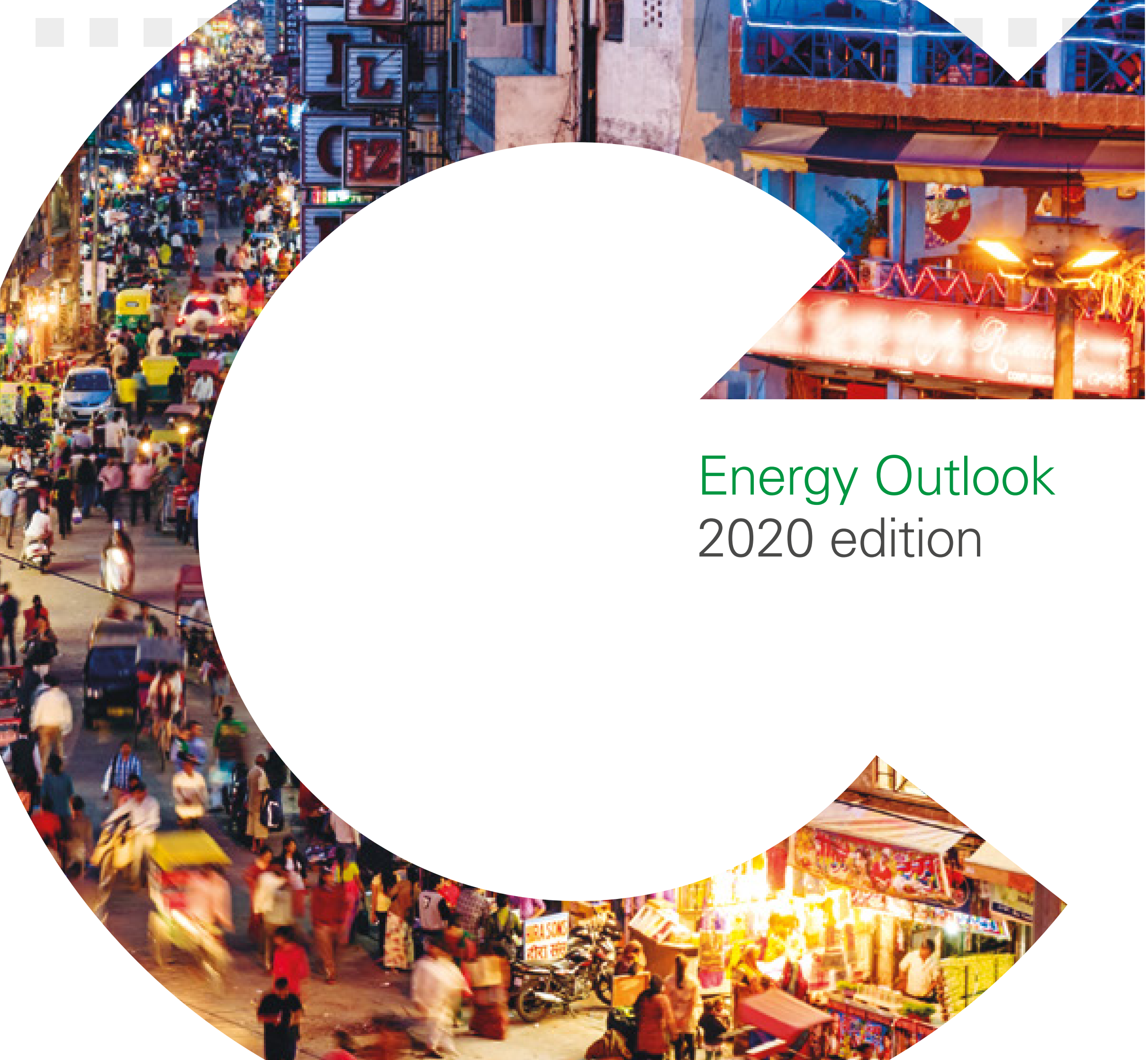


Energy Outlook

2020 edition

The Energy Outlook explores the forces shaping the global energy transition out to 2050 and the key uncertainties surrounding that transition

The *Energy Outlook* considers a number of different scenarios. These 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 and developing technologies which are known about today and do not consider the possibility of entirely new or unknown technologies emerging.

Much of the analysis in the Outlook is focussed around three scenarios: *Rapid*, *Net Zero* and *Business-as-usual*. The multitude of uncertainties means that the probability of any one of these scenarios materializing exactly as described is negligible. Moreover, the three scenarios do not provide a comprehensive description of all possible outcomes. However, the scenarios do span a wide range of possible outcomes and so might help to inform a judgement about the uncertainty surrounding energy markets out to 2050.

The *Energy Outlook* is produced to inform bp's analysis and strategy and is published as a contribution to the wider debate. But the Outlook is only one source among many when considering the future of global energy markets and bp considers a wide range of other analysis and information when forming its long-term strategy.

Welcome to the 2020 edition of bp's Energy Outlook

In February of this year, bp announced a new purpose – to reimagine energy for people and our planet. This purpose was supported by a new ambition, to be a net-zero company by 2050 or sooner and to help get the world to net zero.

Our new purpose and ambition are underpinned by four fundamental judgements about the future. That the world is on an unsustainable path and its carbon budget is running out. That energy markets will undergo lasting change, shifting towards renewable and other forms of zero- or low-carbon energy. That demand for oil and gas will be increasingly challenged. And that, alongside many others, bp can contribute to the energy transition that the world wants and needs, and create value doing so.

In August, we set out a new strategy in support of this purpose and ambition. It will see bp transform from an International Oil Company focused on producing resources to an Integrated Energy Company focused on delivering solutions for customers. From IOC to IEC. And while the Covid-19 pandemic has had a huge impact on the global economy and energy markets, it has not affected our belief in and commitment to our purpose, ambition and strategy.

That belief and commitment is in no small part down to the objective analysis that goes into every edition of the *Energy Outlook*. It does not to try to predict precise future outcomes – any attempt to do that is doomed to fail. Instead, it helps us to understand the many uncertainties ahead – in the near and longer term – by considering a range of possible pathways the energy transition may take over the next 30 years. This year's Outlook explores three main scenarios – *Rapid*, *Net Zero* and *Business-as-usual* – which span a wide range of possible outcomes. Those three scenarios have helped us to develop a strategy that we think is robust to the uncertainty around the pace and nature of the energy transition.

Three features are common across those scenarios and they form **a set of core beliefs as to how energy demand is likely to change** over the next three decades:

- Renewable energy will play an increasingly important role in meeting the world's growing energy needs.
- Customers will continue to redefine mobility and convenience, underpinned by the mobility revolution that is already underway combining electric vehicles, shared mobility and autonomy.
- Oil and gas – while remaining needed for decades – will be increasingly challenged as society shifts away from its reliance on fossil fuels

And those core beliefs lead us to **three more about how the energy system will change** out to 2050:

- The energy mix will become more diverse, driven increasingly by customer choice rather than resource availability.
- Markets will need more integration to accommodate this more diverse supply and will become more localized as the world electrifies and the role of hydrogen expands.
- Countries, cities and industries will increasing want their decarbonized energy and mobility needs met with bespoke solutions, shifting the centre of gravity of energy markets towards consumers and away from traditional upstream producers.

The *Energy Outlook* has been tracking and analysing the trajectory of the world's energy system for the past 10 years. This year's Outlook has been instrumental in the development of the new strategy we announced in August. I hope it is useful to everyone else seeking ways to accelerate the energy transition and get to net zero. We welcome any feedback on the content and how we can improve.

Bernard Looney
chief executive officer

Key messages

- Global energy demand continues to grow, at least for a period, driven by increasing prosperity and living standards in the emerging world. Significant inequalities in energy consumption and access to energy persist.
- The structure of energy demand is likely to change over time: declining role of fossil fuels, offset by an increasing share of renewable energy and a growing role for electricity. These changes underpin core beliefs about how the structure of energy demand may change.
- A transition to a lower carbon energy system is likely to lead to fundamental restructuring of the global energy system, with a more diverse energy mix, greater consumer choice, more localized energy markets, and increasing levels of integration and competition. These changes underpin core beliefs about how the global energy system may restructure in a low-carbon transition.
- Demand for oil falls over the next 30 years. The scale and pace of this decline is driven by the increasing efficiency and electrification of road transportation.
- The outlook for natural gas is more resilient than for oil, underpinned by the role of natural gas in supporting fast growing developing economies as they decarbonized and reduce their reliance on coal, and as a source of near-zero carbon energy when combined with carbon capture use and storage (CCUS).

- Renewable energy, led by wind and solar power, is the fastest growing source of energy over the next 30 years, supported by a significant increase in the development of – and investment in – new wind and solar capacity.
- The importance of electricity in final energy consumption increases materially over the next 30 years. The carbon intensity of power generation falls markedly, driven by renewables gaining share relative to coal.
- The intermittency associated with the growing use of wind and solar power means a variety of different technologies and solutions are needed to balance the energy system and ensure the availability of firm power.
- The use of hydrogen increases as the energy system progressively decarbonizes, carrying energy to activities which are difficult or costly to electrify. The production of hydrogen is dominated by a mix of blue and green hydrogen.
- The importance of bioenergy – biofuels, biomethane and biomass – increases as consumption shifts away from fossil fuels.
- The world is on an unsustainable path. A rapid and sustained fall in carbon emissions is likely to require a series of policy measures, led by a significant increase in carbon prices. These policies may need to be reinforced by shifts in societal behaviours and preferences. Delaying these policies measures and societal shifts may lead to significant economic costs and disruption.

Contents

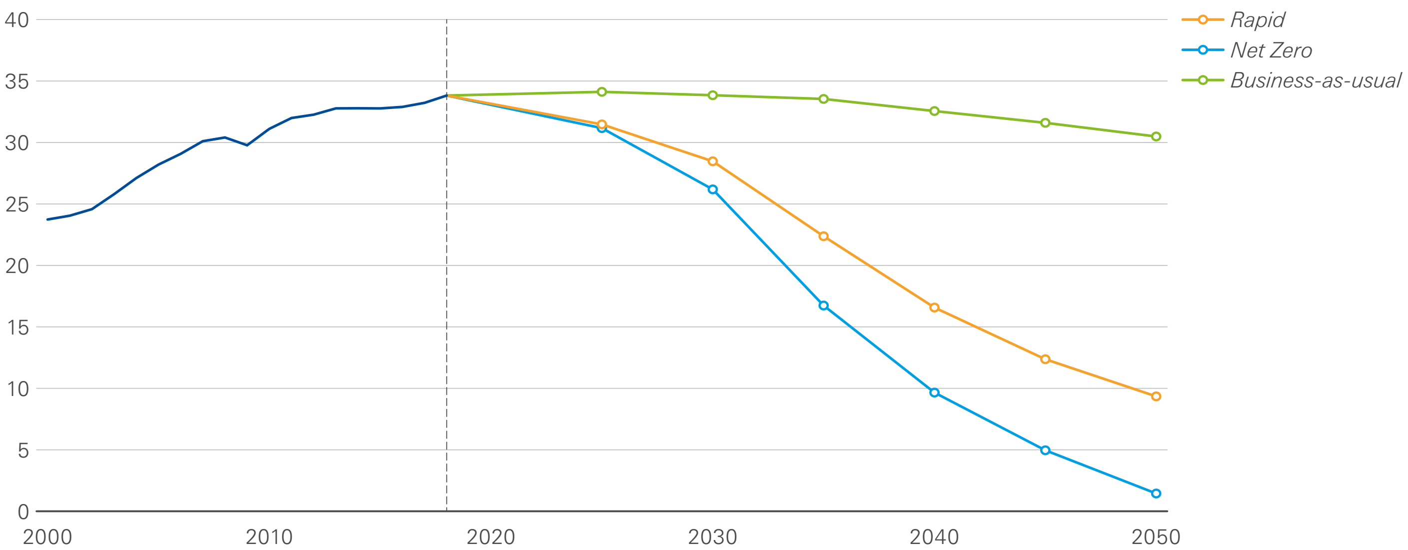
Overview

Three scenarios: *Rapid*, *Net Zero* and *Business-as-usual*
Changing nature of global energy system

Three scenarios to explore the energy transition to 2050

CO_2 emissions from energy use

Gt of CO_2



Key points

- This year's *Energy Outlook* considers three main scenarios which explore different pathways for the global energy system to 2050.

- The scenarios are not predictions of what is likely to happen or what bp would like to happen. Rather, the scenarios help to illustrate the range of outcomes possible over the next thirty years, although the uncertainty is substantial and the scenarios do not provide a comprehensive description of all possible outcomes.

