, long-haul road transport.

Demand for low carbon hydrogen is more significant in *Below 2°*, particularly over the second half of the outlook. In addition to the displacement of the majority of grey hydrogen and meeting higher demand for hydrogen-derived fuels to decarbonize the marine and aviation sectors, low carbon hydrogen is increasingly used to decarbonize high-temperature heat applications, for example in the production of iron and steel (where it is also used as a reducing agent). It also provides long-duration storage and dispatchable supply in some power sectors. Overall demand for low carbon hydrogen reaches around 350Mt per year by 2050.

Carbon capture, use and storage

As with low carbon hydrogen, CCUS deployment is limited in *Current Trajectory*, reaching less than 100MtCO_2 annually in 2035 and remaining below 1GtCO_2 even by 2050. That means that only 2% of energy system emissions at the end of the outlook period are being captured in *Current Trajectory*.

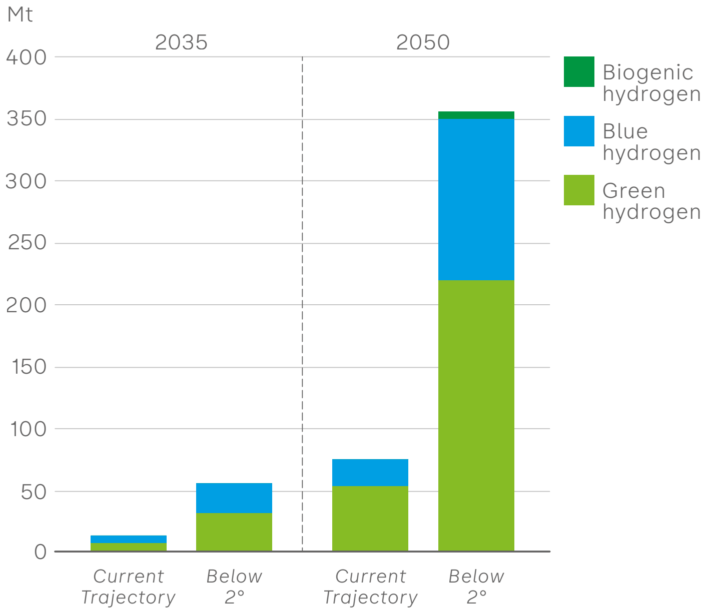
CCUS plays a larger role in *Below 2°*, where more forceful policies to accelerate decarbonization mean that the extra costs of decarbonizing industrial processes and abating fossil fuel use are absorbed. Even then, long project lead times mean that most of the deployment takes place in the second half of the outlook, reaching around 6GtCO_2 per year by 2050.

In the late 2030s and 2040s, CCUS plays a key role in the decarbonization of harder-to-abate industrial processes, especially the cement sector, accounting for around 2GtCO_2 of the total by 2050. It also helps provide a source of low-emission-dispatchable power as a complement to renewables (around 1.5GtCO_2 in 2050), with another 1Gt of capture associated with the production of blue hydrogen.

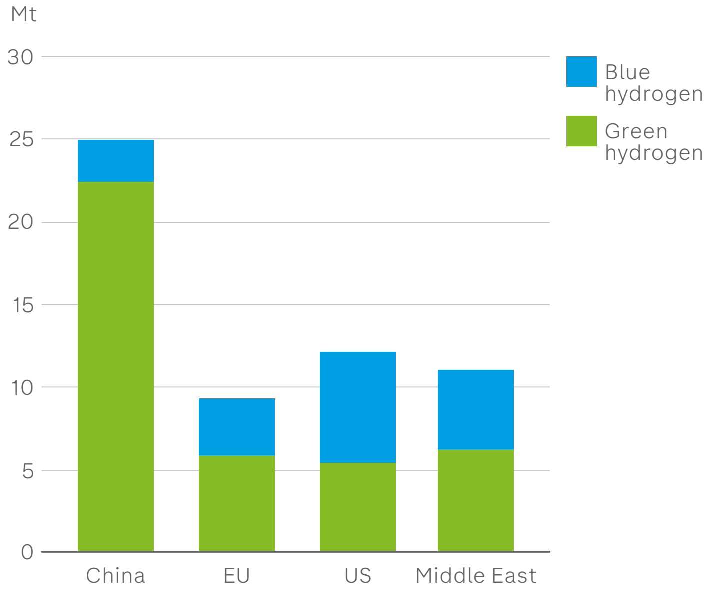
The use of CCUS supports some limited continued use of natural gas and coal in *Below 2°*. But the scale of natural gas and coal combined with CCUS in 2050 is a small fraction of consumption levels in 2023. CCUS complements the substantial decline of fossil fuels needed in rapid decarbonization pathways: it does not provide an alternative to those declines.

The mix of green and blue hydrogen is driven by the regional pattern of production

Low carbon hydrogen production



Low carbon hydrogen production in *Current Trajectory* in 2050



Low carbon hydrogen production is primarily a combination of green hydrogen – made via electrolysis of water using renewable power – and blue hydrogen – made from natural gas (or coal) with the associated carbon emissions captured and stored. Given the high cost of transporting hydrogen, the global balance between green and blue hydrogen is determined by the relative costs of production in different regions, together with the relative size of the different regional markets.

Green and blue hydrogen production

The relative costs of blue and green hydrogen differ materially between regions. For regions that have domestic natural gas (or coal) resources and suitable CO_2 storage sites, blue hydrogen will tend to be most cost advantaged. But for others without those resources, green hydrogen may be preferable, especially if they have access to plentiful renewable power.

In *Current Trajectory*, green hydrogen accounts for around 70% of low carbon hydrogen in 2050. This mix is driven primarily by production patterns in four key regions, led by China, together with the US, Middle East, and the EU, which together account for over three-quarters of global production in 2050.

China

China produces around 25Mt of low carbon hydrogen per year by 2050 in *Current Trajectory*, accounting for around a third of global production.

The vast majority (90%) of this Chinese production is in the form of green hydrogen. This reflects both China's ability to leverage its extensive renewable energy capacity to provide a plentiful low-cost source of low carbon electricity and its relatively limited domestic natural gas resources.

Rising production of green hydrogen over the outlook allows China to utilize its mass-manufacturing capabilities to bring down the cost of electrolyzers over time. Some other elements of green hydrogen costs, however, for example relating to balance of plant, infrastructure and storage, are harder for manufacturers to reduce through learning and technological advancement.

EU

The EU's production of low carbon hydrogen is also weighted towards green hydrogen. This skew is underpinned by the EU's dependency on imports of natural gas, which both increases the cost of blue hydrogen and raises the EU's exposure to the energy security risks associated with high dependency on imported energy.

US and Middle East

The other two main hydrogen-producing regions in *Current Trajectory* – the US and the Middle East – have access to domestic supplies of natural gas and suitable sites for CO_2 storage. For these regions, blue hydrogen starts the outlook with a cost advantage over green, but this cost differential diminishes over the outlook as the relative cost of green hydrogen falls, helped by falling costs of both electrolyzers and renewable energy. By 2050 in *Current Trajectory*, there is a broadly equal split between blue and green hydrogen in both regions.

More balanced mix in *Below 2°*

The stronger growth of low carbon hydrogen in *Below 2°* – reaching around 350Mtpa by 2050 – means production is more broadly-based globally, although China is still the largest single producer. This wider geographical spread results in a less skewed mix between green and blue hydrogen, reflecting the persistent – albeit diminishing – cost advantage of blue hydrogen in many regions.

Sensitivities

Exploring the implications of three key issues affecting the energy transition

Increased geopolitical fragmentation

Sustained weakness in energy efficiency

Delayed and disorderly transition

By varying key aspects of *Current Trajectory* and *Below 2°* it is possible to explore the impact of other issues and uncertainties affecting the outlook of the energy system.

The two scenarios used in the *Outlook* – *Current Trajectory* and *Below 2°* – help to explore some of the uncertainties surrounding the evolution of the energy system stemming from differences in the speed and nature of the energy transition.

But there are many other uncertainties and issues influencing the outlook for global energy.

This section considers three current issues that have the potential to have an important bearing on the future evolution of energy system.

Increased geopolitical fragmentation
(pages 72-77)

There have been significant increases in geopolitical conflicts and tensions in recent years, including the wars in Ukraine and the Middle East, and the greater use of trade sanctions and tariffs. Further escalation in these tensions could lead to increased geopolitical fragmentation, in which countries reduce their exposure to international trade and become increasingly self-reliant, with significant implications for the global energy system.

Sustained weakness in energy efficiency
(pages 78-81)

Improvements in energy efficiency – reducing the amount of energy needed to produce a given amount of goods and services – have an important bearing on the size and nature of the energy system. The pace of improvement in energy efficiency over the past five years or so has been materially weaker than its historical average. If this weakness persists, it could have significant implications for both the overall level of energy demand and the mix of fossil and non-fossil fuels.

Delayed and disorderly transition (pages 82-85)

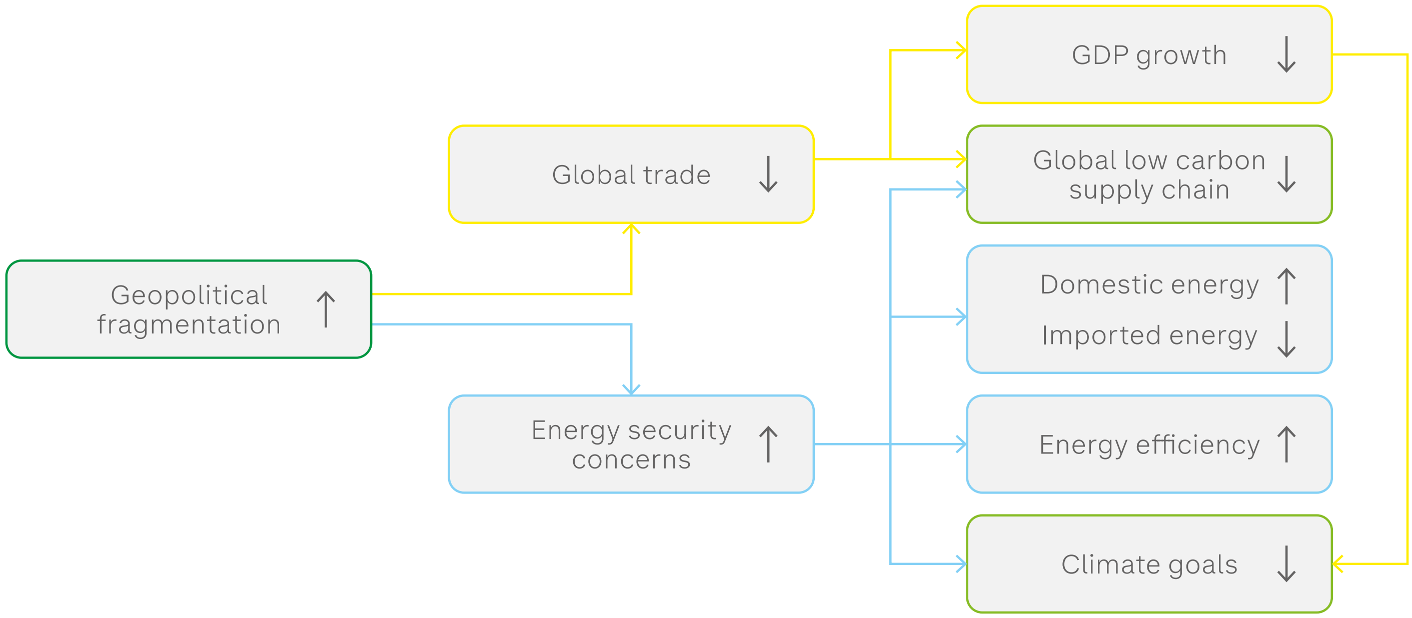
Carbon emissions from energy and industrial use have continued to increase, growing at an average annual rate of 0.6% over the past five years. In doing so, the world is gradually exhausting carbon budgets consistent with limiting global temperature rises. The longer the world remains on its current pathway, the greater the risk of there being a costly and disorderly transition if the world wishes to remain within a given carbon budget.

Sensitivity analysis

The possible implications of these three issues for global energy are investigated by undertaking some 'sensitivity analysis' to the main scenarios. This type of analysis has the benefit that most elements of the existing scenarios are assumed to be unchanged, allowing the key features of each of the issues to be isolated and explored.

In reality, other elements of the energy system would not be completely unchanged if any of these three alternative issues were to materialize. As such, the results of the sensitivity analysis should be viewed as illustrative of the broad ways in which each issue may impact the global energy system, rather than as providing a complete characterization or detailed quantification.

Main economic channels through which increasing levels of geopolitical fragmentation might impact the energy system



A pronounced and sustained increase in geopolitical fragmentation in which countries become increasing self-reliant, would be likely to both slow the growth of international trade and increase countries' focus on their energy security, with implications for the level and mix of energy demand.

Weaker international trade leading to lower GDP

Increased geopolitical tensions and conflicts might dampen the growth of international trade as supply chains are moved onshore or are restricted to countries and regions seen as most politically stable or aligned.

Reduced growth in international trade would be likely to weigh on global economic growth by limiting the scope for increased specialization and competition and by slowing the rate at which new technologies and best practices are diffused globally.

This drag on economic growth is likely to be concentrated in economies which are most dependent on international trade.

Increased energy security

In a similar vein, increased geopolitical fragmentation may also cause countries to increase the importance they attach to their energy security as they seek to reduce their dependency on imported energy and energy technologies.

This might cause countries and regions to react in three main ways:

- Placing an additional cost premium or penalty on imported energy relative to domestically produced energy;
- Developing their own supply chains or aiming for greater diversification of supply for key energy technologies, including for green technologies such as photovoltaic cells and batteries, rather than relying on international or geographically highly concentrated supply chains;
- Increasing the weight placed on improving energy efficiency, as this reduces the need for all types of energy and so further bolsters energy security.

Less weight on climate and sustainability

Increased geopolitical fragmentation might also lead some countries to place less weight on climate and sustainability goals. This partly reflects the nature of the so-called energy trilemma, as countries seek to balance the competing needs for their energy systems to provide secure, affordable, and sustainable energies. If countries placed greater priority on energy security, that must be counter-balanced by placing less combined weight on the other two dimensions.

The potential for reduced emphasis on sustainability and climate goals may be exacerbated by slower economic growth stemming from weaker net trade. That would mean countries have less wealth and resources to devote to decarbonization, and especially to higher-cost, low carbon energies and technologies such as low carbon hydrogen, SAF, and CCUS.

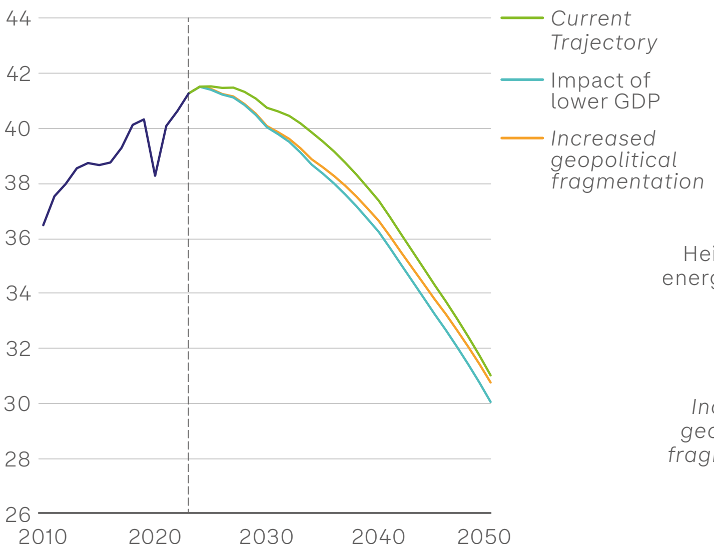
Level and mix effects

The impact of weaker growth in international trade and GDP is likely to affect primarily the overall level of energy demand, whereas the other channels, stemming largely from increasing energy security concerns, would mostly impact the mix of different types of energy within overall demand.

Increased geopolitical fragmentation reduces overall energy demand and has offsetting impacts on the fuel mix

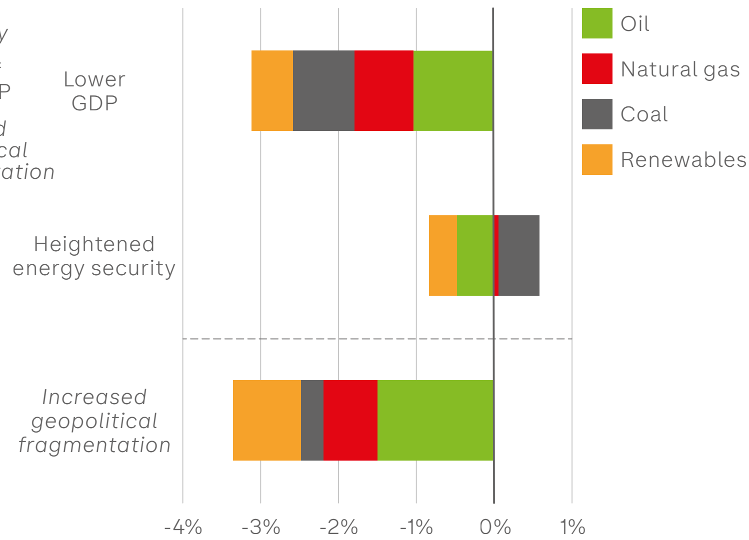
Carbon emissions

Gt of CO_2e



Change in global primary energy by channel

Percentage difference vs *Current Trajectory* in 2035



For more details, see the Annex on the fragmentation modelling approach.