- The Rapid Transition Scenario (*Rapid*) posts a series of policy measures, led by a significant increase in carbon prices and supported by more-targeted sector specific measures, which cause carbon emissions from energy use to fall by around 70% by 2050. This fall in emissions is in line with scenarios which are consistent with limiting the rise in global temperatures by 2100 to well below 2-degrees Celsius above pre-industrial levels.

- The Net Zero Scenario (*Net Zero*) assumes that the policy measures embodied in *Rapid* are both added to and reinforced by significant shifts in societal behaviour and preferences, which further accelerate the reduction in carbon emissions. Global carbon emissions from energy use fall by over 95% by 2050, broadly in line with a range of scenarios which are consistent with limiting temperature rises to 1.5-degrees Celsius.

- The *Business-as-usual* Scenario (*BAU*) assumes that government policies, technologies and social preferences continue to evolve in a manner and speed seen over the recent past*. A continuation of that progress, albeit relatively slow, means carbon emissions peak in the mid-2020s. Despite this peaking, little headway is made in terms of reducing carbon emissions from energy use, with emissions in 2050 less than 10% below 2018 levels.

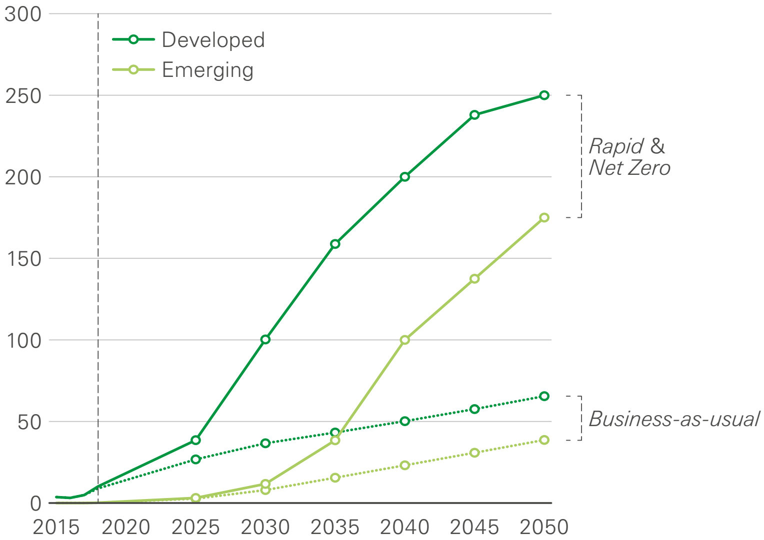
- Primary energy demand increases by around 10% in *Rapid* and *Net Zero* over the Outlook and by around 25% in *BAU*.

**BAU* is comparable with the Evolving Transition Scenario in previous editions of the *Energy Outlook*

Scenarios differ due to alternative assumptions about policies and societal preferences

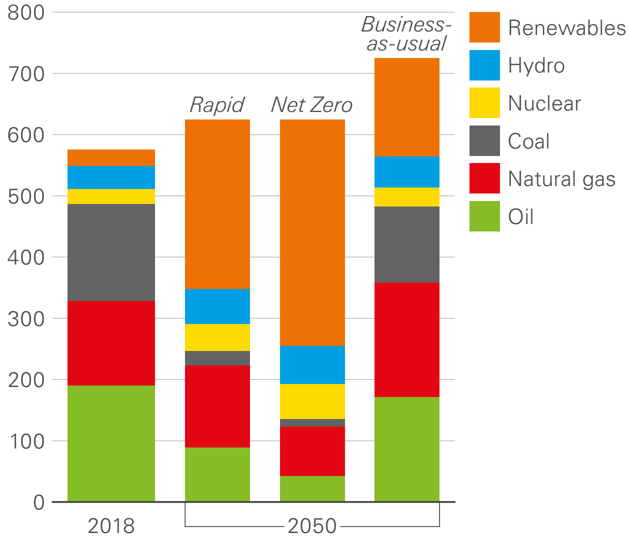
Average carbon prices in developed and emerging regions

US$ per tonne (real 2018)



Primary energy consumption by source

EJ



Key points

- The differences between the scenarios are driven by a combination of different assumptions about economic and energy policies and social preferences.

- Both *Rapid* and *Net Zero* assume a significant increase in carbon prices, which reach $250/tonne of CO_2 ($2018 prices) in the developed world by 2050 and $175 in emerging economies. This increase in carbon prices incentivizes significant gains in both energy efficiency and the use of lower-carbon energy sources. This policy impulse is much smaller in *BAU*, with carbon prices reaching only $65 and $35 per tonne of CO_2 by 2050 in developed and emerging economies respectively.

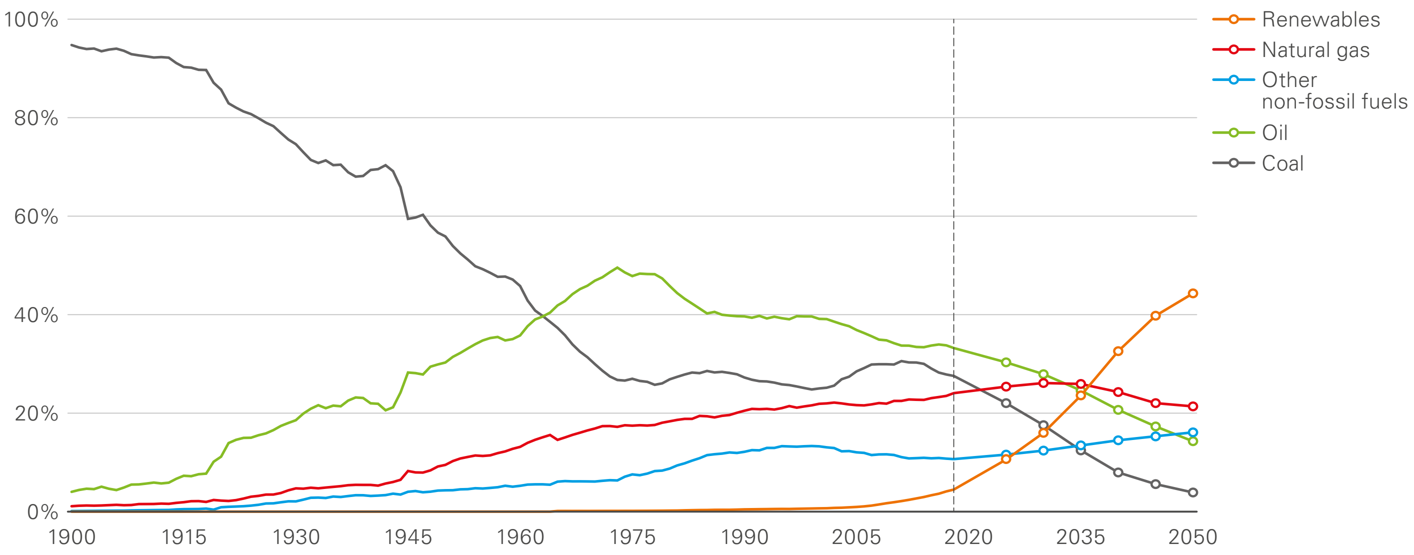
- In addition to carbon prices, the three scenarios assume a number of other policies are enacted to affect both the growth of energy consumption and the mix of energy sources across different sectors of the economy: industry (pp 36-37); buildings (pp 40-41) and transport (pp 42-49).

- *Net Zero* is based on the view that there may be economic and political limits to the extent to which an accelerated energy transition can be driven solely by government policies. It assumes that the impact of these policies is accentuated by the changing behaviour and preferences of companies and households, with greater adoption of circular and sharing economies; increased propensity to switch to low-carbon energy sources; and less resistance to the accelerated buildout of low-carbon technologies and distribution networks.

- As a result of these policies and shifts in societal preferences, there is a decline in the share of hydrocarbons (coal, oil and natural gas) in the global energy system in all three scenarios. This is matched by a corresponding increase in the role of renewable energy as the world increasingly electrifies. The scale of this shift varies significantly across the three scenarios, with the share of hydrocarbons in primary energy declining from around 85% in 2018 to between 70-20% by 2050 and the share of renewable energy increasing to between 20-60%.

Low-carbon transition leads to a fundamental shift in the global energy system

Shares of primary energy in *Rapid*



Key points

- The transition to a lower carbon energy system in *Rapid* leads to a fundamental restructuring and reshaping of the global energy system. There are several different aspects to these changes.

- First, there is a significant shift away from traditional hydrocarbons (oil, natural gas and coal) towards non-fossil fuels, led by renewable energy. In *Rapid*, non-fossil fuels account for the majority of global energy from the early 2040s onwards, with the share of hydrocarbons in global energy more than halving over the next 30 years.

- Second, the energy mix becomes far more diversified. For much of history, the global energy system has tended to be dominated by a single energy source. For the first half of the previous century, coal provided most of the world's energy. As the importance of coal declined, oil became the predominant energy source. The energy transition in *Rapid* means that for much of the next 20 years the global fuel mix is far more diversified than previously seen, with oil, natural gas, renewables and coal (for a time) all providing material shares of world energy. The greater variety of fuels means that the fuel mix is increasingly driven by customer choice rather than the availability of fuels, with increasing demands for integration across different fuels and energy services.

- This increased differentiation is further enhanced by the growing importance of electricity and hydrogen at the final point of energy use in *Rapid*. These energy carriers are more costly to transport than traditional hydrocarbons causing energy markets to become more localized.

- The increasing diversification of the fuel mix also leads to greater competition across different forms of energy as they compete for market share against a backdrop of plateauing energy demand in the second half of the Outlook in *Rapid*. Moreover, the peaking and subsequent decline in the consumption of coal, oil and natural gas in *Rapid* triggers greater competition within individual fuels, as resource owners compete to ensure their energy resources are produced and consumed. This heightened competition increases the bargaining power of consumers, with economic rents shifting away from traditional upstream producers towards energy consumers.

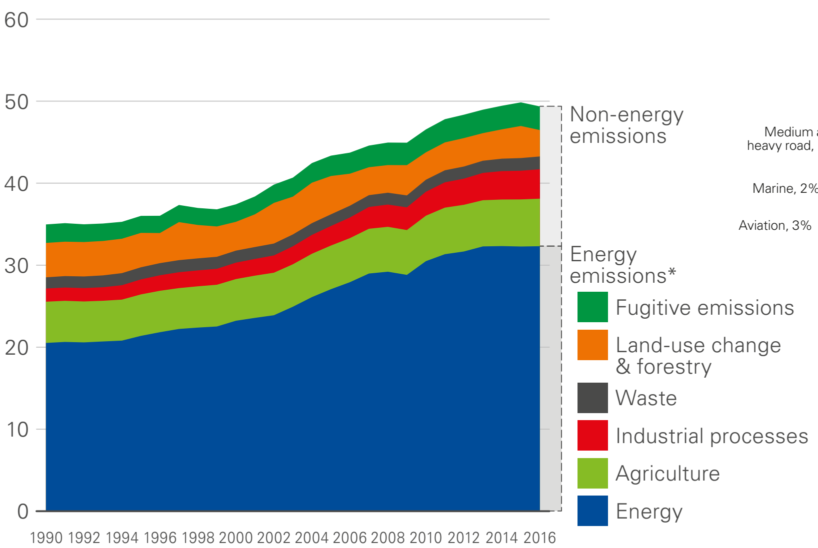
- Similar trends are also apparent in *Net Zero*, although the pace with which the share of renewables grows is even faster.

Global backdrop

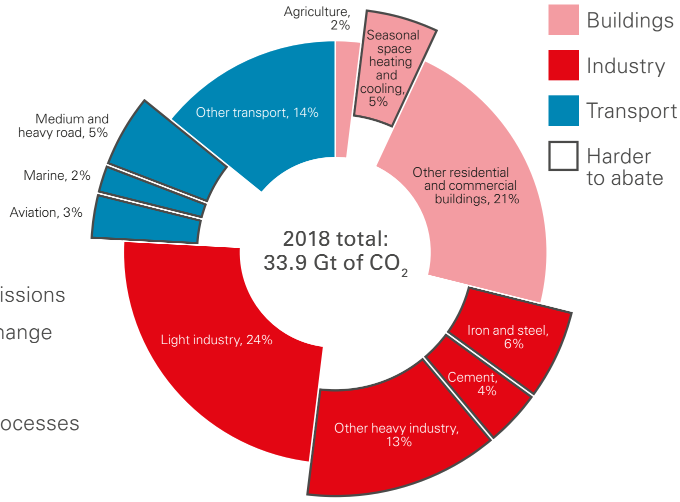
Total greenhouse gases
Global GDP
Climate impacts on GDP growth
Energy demand
Impact of Covid-19
Energy access and economic development

Carbon emissions from energy use are the largest source of greenhouse gas emissions

Global GHG emissions



Carbon emissions from energy use, 2018



Source: WRI estimates
**Energy Outlook* definition which includes CO_2 emissions from the combustion of fossil fuels.
Non-CO_2 emissions from energy as defined by WRI are allocated to Industrial processes and Fugitive emissions

Key points

- Scientific evidence suggests that the dominant cause of climate change is the release of greenhouse gases (GHGs). The World Resources Institute (WRI) estimates that total GHGs were equal to 49.4 Gt CO_2e in 2016, with carbon emissions from energy use being the largest source of GHGs, accounting for around 65% of all GHGs.