The impact of increased geopolitical fragmentation on the growth of international trade and GDP lowers energy demand, while heightened energy security concerns have different, and in some cases offsetting, impacts on the fuel mix.

Economic channels

The potential impact of increased geopolitical fragmentation can be explored by modifying *Current Trajectory* to illustrate the main economic channels through which such an increase might impact the energy system[6]. In particular:

- The pace of GDP growth out to 2035 is reduced to reflect the impact of weaker global trade, with this impact concentrated in countries and regions most exposed to international trade;
- A cost 'premium' is added to imported energy to reflect countries' increased preference for domestically produced rather than imported energy;
- The levelized cost of electricity (LCOE) generated by renewable energy is increased to capture countries' increased preference for domestic supply chains for renewable technologies, reducing their dependence on the lowest-cost producers;
- The rate of improvement in energy efficiency is increased, driven by the higher cost of imported and renewable energy;
- The pace of adoption of high-cost, low carbon energies and technologies – low carbon hydrogen, SAF, and CCUS – is delayed in response to the lower weight attached to climate and sustainability aims.

The combined impact of these alternative assumptions is shown in the *Increased geopolitical fragmentation* sensitivity. The size and duration of the different channels are uncertain and would depend on the circumstances causing the increase in geopolitical fragmentation. As such, the sensitivity analysis should be seen as illustrative of the broad size and nature of the impacts, rather than as a detailed quantification.

Slower GDP growth

The slower growth in global trade and hence GDP lowers the amount of energy needed to fuel the global economy. This lower level of energy demand leads to a corresponding reduction in carbon emissions, relative to *Current Trajectory*.

Energy security

The other channels, stemming largely from heightened concerns about energy security, operate primarily through changing the fuel mix.

The increased preference for domestic relative to imported energy leads to a shift away from oil and natural gas – which are the most heavily traded fuels – towards renewables and coal, which tend more to be produced and consumed domestically.

In contrast, the higher cost of renewable energy and the lower weight attached to climate and sustainability aims weighs on low carbon energy and favours oil and coal.

The net impact of these impacts at a global level is to slightly increase the share of coal at the expense of oil and renewables, with the share of natural gas little changed.

This shift increases the carbon intensity of the fuel mix, partially offsetting the reduced carbon emissions associated with the lower level of energy demand.

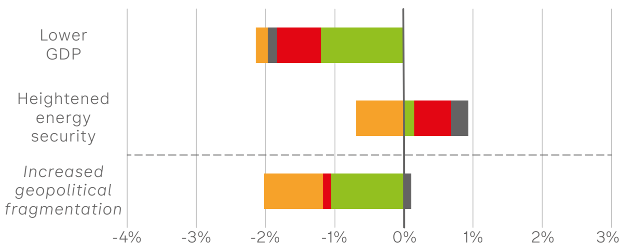
The net impact is for *Increased geopolitical fragmentation* to have a marginally faster fall in global carbon emissions relative to *Current Trajectory*, with this difference fading over time as the adverse shift in carbon intensity gradually builds.

[6] Details of these changes are provided on page 96 in the Annex.

The impact of *Increased geopolitical fragmentation* depends on the structure of the energy systems in different countries

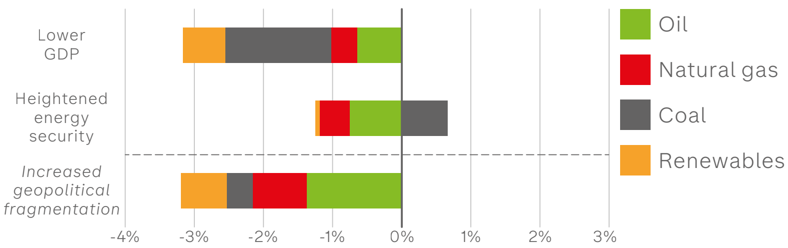
Change in the US's primary energy by channel

Percentage difference vs *Current Trajectory* in 2035



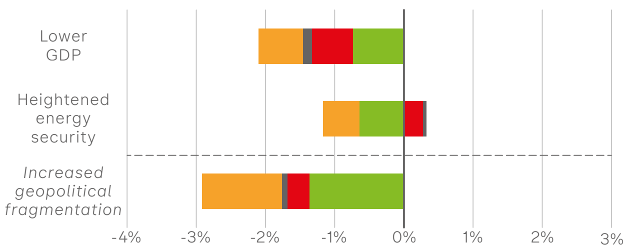
Change in China's primary energy by channel

Percentage difference vs *Current Trajectory* in 2035



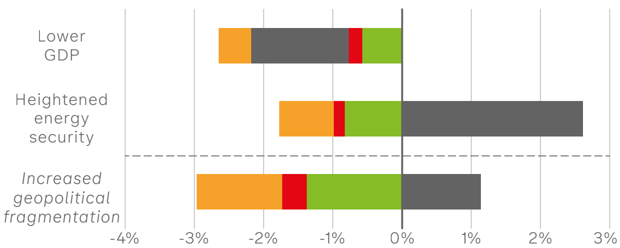
Change in the EU's primary energy by channel

Percentage difference vs *Current Trajectory* in 2035



Change in India's primary energy by channel

Percentage difference vs *Current Trajectory* in 2035



The implications of *Increased geopolitical fragmentation* differ across countries depending on the structure of their energy systems.

These differences can be explored by considering four energy 'archetypes', illustrated by the US, China, the EU and India.

US: energy exporter

The US is a net energy exporter and so is not affected in the same way as energy importers wishing to reduce their dependence on imported energy in response to heightened energy security concerns. Moreover, the US is a relatively less trade-intensive economy and is therefore less exposed to the impact of weaker net trade.

As a result, the proportionate reduction in US GDP and hence energy demand is smaller than the global average. The change in the US fuel mix is driven by the higher cost of renewable energy and the delay in the adoption of higher-cost, low carbon technologies. Together these channels reduce the share of renewable energy, with a corresponding boost to the role of fossil fuels.

China: energy importer, low-cost producer of green technologies

China is a net energy importer, but as a global leader in producing low-cost green technologies, it is less impacted by a higher LCOE from a greater focus on domestic supply chains for these technologies. China is also highly exposed to international trade and so is more affected by the impact of weaker net trade on economic growth.

The larger impact on China's GDP causes the reduction in its energy demand to be greater than the global average.

China's increased preference for domestic energy increases the share of coal and renewable energy at the expense of imported oil and natural gas. But this boost to renewable energy is broadly offset by the slower adoption of higher cost low carbon technologies. As a result, the reduction in China's energy demand is broadly based across all fuel types but most concentrated in its use of oil and natural gas.

EU and India: energy importers

The EU and India are both net energy importers and both are reliant (to differing degrees) on international supply chains for low carbon technologies. As such, they are exposed to all the various channels stemming from increased energy security concerns.

In the EU, the increased preference for domestic energy reduces the share of oil and natural gas, boosting renewables. But these effects are offset by the increasing cost of renewable energy and the delay in adopting higher cost low carbon technologies. Natural gas benefits from these headwinds to low carbon energy, since it is more easily substitutable for renewables in the EU power sector.

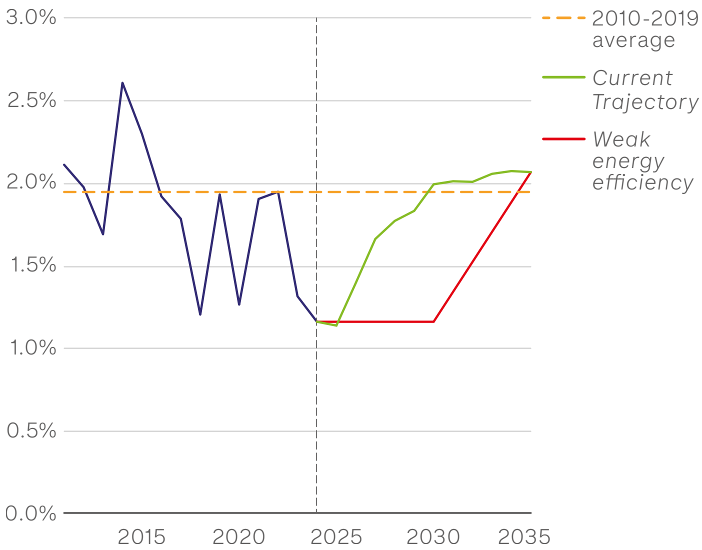
The same qualitative channels operate in India, but the counterpart to the increasing cost of renewable energy and slower adoption of low carbon technologies is concentrated in higher consumption of (domestically produced) coal.

The net impact in *Increased geopolitical fragmentation* is a reduction in the EU's and India's overall energy demands. For the EU, this is concentrated in lower oil and renewable energy, with natural gas less impacted. For India, oil, natural gas, and renewable energy demand fall by broadly similar proportionate amounts, offset by a greater share of coal in its energy mix.

Sustained weakness in energy efficiency gains could lead to a markedly higher outlook for energy demand

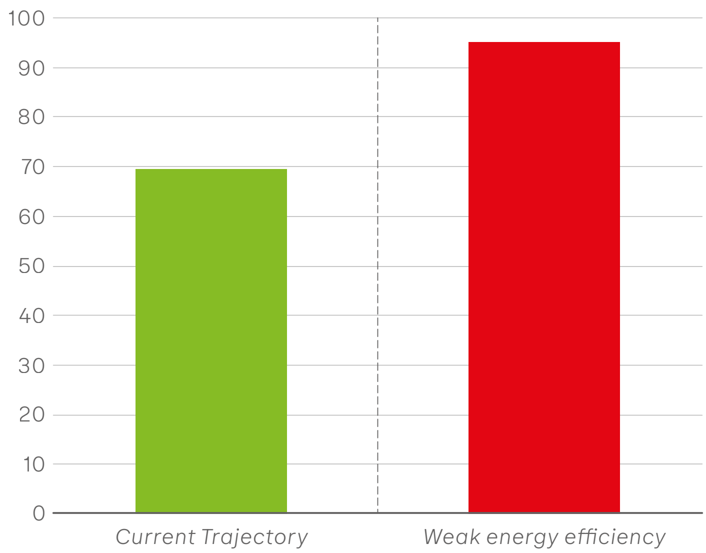
Improvements in global energy efficiency

Annual percentage change



Increase in total final consumption (2023-2035)

EJ



Change in global GDP relative to global final consumption of energy.

Improvements in energy efficiency have slowed in recent years relative to their previous pace of growth. Persistent weakness in efficiency gains could lead to a significantly higher outlook for global energy demand.

Importance of energy efficiency

The pace of improvement in energy efficiency plays a central role in shaping the size and structure of the global energy system.

Indeed, this importance was recognized in the COP28 'UAE Consensus' which committed to doubling the annual rate of energy efficiency improvements by 2030.

Recent weakness in energy efficiency

But the pace of efficiency gains over the past five years has instead slowed: averaging just 1.5% per annum (measured in terms of total final energy consumption), down from 1.9% per annum in the previous 10 years, with particular weakness in both 2023 and 2024.

The causes of this sluggishness in efficiency gains are not well understood. The IEA suggest it may reflect a number of factors including: the increased importance of manufacturing-intensive industries in driving the post-Covid economic recovery in some emerging economies; the increasing intensity of extreme weather events and their impact on energy use; and, more recently, a slowing in investment on projects which improve energy efficiency.[7]

Outlook for energy efficiency

In *Current Trajectory*, the recent weakness in efficiency improvements gradually dissipates, such that by 2030 the pace of efficiency gains is close to its historical average.

But there is considerable uncertainty about this outlook, and more persistent weakness in efficiency gains could have a significant impact on the energy system.

This possibility is explored in the *Weak energy efficiency* sensitivity, which is based on *Current Trajectory* but assumes that the recent weakness in efficiency gains persists until 2030, before gradually converging to *Current Trajectory* (and its previous historical average) by 2035.

Implications for energy demand

This weaker profile for energy efficiency – holding constant all other elements of *Current Trajectory* – leads to a materially stronger outlook for energy demand, with total final energy consumption growing by around 20% between 2023 and 2035, compared with less than 15% in *Current Trajectory*.

[7] IEA Global Energy Review 2025, see https://www.iea.org/reports/global-energy-review-2025 for more details.

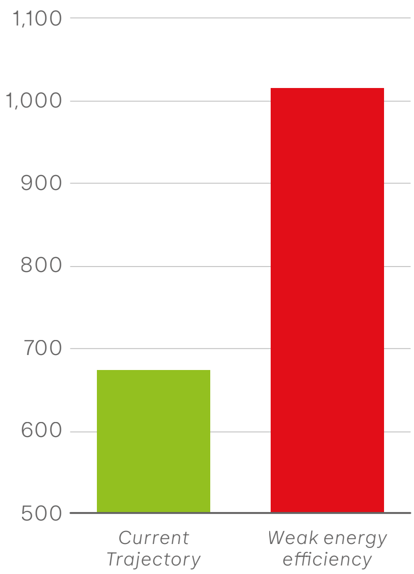
The higher level of energy demand in *Weak energy efficiency* increases fossil fuels and carbon emissions

Growth in oil demand (2023-2035)

Mb/d

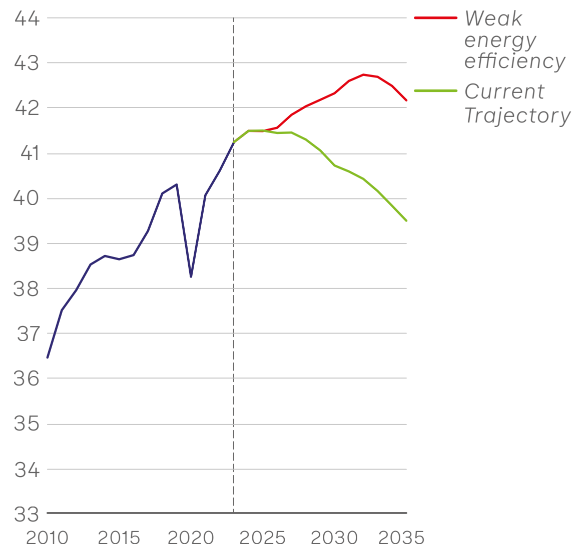
Growth in natural gas demand (2023-2035)

Bcm



Carbon emissions

Gt of CO_2e



The higher level of energy demand in *Weak energy efficiency* is met by additional use of fossil fuels, boosting their near-term growth and leading to a marked increase in the profile for carbon emissions.

Greater cyclicality of fossil fuels

Short term cyclical fluctuations in energy demand are typically largely met by changes in fossil fuel use, rather than by fluctuations in renewables or other non-fossil fuels (see page 98 in Annex for details). The greater responsiveness of fossil fuels to cyclical fluctuations in final energy demand reflects several factors, including:

- The cost structure of renewable projects, with high levels of upfront capital expenditure and low operating costs making them less responsive to cyclical fluctuations;
- Greater scope to vary the production and storage levels of fossil fuels over relatively short periods;
- Many renewable projects are based around long-term regulatory regimes or purchasing agreements.

For these reasons, much of the stronger energy demand associated with a further period of weak efficiency gains is likely to be met by fossil fuels, at least in the near term. Moreover, the difficulty of basing long-term energy investments on fluctuations in efficiency gains means it may take an extended period of weakness until the supply of non-fossil fuels responds materially.

Given these factors, in *Weak energy efficiency* the growth of non-fossil fuels out to 2035 is held unchanged from *Current Trajectory*, with the additional energy demand implied by the slower efficiency gains met by fossil fuels. That is, the additional demand is distributed across oil, natural gas and coal in line with their relative shares in total final energy consumption in *Current Trajectory*.

If it materialized, the sustained weakness of efficiency gains in *Weak energy efficiency* may prompt some additional investment in non-fossil fuels over the next 10 years. As such, the assumption that all the additional growth in energy demand is met by fossil fuels should be viewed as a limiting case.

Boost to fossil fuels

Under these assumptions, the stronger energy demand in *Weak energy efficiency* leads to a significant boost to both oil and natural gas relative to *Current Trajectory*:

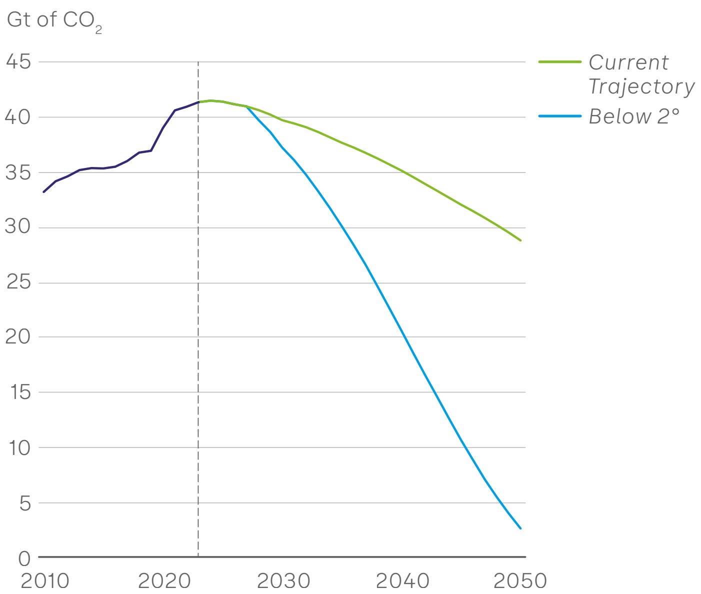
- Oil demand in *Weak energy efficiency* increases by almost 6Mb/d to close to 106Mb/d by 2035, compared to the broadly flat oil demand profile out to 2035 in *Current Trajectory*;
- Natural gas demand increases by over 1,000Bcm by 2035 in *Weak energy efficiency*, compared with less than 700Bcm in *Current Trajectory*.