- The estimate of carbon emissions from energy used in the *Energy Outlook* differs slightly from the WRI definition. The *Energy Outlook* does not model fugitive methane emissions from the production of hydrocarbons and so they are excluded from the estimates used. The *Outlook* does, however, include emissions from bunker fuels which are excluded from the WRI definition. Based on the *Energy Outlook* definition, carbon emissions from energy use in 2016 were 32.9 Gt CO_2e, similar to the WRI estimate of 32.3 Gt CO_2e.

- In addition to carbon emissions from energy use, the WRI estimates that the other main sources of emissions in 2016 were: agriculture (5.8 Gt CO_2e); industrial processes (2.8 Gt CO_2e); land-use and forestry change 3.2 Gt CO_2e); and waste management facilities (1.6 Gt CO_2e).

- In terms of the carbon emissions from energy use, nearly half of the emissions stem from energy used within industry. The remainder is split roughly evenly between the transport and buildings (including agriculture) sectors.

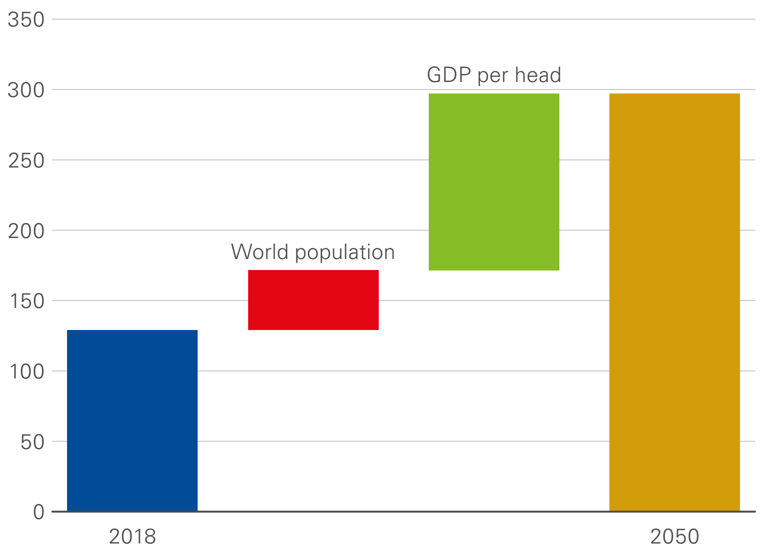
- As the energy transition advances, some emissions can be more readily prevented than others. In particular, carbon emissions from activities or processes which are relatively straightforward or inexpensive to electrify can be reduced as the power sector is increasingly decarbonized. One exception to this is seasonal space heating and cooling demands in buildings. Although these demands can be electrified, the scale of the seasonal fluctuations are hard to meet in a power sector based heavily on intermittent renewable power (see pp 124-125).

- The majority of emissions which are hard-to-abate stem from activities or processes that are difficult to electrify and so need alternative sources of low-carbon energy. This includes high temperature industrial processes, such as those used in iron and steel, cement and chemicals. It also includes long-distance transportation services, including heavy duty trucks, aviation and marine.

Global GDP continues to expand, but at a slower rate

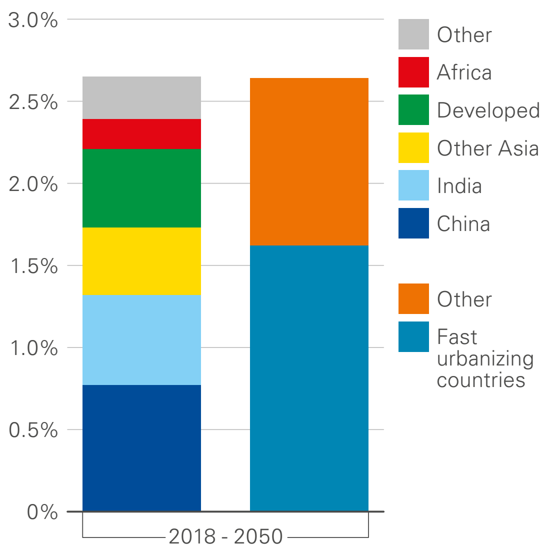
Global GDP, 2018-2050

Trillion $US (2015) PPP



Global GDP growth and regional contributions

% per annum

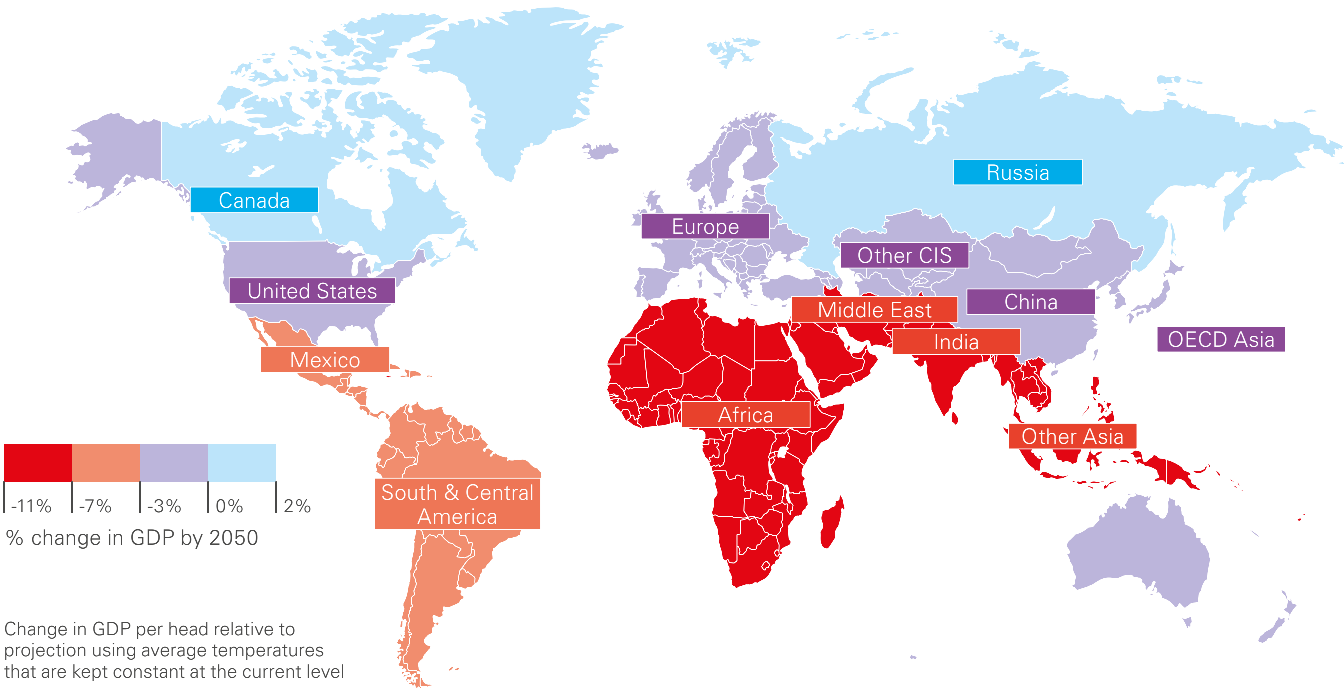


Key points

- The world economy continues to grow over the next 30 years, driven by increasing wealth and living standards in the developing world, but at a slower rate than in the past.
- Global GDP annual growth averages around 2.6% (on a 2015 Purchasing Power Parity basis) in all three scenarios. This growth is considerably slower than its average over the past 20-years, in part reflecting the persistent impact of Covid-19 on economic activity. See pp 28-29 for a discussion of the treatment of Covid-19 in this year's *Energy Outlook*.
- The weaker economic growth than in the past also reflects the assumed increasing impact of climate change on the productive potential of the economy (see pp 24-25, 148-149 for a discussion of this impact).
- The expansion in global activity is supported by population growth, with the world's population increasing by over 2 billion people to around 9.6 billion by 2050.
- But the most important factor underpinning global growth is increasing productivity (GDP per head) – and hence prosperity (income per head) – which drives around 80% of the expansion in global GDP over the Outlook.
- Developing economies account for over 80% of the growth in the world economy, with China and India contributing around half of that increase.
- The growth in global activity and prosperity is underpinned by continuing high levels of urbanization, which is often an integral part of the development process leading to increasing levels of industrialization and productivity. Countries which are projected to have a relatively fast pace of urbanization over the next 30 years – that is, the level of urbanization is projected to increase by at least a third by 2050 – contribute well over half of the increase in world output over the Outlook, despite making up less than a third of global GDP in 2018.

The impact from climate change on economic growth increases over the Outlook

Climate change impact on level of GDP in 2050



Change in GDP per head relative to projection using average temperatures that are kept constant at the current level

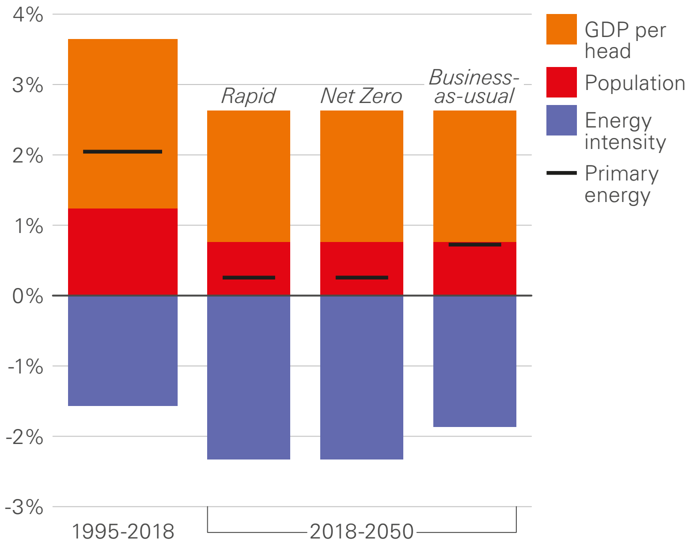
Key points

- The growing concentration of greenhouse gases in all three scenarios is assumed to have an increasing impact on the growth and productive potential of the global economy.
- Increasing temperatures, combined with more extreme weather patterns and rising sea levels, may trigger a range of impacts that lower economic growth. Efforts to reduce or mitigate carbon emissions may also divert investment from other sources of growth.
- Estimating the potential size of these impacts is highly uncertain, with most existing environmental and economic models and studies capturing only a subset of these effects, often very imperfectly. For instance, the economic literature on which our illustrative impact on GDP is based considers only increasing temperatures.
- For illustrative purposes, the level of GDP in 2050 in all three scenarios is projected to be around 5% lower relative to a hypothetical world in which the concentration of greenhouse gases was frozen at current levels. These effects are assumed to be greatest in regions which have the highest average temperatures currently (see pp 148-149).
- The negative impact from rising temperature levels is largest in *BAU* where little progress is made in reducing carbon emissions. But the upfront costs of the policy actions taken to reduce emissions are greater in *Rapid* and *Net Zero*, such that the overall impact on GDP over the next 30 years is projected to be broadly similar in all three scenarios.
- Importantly, if the scenarios were extrapolated beyond 2050, the erosion of wealth and prosperity in *BAU* would get progressively worse, leading to significantly lower levels of activity and well-being than in *Rapid* or *Net Zero*.
- The environment and economic models and studies underpinning these illustrative estimates of the impact of global warming on economic activity are highly uncertain and almost certainly incomplete – for example, they do not capture many of the potential human costs. Future editions of the *Energy Outlook* will update these estimates as the scientific and economic understanding of these effects improves.