Deterioration in carbon emissions

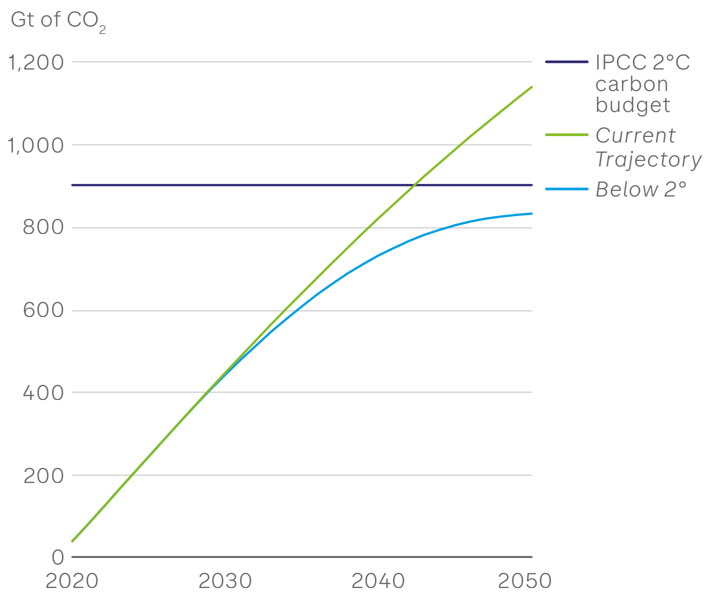
The stronger growth of fossil fuels in *Weak energy efficiency* leads to a marked deterioration in the outlook for carbon emissions. In contrast to the path in *Current Trajectory* in which carbon emissions peak towards the end of this decade and then gradually decline, carbon emissions in *Weak energy efficiency* continue to increase through much of the first half of the 2030s. As a result, carbon emissions in *Weak energy efficiency* in 2035 are still higher than in 2023 and are around 7% higher than in *Current Trajectory*.

Challenges to remaining within a 2°C carbon budget

CO_2 emissions



Cumulative CO_2 emissions, 2020 onwards



Includes emissions from AFOLU and excludes methane emissions from energy.

Carbon emissions have continued to rise. The longer the energy system remains on its current pathway, the harder it will be to remain within a 2°C carbon budget.

Climate science suggests that average global temperature rises depend on cumulative emissions of greenhouse gases. In that context, the IPCC provides estimates of carbon budgets consistent with different probabilities of limiting average global temperature rises to different levels.

2°C carbon budget

The IPCC estimates that for a high (83%) probability of limiting global temperature rises to 2°C, the remaining carbon budget is around 900GtCO_2 (measured from the beginning of 2020). This budget estimate includes anthropogenic CO_2 emissions from agriculture, forestry and other land use (AFOLU), but excludes the global warming effects from non-CO_2 emissions (such as methane) whose global warming effects are accounted for separately when estimating the CO_2 budget.[8]

It should be recognized that the IPCC estimates of carbon budgets are uncertain. For example, if the assessed probability of temperature rises remaining within 2°C is reduced from 83% to 67%, the estimated remaining carbon budget increases from 900GtCO_2 to 1,150GtCO_2. This uncertainty, and the broader uncertainties around the links between emissions and average temperature rises, mean that any analysis based on estimates of carbon budgets should be viewed as only illustrative.

Adjusting the emission pathways

To compare the carbon emissions implied by *Current Trajectory* and *Below 2°* with the IPCC 2°C carbon budget, the emission pathways implied by the scenarios are adjusted to include IPCC estimates of AFOLU-related emissions and to exclude estimates of methane emissions associated with the production, transportation and distribution of fossil fuels and from the incomplete combustion of traditional biomass (see page 100 in the Annex).

The adjusted emissions pathway for *Below 2°* suggests that, given the low level of net emissions in 2050 and the pace at which they are declining, cumulative carbon emissions in *Below 2°* are likely to stay within the IPCC 2°C carbon budget.

Risk of exceeding 2°C carbon budget

In contrast, cumulative carbon emissions in *Current Trajectory* exceed the IPCC 2°C carbon budget in the early 2040s.

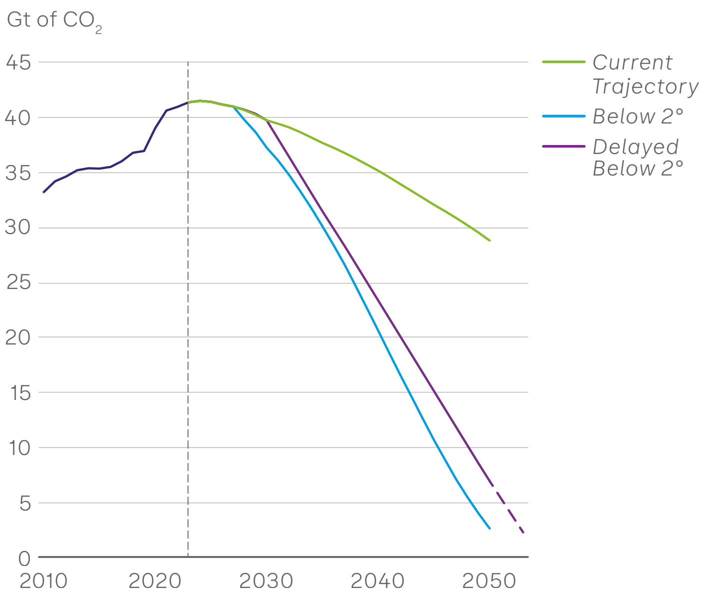
This suggests that the longer the world remains on a pathway like *Current Trajectory*, the harder it would be to stay within a 2°C carbon budget. This raises the risk that an extended period of delay could increase the economic and social cost of remaining within a 2°C budget.

This risk is explored in an alternative *Delayed and disorderly* sensitivity.

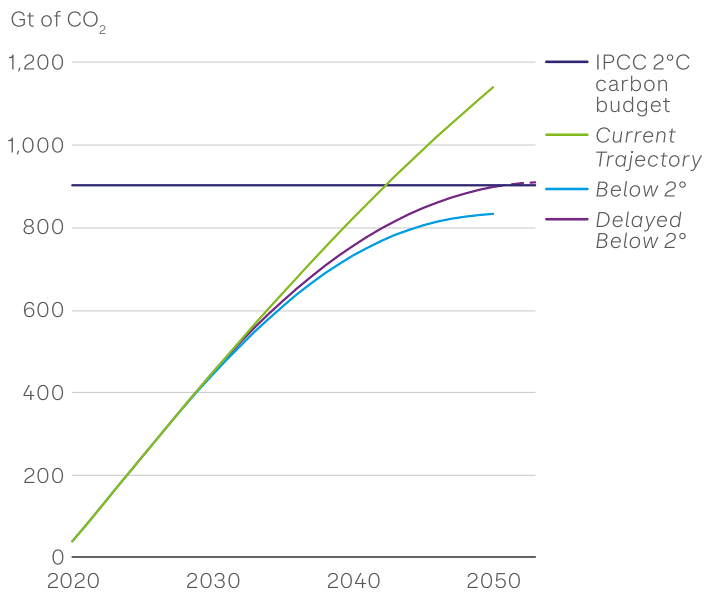
[8] See Table SPM.2 | Estimates of historical carbon dioxide (CO_2) emissions and remaining carbon budgets. IPCC, 2021: Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.

Delaying the energy transition could lead to a costly and disorderly adjustment pathway

CO_2 emissions



Cumulative CO_2 emissions, 2020 onwards



For more details, see the Annex on the modelling approach to *Delayed Below 2°*.

If the move to a faster decarbonization pathway is delayed beyond the early 2030s, it would be increasingly difficult to meet a 2°C carbon budget without incurring a costly and disorderly transition.

Delayed and disorderly

The *Delayed and disorderly* sensitivity assumes that the global energy system moves in line with *Current Trajectory* for a period, after which sufficient polices and actions are undertaken to bring about an accelerated fall in carbon emissions consistent with meeting a 2°C carbon budget.

Delayed and disorderly also assumes that there is a maximum speed at which the energy system can decarbonized in an 'orderly' way: that is, without having to resort to policies and actions that have substantial and widespread economic and social costs.

The maximum pace of an 'orderly' transition is uncertain and would depend on the circumstances that trigger the decision to pursue an accelerated energy transition, and on the technologies available at that time that might help enable a rapid decarbonization.

'Orderly' transition

For illustrative purposes, *Delayed and disorderly* assumes that the maximum pace of an 'orderly' transition can be approximated by the speed of decarbonization in *Below 2°*.

This stylised assumption suggests that the global energy system could not continue along the *Current Trajectory* pathway much beyond the early 2030s and still be able to bring about an orderly transition consistent with meeting a 2°C carbon budget.

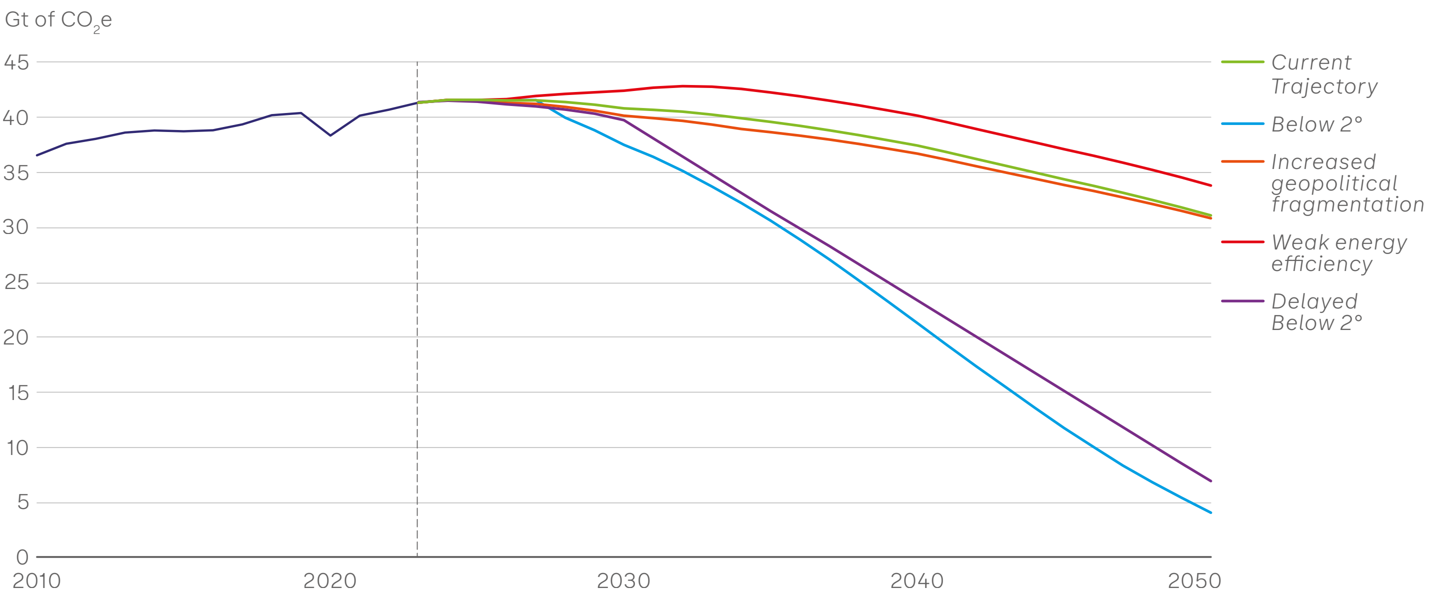
'Disorderly' transition

This rough approximation suggests that if a move to an accelerated transition is delayed beyond the early 2030s, it would be increasingly hard to stay within a 2°C carbon budget without the subsequent need for costly – or 'disorderly' – measures.

These measures – which could take many different forms – would need to rapidly reduce or curtail the use of unabated fossil fuels and highly emitting activities, in order to further accelerate the speed of decarbonization.

Comparing the three sensitivities

Carbon emissions



Delayed Below 2° includes emissions from AFOLU but excludes methane emissions from energy.

Comparing the three sensitivities with the main scenarios highlights the importance of the pace of energy efficiency gains in influencing the speed of the energy transition.

Comparing the three sensitivities with *Current Trajectory* and *Below 2°C* highlights three notable observations.

Weak energy efficiency gains

The most striking is the importance of energy efficiency in influencing the speed of the energy transition. Even though *Weak energy efficiency* assumes that the recent weakness in efficiency gains persists for only around five years longer than in *Current Trajectory*, this leads to a marked deterioration in the outlook for carbon emissions.

A key factor driving this impact is the recognition that fossil fuels, rather than renewables and other forms of low carbon energy, will tend to be most affected by cyclical fluctuations in efficiency gains.

This greater cyclicality of fossil fuels is also important when interpreting the pace of the energy transition over the past five years or so, during which efficiency gains have been historically weak.

If energy efficiency had increased in line with its previous historical average over this period, and the growth of non-fossil fuels had been unchanged, with the weaker growth in total final energy consumption by fossil fuels, then the cumulative growth in both oil and natural gas over this period would have been reduced by more than two-thirds. And carbon emissions would have been broadly flat, rather than rising by around 3%.

Geopolitical fragmentation

Second, the net impact of the *Increased geopolitical fragmentation* scenario on the overall pace of the energy transition relative to *Current Trajectory* is relatively small, despite the sizeable adjustments made to various aspects of the scenario.

That partly reflects that different elements of increasing geopolitical fragmentation – at least as modelled in this sensitivity – have offsetting impacts on the mix of fossil and non-fossil fuels.

However, the impact of increased fragmentation on individual countries is likely to be more pronounced, depending on the structure of their energy systems. Moreover, these differing responses could lead to greater disparities across energy pathways, as countries pursue energy strategies determined more greatly by self-reliance and energy security, rather than by the more common goal of decarbonization.

Delayed transition

Third, the *Delayed Below 2°* sensitivity, which roughly approximates the latest point at which the world can decarbonize in an orderly way and remain within a 2°C carbon budget, is relatively close to *Below 2°*. This reflects that the remaining period during which the world can continue along its current pathway and still achieve a 2°C carbon budget without resorting to costly and disruptive measures is relatively short.

The three sensitivities – just like the two main scenarios – are highly simplified and stylised. As such, they should be used to help understand some of the broad ways in which different uncertainties and issues may impact the energy system, rather than to provide a comprehensive or detailed estimation.

Annex

Summary data table

	2023	Level in 2050* Current Trajectory	Level in 2050* Below 2°	Change 2023-2050 (p.a.) Current Trajectory	Change 2023-2050 (p.a.) Below 2°	Share of primary energy in 2050 Current Trajectory	Share of primary energy in 2050 Below 2°
Primary energy by fuel							
Total	**601**	**653**	**449**	**0.3%**	**-1.1%**	**100%**	**100%**
Oil	197	158	62	-0.8%	-4.2%	24%	14%
Natural gas	144	173	66	0.7%	-2.9%	27%	15%
Coal	167	102	24	-1.8%	-6.9%	16%	5%
Nuclear	10	16	22	1.8%	3.0%	2%	5%
Hydropower	15	21	24	1.2%	1.7%	3%	5%
Renewables (incl. bioenergy)	68	182	251	3.7%	5.0%	28%	56%
Primary energy by fuel (native units)							
Oil (Mb/d)	100	83	34				
Natural gas (Bcm)	4,007	4,806	1,823				
Primary energy by region							
Developed	**202**	**168**	**123**	**-0.7%**	**-1.8%**	**26%**	**28%**
United States	87	79	59	-0.3%	-1.4%	12%	13%
European Union	52	39	27	-1.1%	-2.3%	5.9%	6.1%
United Kingdom	6.3	5.0	4.7	-0.9%	-1.1%	0.8%	1.0%
Emerging	**399**	**484**	**325**	**0.7%**	**-0.8%**	**74%**	**72%**
China	156	135	98	-0.5%	-1.7%	21%	22%
India	45	81	54	2.2%	0.7%	12%	12%
Brazil	13	16	13	0.7%	-0.1%	2%	3%

	2023	Level in 2050* Current Trajectory	Level in 2050* Below 2°	Change 2023-2050 (p.a.) Current Trajectory	Change 2023-2050 (p.a.) Below 2°	Share of final consumption in 2050 Current Trajectory	Share of final consumption in 2050 Below 2°
Total final consumption by sector							
Total	**493**	**572**	**406**	**0.6%**	**-0.7%**	**100%**	**100%**
Transport	121	122	92	0.0%	-1.0%	21%	23%
Industry	214	246	186	0.5%	-0.5%	43%	46%
Feedstocks	41	58	42	1.3%	0.1%	10%	10%
Buildings	117	145	85	0.8%	-1.2%	25%	21%
Generation							
Power ('000 TWh)	30	58	70	2.5%	3.2%		
Hydrogen (Mt)	79	136	359	2.0%	5.8%		
Production							
Oil (Mb/d)	99	88	32	-0.5%	-4.1%		
Natural gas (Bcm)	4,059	4,806	1,844	0.6%	-2.9%		
Coal (EJ)	179	108	22	-1.8%	-7.4%		
Emissions							
Carbon emissions (net Gt of CO_2e)	41	31	4.1	-1.1%	-8.2%		
Carbon capture & storage (Gt of CO_2)	0.0	0.7	5.5	16.4%	25.5%		
Macro							
GDP (trillion US$ PPP)	142	279	279	2.5%	2.5%		
Energy intensity (MJ of PE per US$ of GDP)	4.2	2.3	1.6	-2.2%	-3.5%		

*Exajoules (EJ) unless otherwise stated

From *Current Trajectory* to *Below 2°*

The analysis of the difference in carbon emissions between *Current Trajectory* (CT) and *Below 2°* (B2) scenarios focuses on both direct and indirect emissions from the power sector and each end-use sector (industry, transport, buildings).