Energy demand grows led by increasing prosperity, partially offset by efficiency gains

Contribution to primary energy demand growth

% per annum



Global primary energy demand

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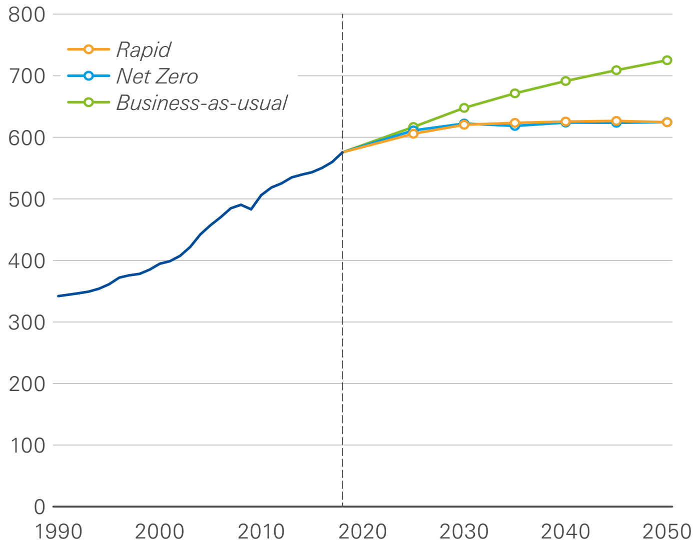


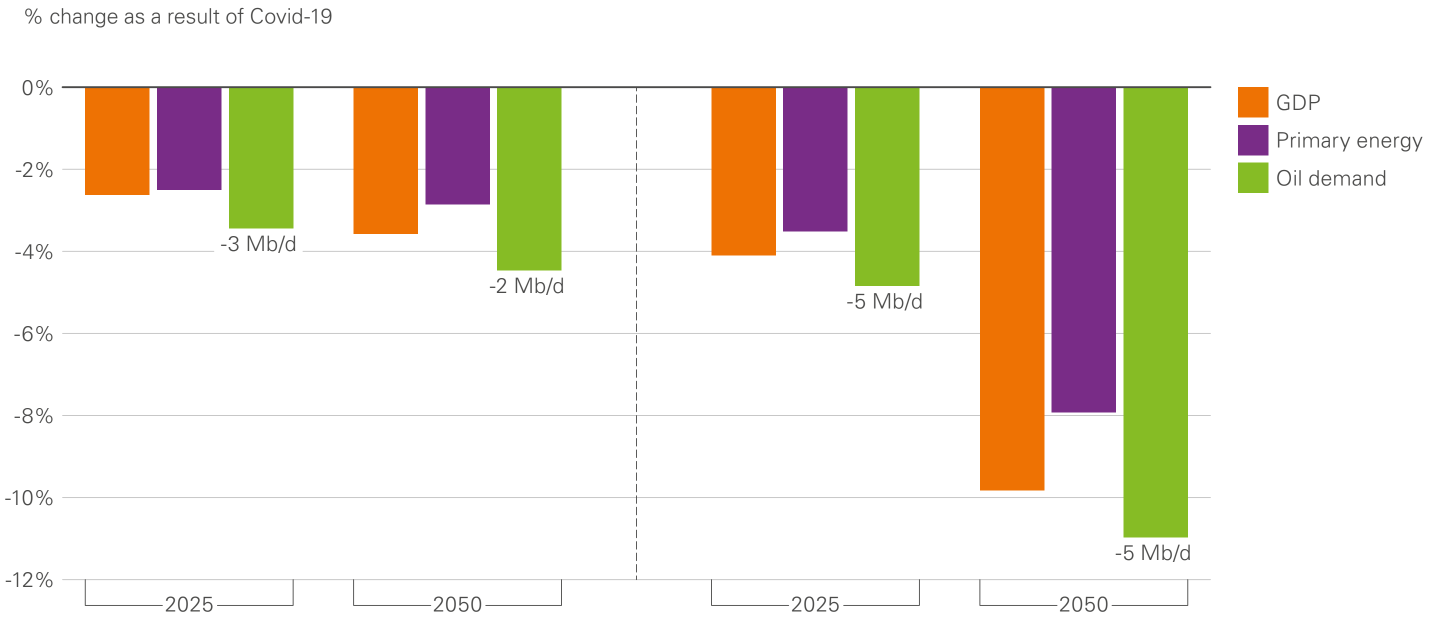
Key points

- Growth in global energy demand is underpinned by increasing levels of prosperity in emerging economies. Primary energy increases by around 10% in *Rapid* and *Net Zero* and around 25% in *BAU*.
- Much of this increase in energy consumption – the entire growth in *Rapid* and *Net Zero* and over half in *BAU* – stems from economies which are urbanizing quickly.
- The average rates of growth of primary energy in *Rapid* (0.3% p.a.) and *Net Zero* (0.3% p.a.) are significantly slower than the past 20 years (2.0% p.a.), reflecting a combination of weaker economic growth and faster improvements in energy intensity (energy used per unit of GDP). Primary energy in both scenarios broadly plateaus in the second half of the Outlook.
- Energy efficiency measured in terms of final energy use improves by more in *Net Zero* than *Rapid*, but these gains are offset in terms of primary energy by the greater use of electricity and hydrogen which require considerable amounts of primary energy to produce.
- Growth of primary energy in *BAU* (0.7% p.a.) is faster and more sustained than in the other two scenarios, reflecting slower gains in energy efficiency.
- The faster declines in energy intensity relative to history in *Rapid* and *Net Zero* are a critical factor in mitigating the growth in carbon emissions. Other things being equal, if energy intensity over the Outlook improved at the same rate as the past 20 years, carbon emissions by 2050 would be more than a quarter higher in *Rapid* and *Net Zero*.
- Policies and actions to promote improvements in energy efficiency are central to achieving a low-carbon transition.

Covid-19 is assumed to have a persistent impact on economic activity and energy demand

Impact of Covid-19 in *Rapid*

Alternative case: Greater impact from Covid-19



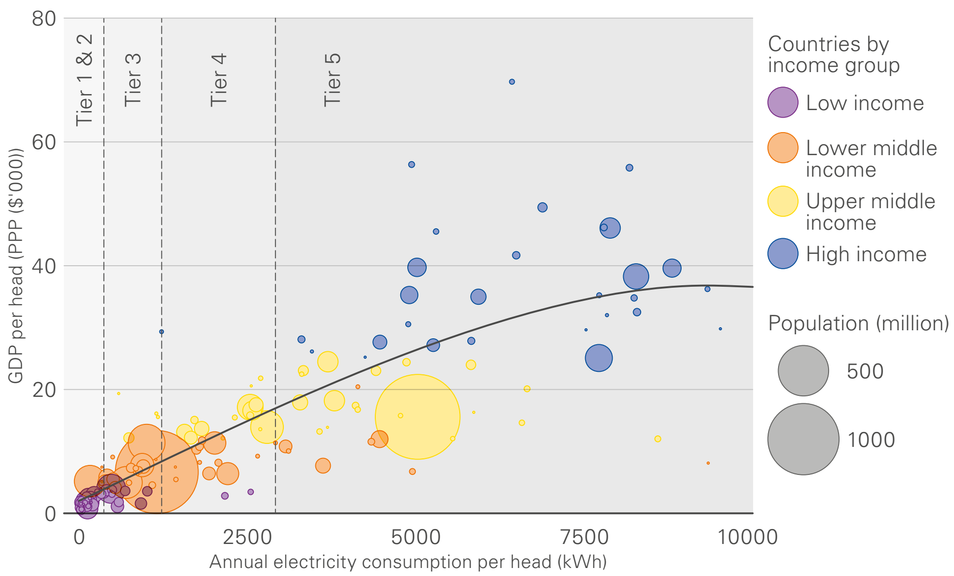
Key points

- The Covid-19 pandemic is foremost a humanitarian crisis, but the scale of the economic cost and disruption is also likely to have a significant and persistent impact on the global economy and energy system. At the time of writing, the number of new cases from the pandemic is still increasing and so assessing its eventual impact is highly uncertain.
- The central view used in the main scenarios it that economic activity partially recovers from the impact of the pandemic over the next few years as restrictions are eased, but that some effects persist. The level of global GDP is assumed to be around 2.5% lower in 2025 and 3.5% in 2050 as a result of the crisis. These economic impacts disproportionately affect emerging economies, such as India, Brazil and Africa, whose economic structures are most exposed to the economic ramifications of Covid-19.
- The pandemic may also lead to a number of behavioural changes; for example, if people choose to travel less, switch from using public transport to other modes of travel, or work from home more frequently. Many of these behavioural changes are likely to dissipate over time as the pandemic is brought under control and public confidence is restored. But some changes, such as increased working from home, may persist.
- In *Rapid*, the impact of the pandemic is assumed to reduce the level of energy demand by around 2.5% in 2025 and 3% in 2050. The impacts are most pronounced on oil demand, which is around 3 Mb/d lower in 2025 and 2 Mb/d in 2050 as a result of the pandemic. The majority of this reduction reflects the weaker economic environment, with around 1 Mb/d of the reduction in 2025 a result of the various behavioural changes. The marginal impacts in *BAU* and *Net Zero* are similar.
- There is a risk that the economic losses from Covid-19 may be significantly bigger, especially if there are further waves of infection. This possibility is explored in a 'greater impact' case, in which Covid-19 reduces the level of global GDP by 4% in 2025 and almost 10% by 2050. In this 'greater impact' case, the crisis causes the level of energy demand in *Rapid* in 2050 to be 8% lower, with the level of oil demand around 5 Mb/d lower.

Economic development depends on both access to energy and the quality of that access

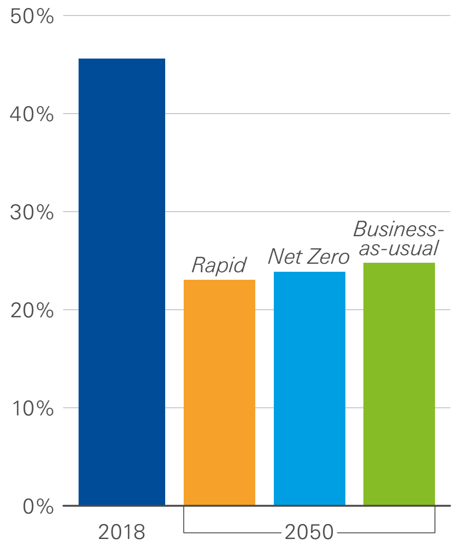
GDP and electricity consumption (per head), 2018

The size of the bubbles are proportional to population



Source: Oxford Economics; BP Statistical Review 2019
Tiers based on World Bank definitions

Proportion of world population with Tier 3* access to electricity or less



*Tier 3 access assumes less than 16 hours of uninterrupted medium power electricity during the day and less than 4 hours during the evening

Key points

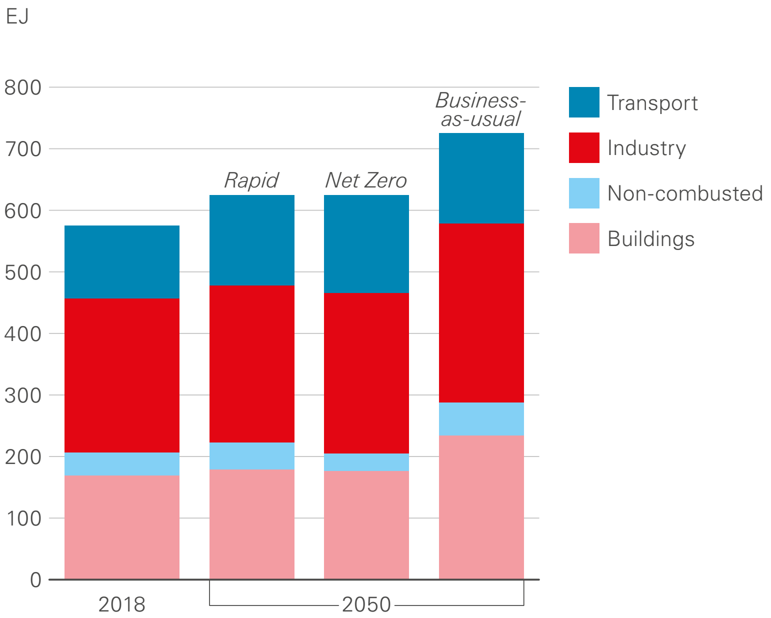
- There is a strong link between access to energy and economic well-being and prosperity. The importance of energy access is embodied in the UN's Sustainable Development Goal (SDG) 7 which seeks to "ensure access to affordable, reliable, sustainable and modern energy for all".
- One measure monitored by SDG 7 is global access to electricity, where the number of people without access is estimated to have decreased from 1.2 billion in 2010 to 790 million in 2018*.
- Economic prosperity and development depend not just on the ability to access electricity, but also on the quantity and quality of the electricity provision.
- The World Bank's multi-tiered framework provides one measure of quality of access, in which Tier 1 access equates to very basic levels of provision (lighting with limited availability) though to Tier 5, which denotes access to plentiful and reliable supplies.
- There is a strong link between economic development and the quality of the access to electricity: around three-quarters of low and lower-middle income countries in 2018 had relatively limited access to electricity (Tier 3 or below); whereas over 90% of high-income countries had Tier 5 access.
- Although the share of the world's population without any access to electricity is estimated to have declined to 10% in 2018, around 45% of the world's population lived in countries with Tier 3 access or below. In all three scenarios, around a quarter of the world's population in 2050 live in countries or regions in which average levels of electricity consumption are still equivalent to Tier 3 access or below.
- Improving the quality of electricity access – and energy access more generally – across the globe is likely to require a range of different policy approaches and technologies, including the development of decentralized and off-grid power generation.