Power sector

To separate the impact of the decarbonization of the power sector from changes in electricity use in the end-use sectors, the following approach is taken:

The difference in direct emissions in the power sector between CT and B2 can be decomposed into two contributions: the change in total electricity demand, and the change in power emissions intensity. Electricity demand is higher in B2 than in CT as the world electrifies more in B2. The carbon intensity of power is lower in B2 than in CT as more low carbon power sources contribute a greater share of generation. When accounting for the difference in emissions between CT and B2 in the power sector, only contributions due to lower carbon intensity are considered. The contribution due to increased electricity demand is instead allocated to the end-use sector as a function of the change in electricity demand in each sector.

Emissions from the production of traded heat (via combined heat and power (CHP) or heat plants) are included within the power sector.

End-use sectors

Turning to end-use sectors, the impact of decarbonizing the power sector is again separated from the impact of increasing electricity demand. This is done by initially calculating the changes in carbon emissions associated with drivers such as energy efficiency improvements and electrification while holding the carbon intensity of power at the CT level. At the end of the analysis, the final step is to calculate the reduction in emissions from moving the carbon intensity of power to the B2 level. The methodology used in each end-use sector is as follows:

i) Industrial sector

The industrial sector decomposition includes the contributions from methane emissions from fossil fuel production and from the hydrogen sector. CCUS includes the capture of process emissions from cement production. The contributions from energy efficiency gains include the effects of process efficiency improvements, increased recycling of industrial products and materials, and measures to reduce the demand for industrial products and materials.

ii) Transport sector

The decomposition for the transport sector includes contributions from transport activity and energy efficiency. These reflect changes in how each mode of transport is used, such as the average distance travelled by light-duty vehicles and improvements in overall energy efficiency. The remaining contributions directly reflect the impact of the shift away from fossil fuels towards low carbon alternatives.

iii) Buildings sector

The contribution of energy conservation includes the effects of improvements in building fabric through retrofitting, the increase in the number of zero-carbon buildings, and energy demand reductions due to behavioural changes. Also included are all other decarbonization measures that involve the switch to electricity, as well as access to fuels that reduce the use of traditional biomass and its associated methane emissions.

Energy addition and energy substitution

This analysis explores whether a region or country is in a phase of energy addition, in which both fossil fuels and low carbon energy use are rising, or energy substitution, when a region is shifting from fossil fuel consumption to low carbon energy consumption.

Energy addition

When overall energy demand is rising, as has been the case for many emerging economies and some developed economies, energy addition is defined to be occurring when both unabated and combusted fossil fuel consumption and low carbon energy use are rising.

Energy substitution

If, in contrast, overall energy demand is rising but unabated fossil fuel is falling, that region is said to be in energy substitution.

In cases where overall energy demand is falling rather than rising, as has been the case for many developed economies, energy substitution is defined to be occurring when fossil fuel consumption is falling more rapidly than low carbon energy consumption, if that is also falling.

To avoid the short-term volatility inherent in annual energy data in the chart "Primary energy of countries in 'energy substitution' in *Current Trajectory*", the Hodrick-Prescott (HP) filter is applied to both primary energy and unabated fossil fuel consumption. This filtering process helps isolate long-term structural trends, providing a clearer view of underlying energy transitions.

Power sector addition or substitution

Regarding power sector addition or substitution, the same concepts of energy addition and substitution are applied exclusively to the power sector. That is, power sector substitution is defined to be occurring when unabated fossil fuel use in the power sector is falling, or is falling more rapidly than low carbon energy use in the power sector. In this case, a centred five-year average is used to smooth short-term volatility in the annual electricity generation series.

Modelling approach for the *Increased geopolitical fragmentation* sensitivity analysis

The *Increased geopolitical fragmentation* sensitivity takes the *Current Trajectory* scenario as a starting point and then layers on four shocks to illustrate the possible impacts of increased geopolitical fragmentation on the evolution of the global energy system.

The first shock is a reduction in the pace of GDP growth out to 2035 to reflect the impact of weaker global trade. The sensitivity assumes a gradual reduction in global trade openness, resulting in a reduction in the level of global economic activity of 4% by 2035 relative to *Current Trajectory*. The economic effects of the global trade shock differ by region, with regions affected with different magnitudes, depending on their level of trade dependency and economic development.

The second shock is an increased preference for domestically produced energy. This is modelled as a cost premium added to imports of energy. The premium is calibrated for each region depending on their relative degree of import dependency for different fuels. The applied premia lead to an increase in global weighted average fossil fuel prices of 10-15%.

The third shock is an increased preference for domestic supply chains for renewable technologies, which is modelled through increases in the levelized cost of electricity. As with the calibration used for the second shock, the applied premia vary by region and technology. The modelling approach results in an increase in the weighted average global capital costs for solar and wind of 12-18%. The calibration aims to capture existing comparative advantages in renewable technology supply chains.

The second and third shocks taken together increase the overall cost of energy for each region modelled. This, in turn, affects overall energy demand, resulting in an improvement in energy efficiency, especially for energy importing regions.

The fourth and final shock is an increased focus on energy security relative to other elements of the 'energy trilemma', slowing the adoption of higher-cost low carbon technologies. These technologies are delayed as countries reduce the relative weight placed on energy sustainability, and also face lower economic activity and therefore more stringent budget constraints. The shock is calibrated as a five-year delay in the deployment of SAF, low carbon hydrogen and CCUS relative to their deployment in *Current Trajectory*.

The first shock (lower GDP) can be interpreted as a direct consequence of lower global trade. The other three shocks aim to capture the different channels through which a heightened focus on energy security may manifest in the global energy system.

Modelling approach for *Weak energy efficiency*

This is a stylized sensitivity in which the recent weakness in energy efficiency is assumed to be more persistent than in *Current Trajectory*. In particular, global energy efficiency growth between 2024 and 2035 is reduced by an average of 0.4 percentage points per year relative to the path of energy efficiency gains in *Current Trajectory*. That reduction is in line with the weakness in energy efficiency gains over the past five years, relative to those in the previous decade. The adjustment in this sensitivity results in energy efficiency improving by 1.4% per year between 2023 and 2035, rather than 1.8% as in *Current Trajectory*. Energy efficiency is defined here as total final consumption of energy divided by GDP.

In this sensitivity, bioenergy, solar, wind, nuclear, and hydropower are assumed to remain identical to those in *Current Trajectory*. *Weak energy efficiency* therefore results only in higher use of fossil fuels: oil, natural gas and coal.

The increase in total final energy consumption resulting from slower improvements in energy efficiency is allocated proportionally to each fuel and energy carrier based on their shares of TFC in *Current Trajectory*. After this initial allocation, the final increase in primary energy is estimated using the thermal efficiencies for power and heat generation as defined in *Current Trajectory*.

The assumption that weaker energy efficiency impacts only fossil fuel use is driven by the past observed correlations between different elements of primary energy and overall primary energy demand. As shown below, those past correlations are very high for fossil fuel use, but are much lower for bioenergy, solar, wind, nuclear, and hydropower, suggesting that short- to medium-term fluctuations in overall energy demand have in the past largely been reflected in fluctuations in fossil fuel use, rather than in low carbon energy vectors.

Primary energy by energy type	Correlation* with overall primary energy
Oil	0.8
Natural gas	0.8
Coal	0.8
Bioenergy	0.5
Solar and wind	0.1
Nuclear	0.3
Hydropower	0.0

*Correlation shown is first differences, 1990-2023 (annual)

Modelling approach for *Delayed Below 2°*

The *Delayed Below 2°* sensitivity combines elements of both *Current Trajectory* and *Below 2°*.

In a first step, the adjusted emissions pathways for *Current Trajectory* and *Below 2°* are calculated. This involves removing methane emissions from energy sources and traditional biomass, and adding CO_2 median emissions from agriculture, forestry and other land use (AFOLU) from the IPCC C3 and C5 scenarios (for *Below 2°* and *Current Trajectory* respectively).

In *Delayed Below 2°*, emissions accrue as in *Current Trajectory* until 2030. After 2030, the energy system transitions at broadly the same speed as in the *Below 2°* pathway, and CO_2 emissions are calculated based on primary consumption levels for different fuels. The level of cumulative emissions of this scenario is around 900GtCO_2.