* Source: Tracking SDG7
The Energy Progress Report 2020

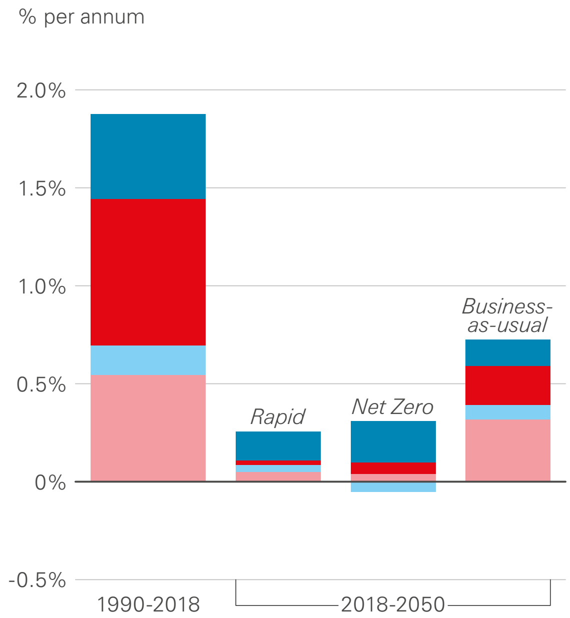
Energy use by sector

Energy consumption grows across all sectors of the economy, although slower than in the past

Primary energy consumption by end-use sector



Annual demand growth and sector contributions

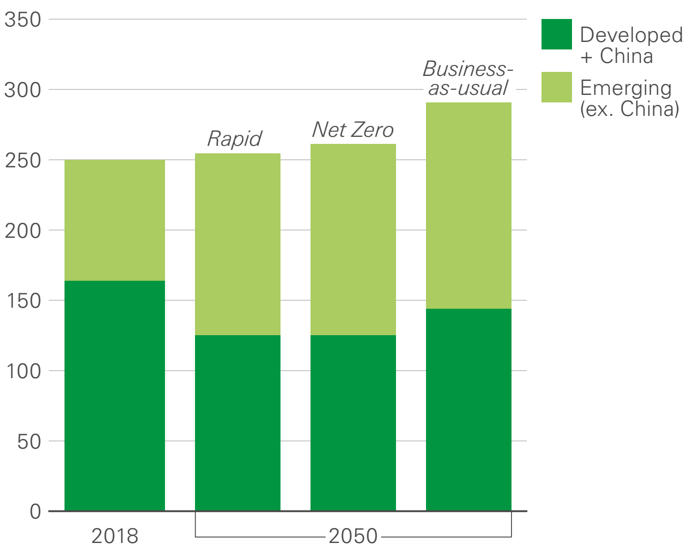


Key points

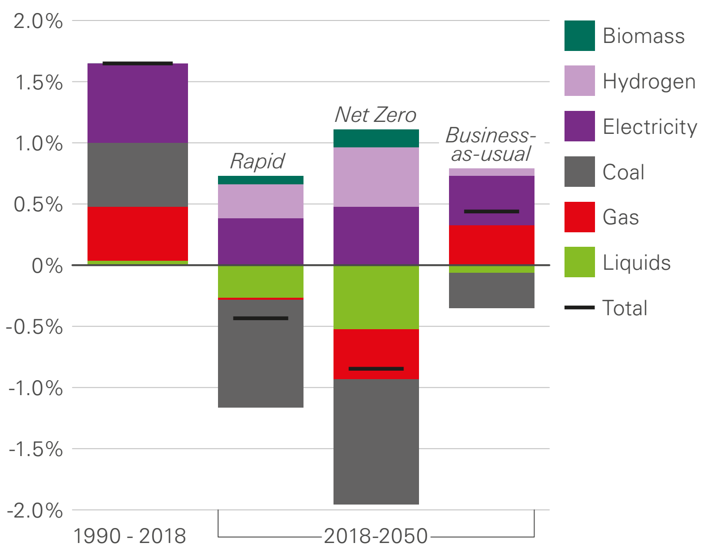
- The strength and composition of energy growth over the next 30 years depends importantly on how that energy is used across the main sectors of the economy.
- The industrial sector (excluding the non-combusted use of fuels) consumed around 45% of global energy in 2018, with the non-combusted use of fuels accounting for an additional 5% or so. The remainder was used within residential and commercial buildings (29%) and transport (21%).
- The outlook for primary energy also depends on the form in which that energy is used at the final point of consumption. In particular, although it is possible to decarbonize the production of electricity and hydrogen, they require considerable amounts of primary energy to produce. As such, increasing the use of these forms of energy carriers tends to boost primary energy.
- In *Rapid*, the growth in primary energy used in all three sectors slows relative to the past 20 years. This deceleration is most pronounced in the industrial and buildings sectors, with the use of primary energy in both sectors falling in the second half of the Outlook. In contrast, primary energy used in transport increases throughout the Outlook – accounting for nearly 60% of the total increase in primary energy in *Rapid* – boosted by greater switching to electricity and hydrogen. This hydrogen can be used either directly or combined with carbon or nitrogen to make it easier to transport.
- The use of electricity and hydrogen expand by even more in *Net Zero*, particularly in transport and industry. As a result, even though the pace of underlying efficiency gains in both sectors is faster than in *Rapid*, the increase in primary energy is somewhat greater. Primary energy used in buildings by 2050 is largely unchanged from its current level.
- In contrast, the use of primary energy increases materially in all three sectors in *BAU*, albeit significantly slower than in the past 20 years. This deceleration is most marked in industry and transport, with energy use in buildings and the non-combusted sector together accounting for around half of the increase in primary energy consumption.

The use of energy within industry shifts towards developing economies and lower-carbon energy

Primary energy demand in industry



Growth of final energy consumption in industry by energy carrier

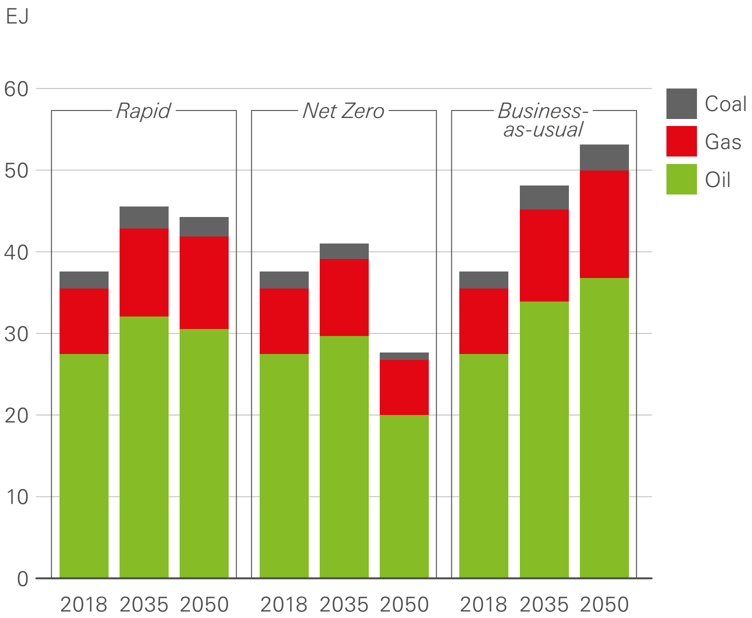


Key points

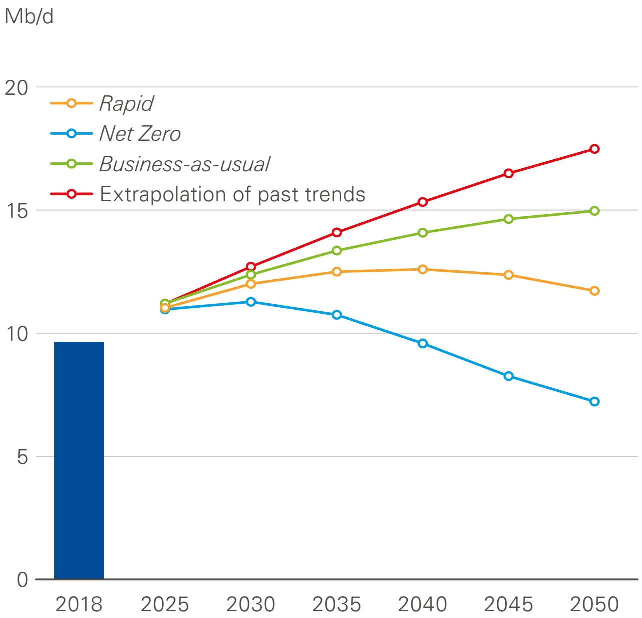
- Industrial energy demand in both *Rapid* and *Net Zero* is relatively flat over the Outlook, dampened by increasing efficiency gains in industrial processes and an expansion of the circular economy. Industrial demand in *BAU* increases by around 15% (0.5% p.a.) by 2050, which is significantly slower growth than the past 20 years.
- The increasing role of the circular economy in *Rapid* and *Net Zero* limits the growth in industrial output, as materials such as steel, aluminium and plastics are used less and are increasing reused and recycled. Combined with increasingly efficient industrial processes, energy used at the final point of consumption in the industrial sector falls by around 15% by 2050 in *Rapid* and by 25% in *Net Zero*. These falls are offset by the increasing use of electricity and hydrogen, especially in *Net Zero*, which boosts the demand for the primary energy used in their production.
- The growth of industrial energy demand in all three scenarios is concentrated in the emerging world (outside of China) – especially, India, Other Asia and Africa – as energy- and labour-intensive industrial activities are increasingly relocated from the developed world and China to lower-cost economies.
- The use of coal within industry falls sharply in all three scenarios. In *BAU*, the increased demand for energy is more than met by the growing use of gas and electricity, with coal consumption falling by around a third. The demise of coal use in industry is much more pronounced in *Rapid* and *Net Zero* where it is almost entirely eliminated in both scenarios by 2050, replaced by an increasing share of electricity, biomass and hydrogen. The shift towards low-carbon energy sources is most pronounced in *Net Zero*, such that the use of gas (and oil) also falls substantially by 2050. In contrast, the use of gas in industry in *Rapid* is broadly unchanged over the Outlook.

The non-combusted use of fuels continues to grow, but at much reduced rates

Non-combusted demand by fuel



Oil feedstock for plastics and fibres



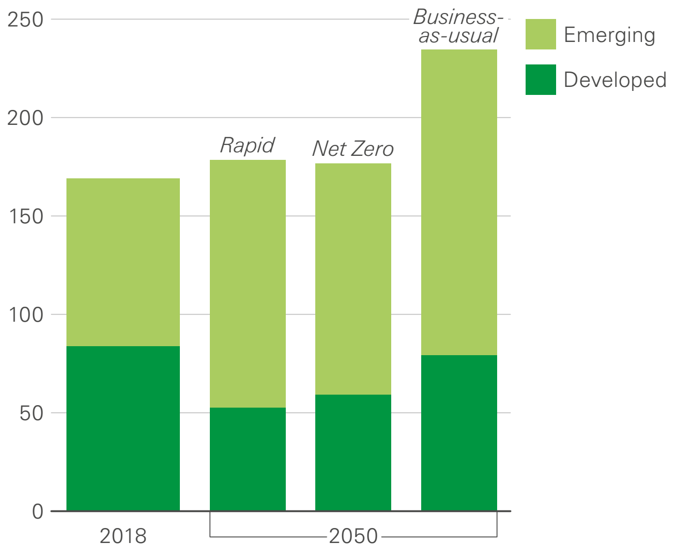
Key points

- The non-combusted use of fuels – predominantly as feedstocks for petrochemicals, bitumen and fertilizers – is an important source of incremental demand for fossil fuels, although less than in the past 20 years as environmental pressures increase.
- The non-combusted use of fuels (oil, natural gas and coal) grows at an average rate of 1.1% p.a. in *BAU*, less than half the rate seen over the past 20 years (2.7% p.a.). This deceleration largely reflects actions to both increase the level of recycling – recycling rates roughly double from current levels to around one third by 2050 – and encourage a shift away from the use of some manufactured products, such as single-use plastics and fertilizers.
- These actions are greatly intensified in *Rapid* and *Net Zero*, with increased use of chemical recycling and a focus on reducing the demand for some products and increasing the reuse of others. As a result, the growth of non-combusted fuels in *Rapid* (0.5% p.a.) is half that of *BAU*, with use gradually declining in the 2040s. In *Net Zero*, the use of non-combusted fuels peaks around 10-years earlier and by 2050 is around 25% below current levels.
- Oil accounts for almost two-thirds of the growth in non-combusted fuels out to 2050 in *BAU* and around half in *Rapid*, driven in large part by the production of plastics and fibres. The actions to reduce, reuse and recycle plastics means that the level of oil used in the production of plastics by 2050 is around 3 Mb/d lower in *BAU* and 6 Mb/d in *Rapid* relative to an extrapolation of past trends linked to the growth in economic activity and prosperity. These trends are even more pronounced in *Net Zero*, with oil demand by 2050 2 Mb/d below current levels and 10 Mb/d below an extrapolation of past trends.

Improving living standards in the developing world drive increasing use of electricity in buildings

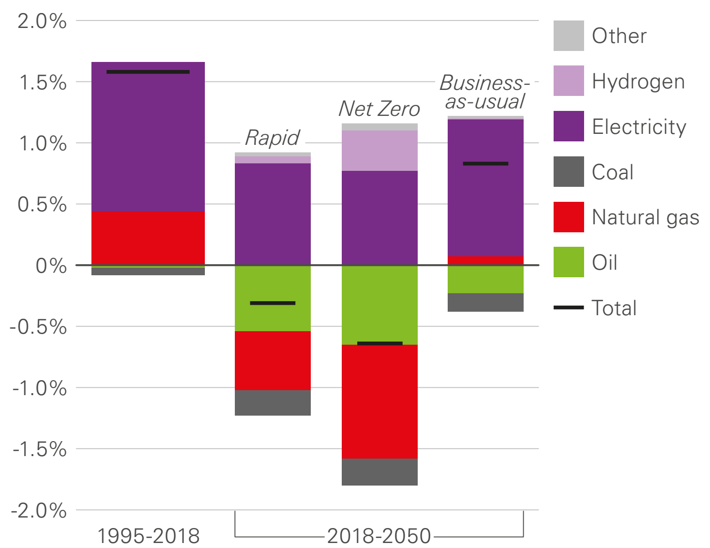
Primary energy demand in buildings

EJ



Growth of final energy consumption in buildings by energy carrier

% per annum

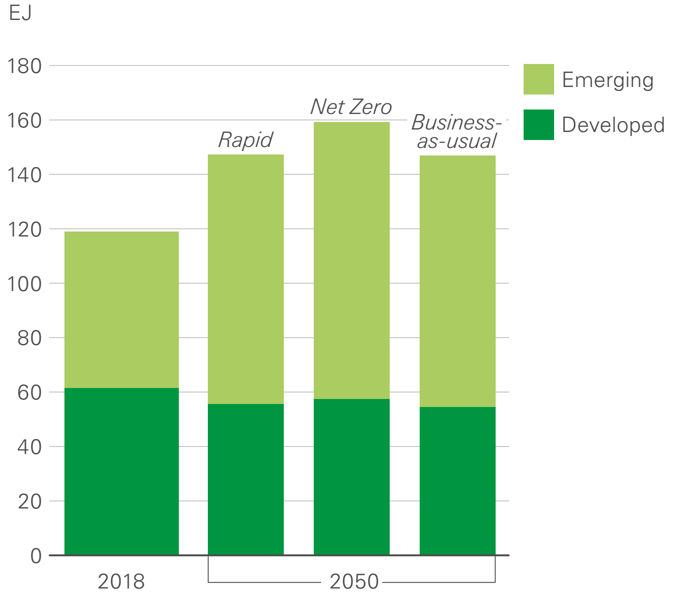


Key points

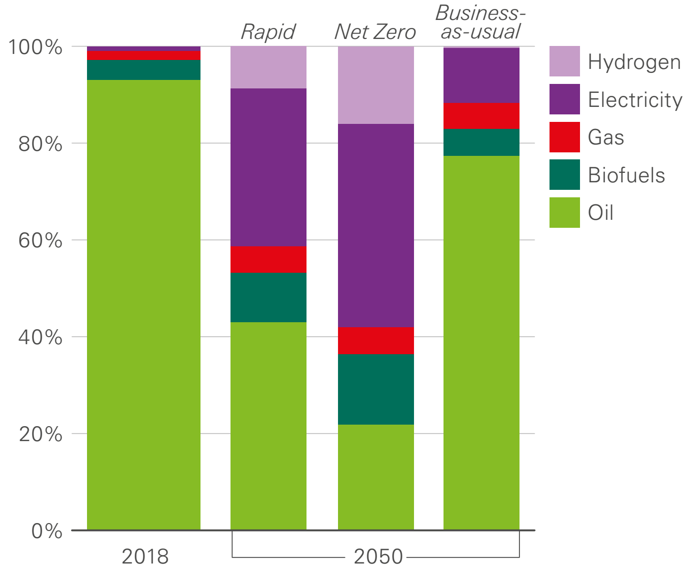
- The growth of energy absorbed by the buildings sector emanates entirely from the developing world, as improving wealth and living standards allow people to live and work in greater comfort.
- In *Rapid* and *Net Zero*, a significant expansion of energy use in buildings in developing Asia and Africa – which enjoy some of the most significant increases in prosperity – is broadly offset by substantial falls in the developed world as efficiency in new and existing buildings stock improves, driven by regulations, carbon prices and consumer preferences. As a result, overall energy use in buildings is relatively little changed over the Outlook in both *Rapid* (0.2% p.a.) and *Net Zero* (0.1% p.a.).
- The efficiency gains are less pronounced in *BAU*, with energy consumed in the buildings sector growing by almost 40% (1.0% p.a.) by 2050, accounting for around 40% of the overall increase in primary energy.
- Electricity consumption increases materially in all three scenarios, driven by the greater use of lighting and electrical appliances (including for space cooling) as living standards increase.
- The increasing use of electricity crowds out the demand for oil, gas and coal which lose share in all three scenarios. The shift away from these traditional energies is most pronounced in *Rapid* and *Net Zero*, in which the use of oil in buildings is largely phased out by 2050, and the demand for gas in buildings falls by around 50% in *Rapid* and over 90% in *Net Zero*.

The growth of energy used in transportation slows, with oil peaking in mid-to-late 2020s

Primary energy demand in transport



Share of final energy consumption in transport by energy carrier



Key points

- The demand for passenger and commercial transportation increases strongly over the Outlook, with road and air travel doubling in all three scenarios. The growth in final energy required to fuel this increased travel is offset by significant gains in vehicle efficiency, especially in passenger cars, trucks and aviation.

- The gains in energy efficiency are partially disguised by a shift away from oil towards the increasing use of electricity and hydrogen in transport. In particular, the conversion process used to produce these energy carriers boosts the total amount of primary energy absorbed by the transport sector. The shift towards electricity and hydrogen is most pronounced in *Rapid* and *Net Zero*, where overall primary energy increases by around 25% and 35% respectively by 2050. Primary energy in transport increases by almost 25% in *BAU*, with slower gains in energy efficiency offset by a smaller shift away from oil.

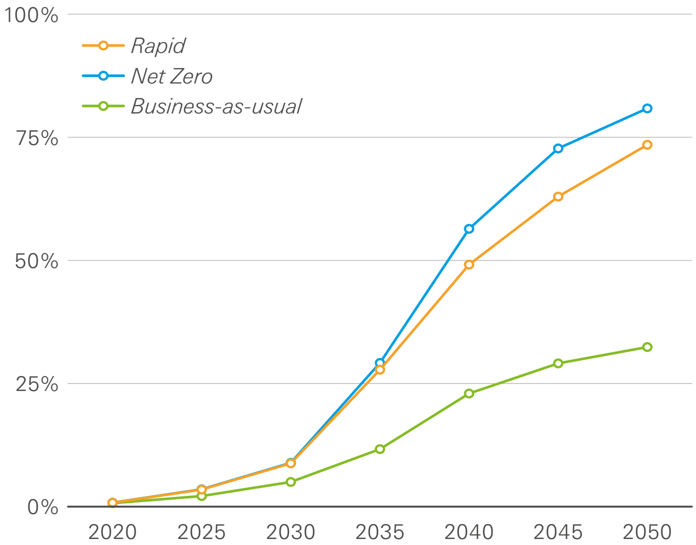
- The growth in primary energy used in transport in all three scenarios stems entirely from the developing world, as increasing prosperity in developing Asia, Africa and Latin America supports greater demand for passenger and freight transportation. Energy use in transport in the developed world is broadly flat.

- The use of oil in transport peaks in the mid-to-late 2020s in all three scenarios: the demand for oil for road transport in emerging markets continues to increase until the early 2030s in *Rapid* and *Net Zero*, and the late 2030s in *BAU*, but this is increasingly offset by falls in the developed world.

- The share of oil in total final consumption falls from over 90% of transport demand in 2018 to around 80% by 2050 in *BAU*, 40% in *Rapid* and just 20% in *Net Zero*. The main counterpart is the increasing use of electricity, especially in passenger cars and light and medium-duty trucks, along with hydrogen, biofuels and gas. The share of electricity in end energy use in transport increases to between 30% and 40% by 2050 in *Rapid* and *Net Zero*.

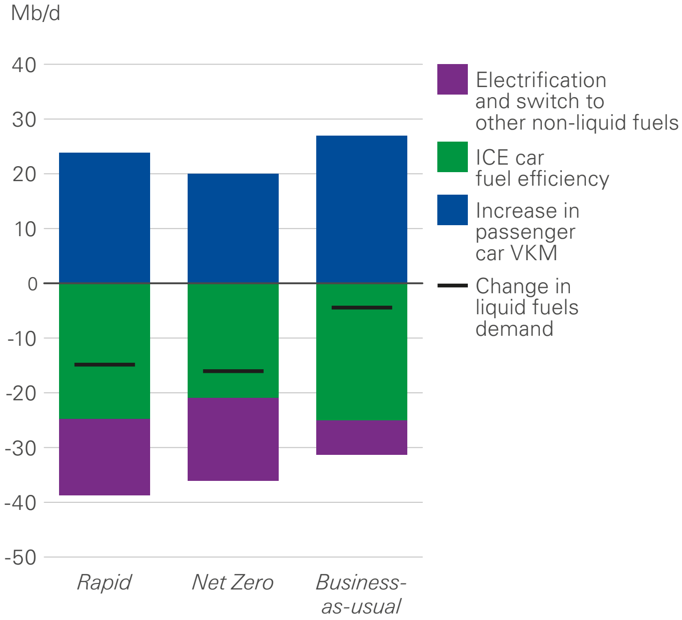
Energy use in road transport is dominated by electrification and vehicle efficiency