This is close to the carbon budget taken from the IPCC Summary for Policymakers report (IPCC, 2021), which estimates that cumulative emissions of 900GtCO_2 are consistent with limiting the global temperature increase below 2°C with a likelihood of 83%.

Emissions after 2050 are calculated on the assumption that the energy system evolves in a similar path as in 2045-50 in each scenario until they reach zero carbon emissions.

Sources

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Economic impact of climate change

The GDP profiles used in the *Energy Outlook* come from Oxford Economics. These long-term forecasts incorporate estimates of the economic impact of climate change. These estimates follow a similar methodology to that used in *Energy Outlooks* since 2020.

The future effects of climate change on global economic activity are highly uncertain, given the unprecedented nature of the phenomenon and its interaction with a modern economic system, and the many uncertainties around the mitigation and adaptation actions that may be taken in response and the technologies that will be available for those in the future. However, there have been attempts to model its possible effects. In particular, Oxford Economics updated and extended the estimation approach developed by Burke, Hsiang and Miguel (2015), which suggests a non-linear relationship between productivity and temperature, in which per capita income growth rises until an average (population weighted) temperature of just under 15°C is reached (Burke et al.'s initial assessment was 13°C). While given the uncertainties, any such conclusions need to be treated with caution, this temperature curve suggests that the income growth of a 'cold country' increases with annual temperatures. However, at annual temperatures above 15°C, per capita income growth is increasingly adversely affected by higher temperatures.

The Oxford Economics baseline emissions forecasts assume average global temperatures reach 1.9°C above pre-industrial levels by 2050. The results suggest that in 2050 global GDP is around 2% lower than in a counterfactual scenario where temperatures remained at their current level. The regional economic impacts are distributed according to the evolution of regional temperatures relative to the concave function estimated by Oxford Economics. While Oxford Economics' approach captures channels associated with average temperatures, these estimates remain uncertain and incomplete; they do not, for example, explicitly include impacts from migration or extensive coastal flooding.

The mitigation costs of actions to decarbonize the energy system are also uncertain, with significant variations across different external estimates. Most estimates, however, suggest that the upfront costs increase with the stringency of the mitigation effort, suggesting that they are likely to be bigger in Below 2° than in Current Trajectory. The IPCC (2022) estimates that mitigation costs to limit global warming to 2°C (with probability >67%) entail losses in global GDP with respect to reference scenarios of between 1.3% and 2.7% in 2050. In pathways limiting warming to 1.5°C (with

probability >50%) with no or limited overshoot, costs are between 2.6% and 4.2% of global GDP. These estimates do not account for the economic benefits of avoided climate change impacts.

Given the huge range of uncertainty surrounding estimates of the economic impact of both climate change and mitigation, and the fact that the *Energy Outlook* scenarios include both types of costs to a greater or lesser extent, the GDP profiles used in the *Outlook* are based on the illustrative assumption that these effects reduce GDP in 2050 by around 2% in both scenarios, relative to the counterfactual in which temperatures are held constant at recent average levels.

Sources:

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Carbon emissions definitions and sources

Unless otherwise stated, carbon emissions refer to:

- CO_2 emissions from energy use (i.e. the production and use of energy in the three final end-use sectors: industry, transport and buildings);
- CO_2 emissions from most non-energy related industrial processes;
- CO_2 emissions from natural gas flaring;
- Methane emissions associated with the production, transmission and distribution of fossil fuels and incomplete combustion of traditional bioenergy, expressed in CO_2-equivalent (CO_2e) terms.

CO_2 emissions from industrial processes refer only to non-energy emissions from cement production. CO_2 emissions associated with the production of hydrogen feedstock for ammonia and methanol are included under hydrogen sector emissions.

Historical data on flaring is sourced from the *Statistical Review of World Energy* by the Energy Institute. Estimates of methane emissions from the production, transportation, and distribution of fossil fuels – as well as from the incomplete combustion of traditional bioenergy – are taken from the IEA's greenhouse gas emissions database.

Future profiles of carbon-equivalent emissions in the scenarios are based on projected fossil fuel production and reflect the impact of policy initiatives such as the Global Methane Pledge. Net changes in emissions result from the combined effects of changes in fossil fuel output, traditional biomass use, and methane intensity.

There is a wide range of uncertainty with respect to both current estimates of methane emissions and the global warming potential of methane emissions. The methane to CO_2e factor used in the scenarios is a 100-year Global Warming Potential (GWP) of 28, recommended by the IPCC Fifth Assessment's GWP values.

To calculate and compare cumulative emissions 2015-50 between IPCC and bp scenarios the following approach is used:

IPCC scenarios are collected from the IPCC Sixth Assessment Report (AR6) Scenario Database, maintained by the International Institute for Applied Systems Analysis (IIASA) in collaboration with the IPCC Working Group III.

In particular, emissions are compared with scenarios in category C3: scenarios that limit global warming below 2°C throughout the century with a probability of greater than 67%.

The median temperature increase of the C3 scenarios in 2100 is 1.6°C. The 5th and 95th percentiles of temperature increases of the IPCC scenarios in 2100 are 1.5°C and 1.8°C respectively.

For each scenario, the database provides CO_2 emissions from energy and industry, and methane emissions from the energy sector. This information enables the calculation of CO_2e emissions directly comparable to those reported in *Current Trajectory* and *Below 2°*.

Since the IPCC database offers data at five-year intervals, linear interpolation is employed to estimate emissions for intermediate years.

To mitigate potential distortions, outliers are eliminated by only including scenarios between the 10th and 90th percentiles for each emission variable within each scenario.

Finally, the resulting figures for cumulative CO_2e emissions are calculated from 2015-50. This timeframe was chosen because recent emission data may deviate significantly from some scenario projections.

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Other data definitions and sources

Data

Data definitions are based on the *Statistical Review of World Energy* by the Energy Institute, unless otherwise noted. Unless otherwise noted, data used for comparisons is rebased to be consistent with the *Statistical Review*. Primary energy, unless otherwise noted, comprises commercially traded fuels and traditional biomass.

In this *Outlook*, primary energy is derived using the direct equivalent method. This method simplifies primary energy accounting by directly equating secondary energy from non-combustible sources (e.g. electricity and heat) to the primary energy used to produce it.

GDP is expressed in terms of real purchasing power parity (PPP) at 2015 prices.

Sectors

Transport includes energy used in light- and heavy-duty road transport, marine, rail and aviation. Light-duty vehicles include four-wheel vehicles under 3.5 tonnes gross vehicle weight. Electric vehicles include all four wheeled vehicles capable of plug-in electric charging. Industry includes energy used in commodity and goods manufacturing, construction, mining, the energy industry including pipeline transport, agriculture, forestry, fishing, and for transformation processes outside of power, heat and hydrogen generation. Feedstocks include non-combusted fuel that is used as a feedstock to create materials such as petrochemicals, lubricant and bitumen. Buildings include energy used in residential and commercial buildings.

Regions

'Developed economies' is approximated as the United States, Canada, developed Europe and developed Asia. 'Emerging economies' refers to all other countries and regions not in 'developed economies'. China refers to mainland China. Developed Asia includes OECD Asia plus other high-income Asian countries and regions. Emerging Asia includes all countries and regions in Asia excluding mainland China, India and developed Asia.

Fuels, energy carriers, carbon and materials

Oil, unless otherwise noted, includes crude (including shale oil and oil sands), natural gas liquids (NGLs), gas-to-liquids (GTLs), coal-to-liquids (CTLs), condensates, and refinery gains. Hydrogen-derived fuels are all fuels derived from low carbon hydrogen, including ammonia, methanol, and other synthetic hydrocarbons.

Renewables, unless otherwise noted, include wind, solar, geothermal, biomass, biomethane, and biofuels, and excludes large-scale hydropower. Non-fossils include renewables, nuclear and hydropower. Traditional biomass refers to solid biomass (typically not traded) used with basic technologies, e.g. for cooking.

Biofuels are liquid fuels made from bio-based solid or gaseous feedstocks. They include i) biogasoline (ethanol), ii) biodiesel, and iii) biojet (ASTM certified jet fuel). Mostly they come to market through blending with the relevant refined oil equivalent products, but the category can include directly usable bio-based liquid drop-in fuels such as renewable diesel (HVO) and bio-methanol.

Biogas is produced via a mature technology (anaerobic digestion) and is used directly for heat and power generation, or upgraded into biomethane for use in transport, utilities and other applications. Biogas which is not upgraded into biomethane is accounted for under modern solid biomass.

Hydrogen demand includes its direct consumption in transport, industry, buildings, power and heat, as well as feedstock demand for the production of hydrogen-derived fuels and for conventional refining and petrochemical feedstock demand. Low carbon hydrogen includes green hydrogen, as well as hydrogen production from biomass, gas with CCUS, and coal with CCUS. CCUS options include CO_2 capture rates of 90-98% over the Outlook.

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