Share of car and truck vehicle kilometres electrified*



*includes buses

Factors impacting passenger car liquid fuels demand over the outlook

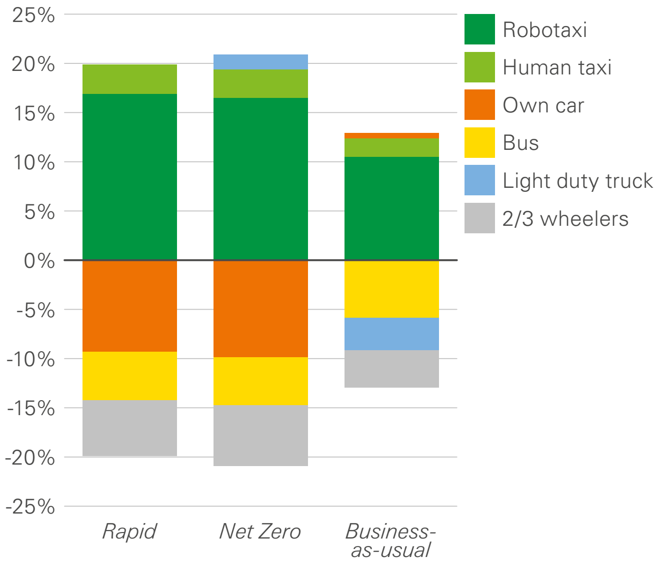


Key points

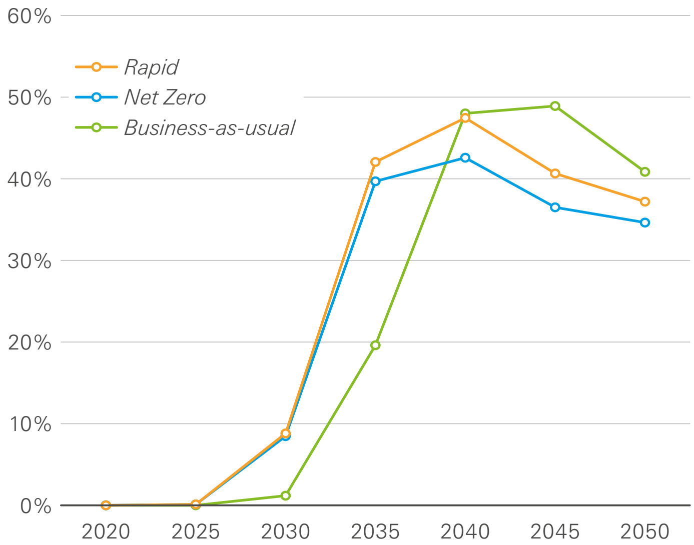
- The outlook for energy use in road transport is dominated by two major trends: increasing electrification and improving vehicle efficiency.
- The electrification of the vehicle parc is most pronounced in *Rapid* and *Net Zero*, concentrated in two and three wheelers, passenger cars and light and medium-duty trucks. Electric vehicles in *Rapid* and *Net Zero* account for around 30% of four-wheeled vehicle kilometres (VKM) travelled on roads in 2035 and between 70-80% in 2050, compared with less than 1% in 2018. The corresponding shares in *BAU* are a little over 10% in 2035 and around 30% in 2050.
- By 2050, electric vehicles account for between 80-85% of the stock of passenger cars in *Rapid* and *Net Zero* and 35% in *BAU*. The corresponding numbers for light and medium-duty trucks are 70-80% and 20%.
- The other dominant trend affecting the use of energy in road transport is the increasing levels of vehicle efficiency, especially passenger cars, driven by tightening vehicle emission standards and rising carbon prices which are largely borne by consumers in the form of higher gasoline and diesel prices. In *Rapid*, the efficiency of a typical new internal combustion engine (ICE) passenger car increases by around 45% over the next 15 years.
- Despite the accelerated electrification of passenger cars, the continuing importance of ICE passenger cars for much of the Outlook means that improvements in their efficiency is the main factor limiting the growth of oil used in passenger cars out to 2050.
- Vehicle efficiency improvements in *Rapid* reduce oil use in passenger cars (and hence emissions) by roughly twice as much as electrification out to 2050

The pattern of road transportation changes led by increasing prosperity and growth of robotaxis

Change in share of road passenger VKM, 2020-2050



Robotaxi share of passenger car VKM powered by electricity



Key points

- The composition of road transportation across different modes of transport, e.g. private cars, taxis, buses etc, is affected by two significant trends over the Outlook: increasing levels of prosperity and the falling cost of shared-mobility transport services. Both trends have important implications for the pace and extent to which the transport sector is decarbonized.

- The increasing levels of prosperity and living standards in emerging economies leads to a shift away from high-occupancy forms of transport (e.g. buses) into passenger cars. This leads to a reduction in average load factors (i.e. average number of passengers per vehicle), putting upward pressure on carbon emissions.

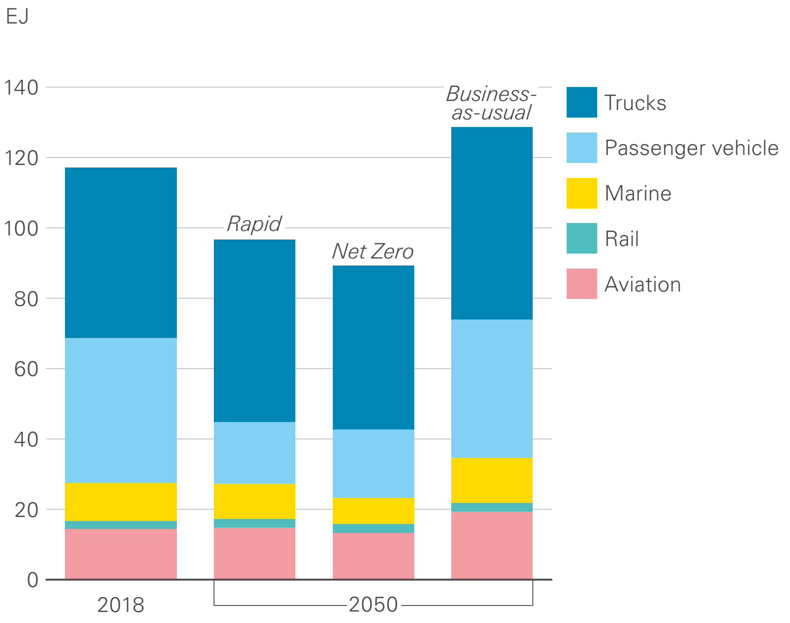
- The relative cost of shared mobility services falls as a result of a range of factors, including continuing advances in digital technologies such as improving connectivity and geospatial technologies. In addition, digital advances enable automated driving systems and the emergence of fully autonomous vehicles (AVs) from the early 2030s in *Rapid* and *Net Zero*, significantly reducing the cost of shared-mobility services, especially in developed economies where average income levels are higher. The falling relative cost of autonomous shared-mobility services (robotaxis) leads to a shift away from private-owned vehicles as well as buses.

- The vast majority of robotaxis are electric in all three scenarios. This reflects the local air quality benefits and lower running costs of electric cars relative to traditional (internal combustion engine). Electric robotaxis provide a significant cost advantage given the intensity of use – up to 9-times greater than private cars by 2050. The growing penetration of robotaxis, combined with their intensity of use, means that by 2035 they account for around 40% of passenger VKM powered by electricity in *Rapid* and *Net Zero* and around 20% in *BAU*. This share declines in the final 10-years or so of the Outlook in *Rapid* and *Net Zero* as the share of private ownership of electric cars increases.

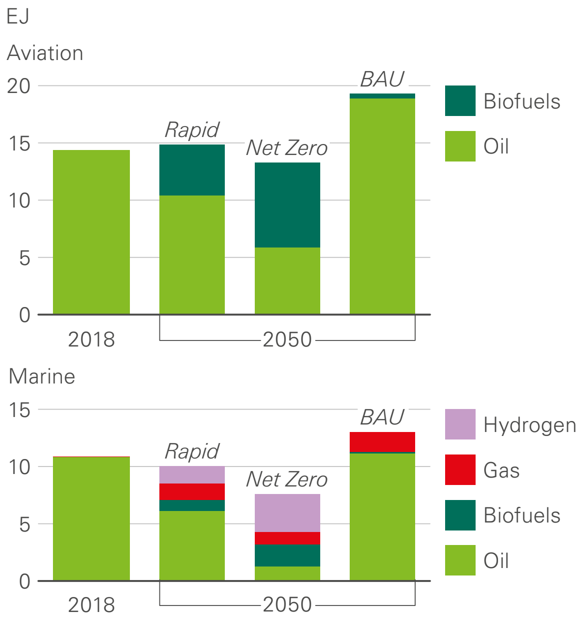
- The potential for robotaxis to help decarbonize road transportation by increasing the share of passenger car VKM powered by electricity means they are supported by government policies, such as higher road pricing and congestion charges for private vehicles, particularly in *Rapid* and *Net Zero*. The importance of robotaxis is also supported in *Net Zero* by a shift in societal attitudes towards a sharing economy.

Biofuels and hydrogen play a key role in decarbonizing aviation and marine

Total final energy demand in transport by mode



Aviation and marine demand by source



Key points

- Aviation and marine transport accounted for around 7 Mb/d and 5 Mb/d of oil consumption in 2018 respectively. Demand for these services increases over the Outlook in both *Rapid* and *BAU*: growth in shipping is driven by increased levels of trade; whilst expansion in air-travel is underpinned by growing prosperity, especially in emerging economies. In *Net Zero*, the growth in air travel by 2050 is around 10% lower than in *BAU*, reflecting in part a shift in societal preferences to use high-speed rail as an alternative to air travel in China and much of the OECD. Similarly, increasing preference for the consumption of locally-produced goods and reduction in oil trade in *Net Zero* contributes to reduced shipping demand by around a third by 2050 relative to *BAU*.
- In *Rapid*, liquids demand from aviation remains relatively stable at around 7 Mb/d over the course of the Outlook, as efficiency improves by around 35%, largely offsetting additional demand for air travel. In *Net Zero*, these efficiency savings plus reduced appetite for flying in some markets means liquids demand from aviation peaks in the early 2030s and declines to a little below 2018 levels by 2050. In contrast, liquids demand continues to grow throughout the Outlook in *BAU*, reaching 10 Mb/d by 2050.
- Biofuels play a critical role in decarbonizing the aviation sector, since neither batteries nor hydrogen are able to deliver the necessary energy density required for aviation. The share of biofuels in jet-fuel increases from less than 1% in 2018 to around 30% by 2050 in *Rapid* and to nearly 60% in *Net Zero*. In contrast, there is minimal growth in the share of biofuels in *BAU*.
- Unlike aviation, the fuel mix in the shipping sector is able to diversify into hydrogen (either as ammonia or in liquid form) and LNG, as well as biofuels. In *Rapid* and *Net Zero*, non-fossil fuels account for 40% and 85% of marine transport fuel by 2050 respectively, with more than half of that coming from hydrogen. Conversely, under *BAU*, marine demand for oil increases slightly by 2050, with natural gas increasing its share of the sector fuel mix to just under 15% and non-fossil fuels accounting for just 1%.

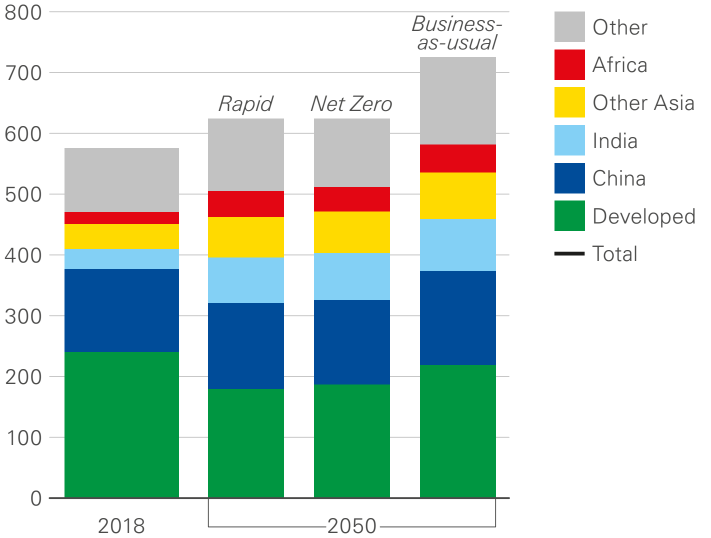
Regions

Summary
Regional energy demand and carbon emissions
Fuel mix across key countries and regions
Global energy trade and energy imbalances
Alternative scenario: *Deglobalization*

Growth in global energy demand comes entirely from emerging economies

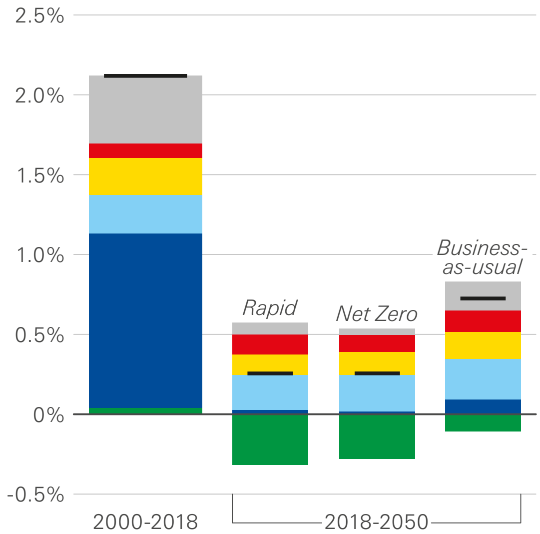
Primary energy consumption by region

EJ



Primary energy growth and regional contributions

% per annum



Key points

- Growth in global energy demand in all three scenarios is driven entirely by emerging economies, underpinned by increasing prosperity and improving access to energy. Energy consumption in the developed world falls as improvements in energy efficiency outweigh demands from higher levels of activity.
- The contrasting energy trends in developed and emerging economies lead to a continuing shift in the centre of gravity of energy consumption, with the emerging world accounting for around 70% of energy demand by 2050 in all three scenarios, up from around 50% as recently as 2008.
- Growth of energy consumption in the emerging economies is led by India and Other Asia, which together account for more than the entire increase in primary energy in *Rapid* and *Net Zero* and almost 60% in *BAU*. India is the largest source of demand growth out to 2050 in all three scenarios.
- Growth in China's energy demand slows sharply relative to past trends, reaching a peak in the early 2030s in all three scenarios. Indeed, China's energy demand in *Rapid* and *Net Zero* by 2050 is back close to 2018 levels, helped by accelerating gains in energy efficiency and a continuing shift in the structure of the economy away from energy-intensive industries. Despite that, China remains the largest market for energy in all three scenarios, accounting for over 20% of the world's energy demand in 2050, almost twice that of India.
- Africa's contribution to demand growth increases in the second half of the Outlook, supported by a growing population and rising prosperity. Even so, Africa's energy consumption remains small relative to its size: although around a quarter of the world's population are projected to live in Africa in 2050, it accounts for less than 10% of total energy demand in all three scenarios.

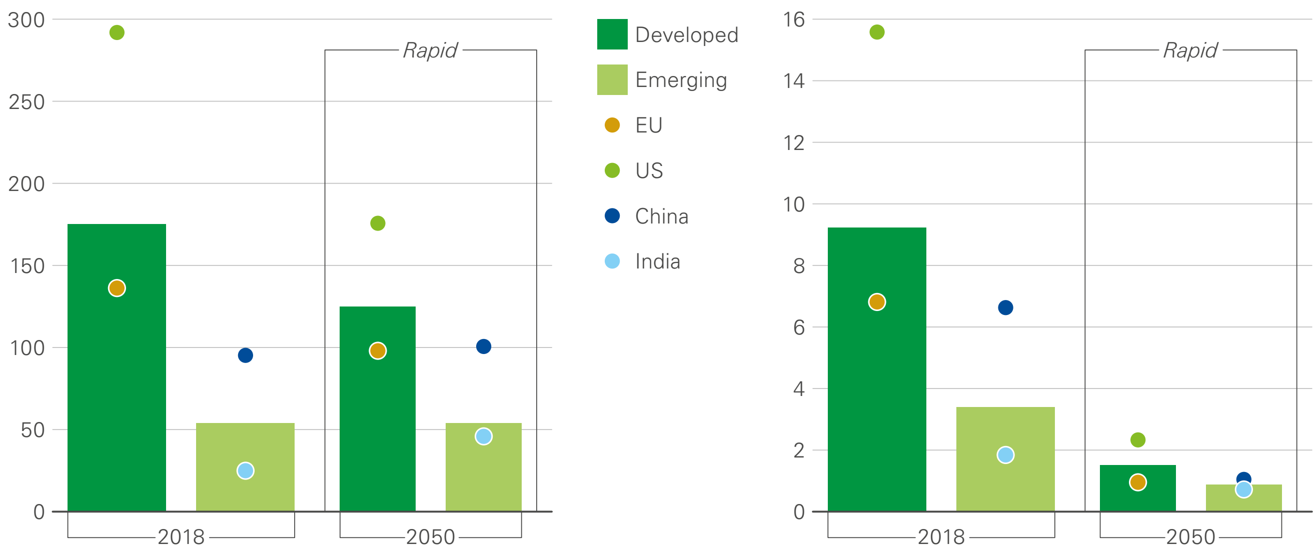
Global differences in energy consumption and carbon emissions narrow over the Outlook

Energy consumption per head in *Rapid*

GJ per head

Carbon emissions per head in *Rapid*

Tonnes of CO_2 per head

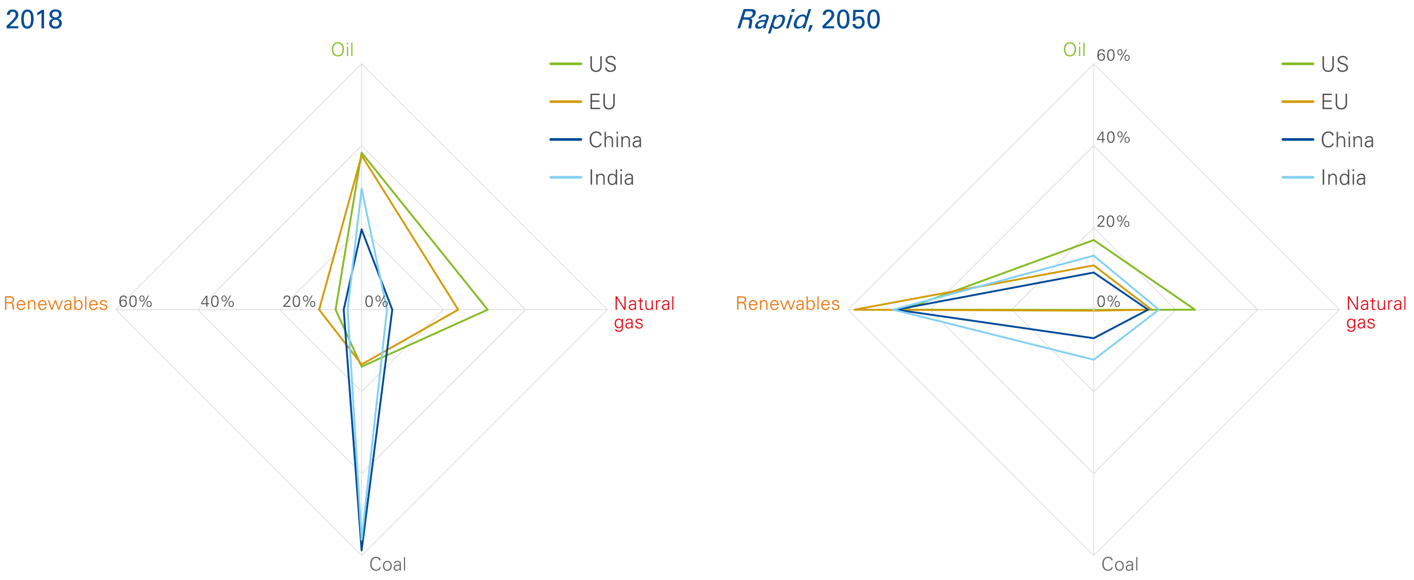


Key points

- A key factor underlying the contrasting trends in energy demand in developed and emerging economies are the significant differences in the level of energy consumption per capita.
- In 2018, average energy consumption per capita in the developed world was more than three times that in emerging economies, with an average person in the US consuming 12 times more energy than an average person in India.
- These differences in energy consumption largely reflect differences in economic development and prosperity, as well as a range of other factors, including economic structure, local climatic conditions and differences in natural resource endowments.
- The degree of this inequality narrows over the Outlook, reflecting both the sustained increases in economic activity and prosperity in the emerging world and the marked falls in energy consumption per capita in developed economies: US energy consumption per capita falls by 40% over the Outlook in *Rapid*. Even so, by 2050, average energy consumption per capita in the developed world in *Rapid* is still more than twice that in emerging economies. Similar convergence in energy consumption per head is also apparent in *Net Zero* and *BAU*.
- These differences in the current levels of energy consumption between developed and emerging economies are also reflected in average carbon emissions per capita, offset only partially by the lower average carbon intensity of the fuel mix in the developed world relative to emerging economies.
- The differential in carbon emissions per capita narrows markedly by the end of the Outlook in *Rapid*. This is almost entirely driven by the narrowing in energy consumption per capita, with the degree of improvement in the average carbon intensity of the fuel mix broadly similar in developed and emerging economies.

The low-carbon transition leads to a gradual convergence in the fuel mix across countries

Shares of energy sources



Key points

- As well as differences in the pattern of energy demand growth across developing and emerging economies, the nature of the energy transition also depends on variations in the fuel mix in different parts of the world.

- There are marked differences in the current mix of energy used across countries and regions, as illustrated, for example, by the varying importance of different energy sources in US, EU, China and India. These differences reflect numerous factors including the level of economic development and the cost and availability of different energy sources.

- The current fuel mix in the US and EU have some similarities, with oil and gas accounting for the majority of energy supplies, and coal and renewable energy having significantly smaller shares. This contrasts with China and India, where coal currently accounts for between 55-60% of primary energy.

- The transition to a lower-carbon energy system in *Rapid* is driven by several common trends which lead to a gradual convergence in the fuel mix across all four countries.

- Most significant is the growing competitiveness of renewable energy, which combined with its widespread availability and the increasing electrification of the energy system, leads renewable energy to be the single largest energy source in all four countries in *Rapid* by 2050, providing between 45-55% of energy supplies.

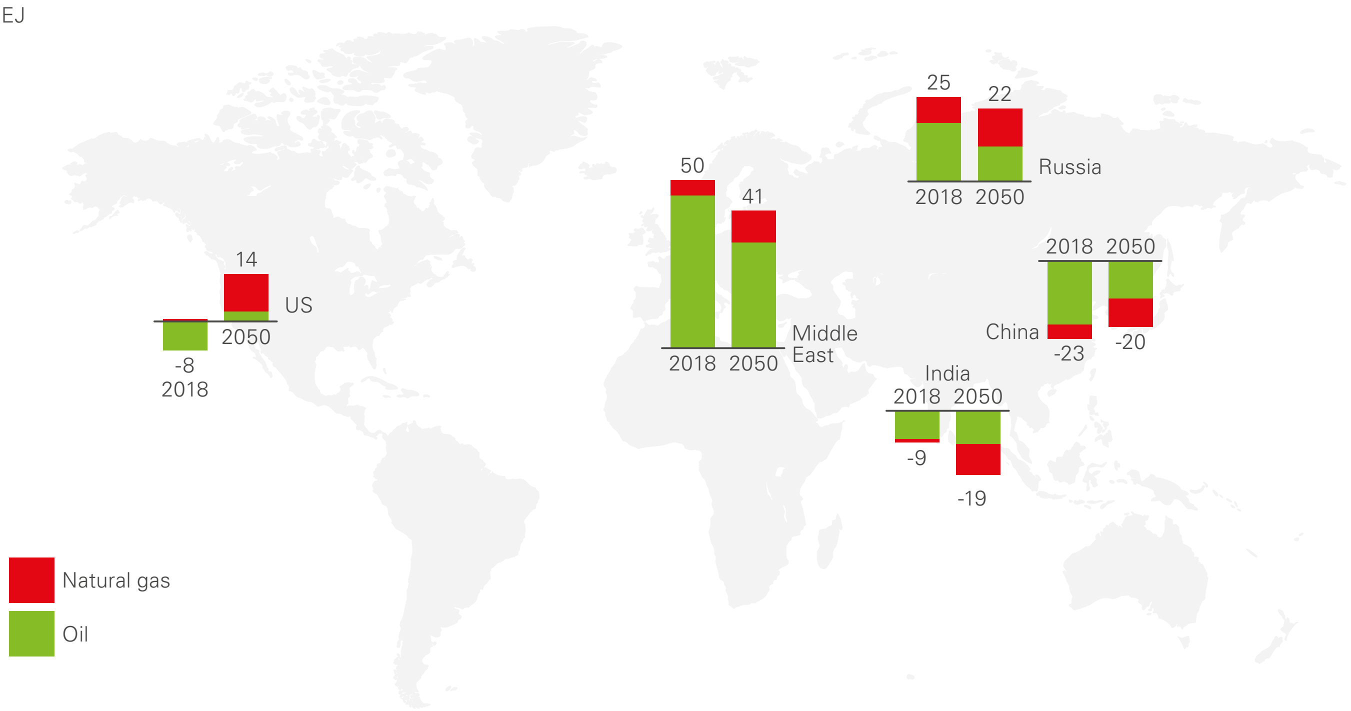
- The growth in renewables (including bioenergy) is part of a broader trend towards a lower carbon fuel mix, supported by higher carbon prices and other policies. This shift is also reflected in a move away from the use of coal, which is substantially reduced in China and India in *Rapid* by 2050, and entirely phased-out in the US and EU.

- These trends also help drive a convergence in the role of natural gas, with its share declining in US and EU, and increasing in China and India, such that by 2050 it accounts for between 15-25% of energy in all four countries.

- A similar degree of convergence is also apparent in *Net Zero*. Although the same qualitative trends are apparent in *BAU*, the more limited progress made in phasing out coal use in China and India means the degree of convergence is considerably less.

Significant energy imbalances persist over the Outlook

Net import and exports of oil and gas by region in *Rapid*



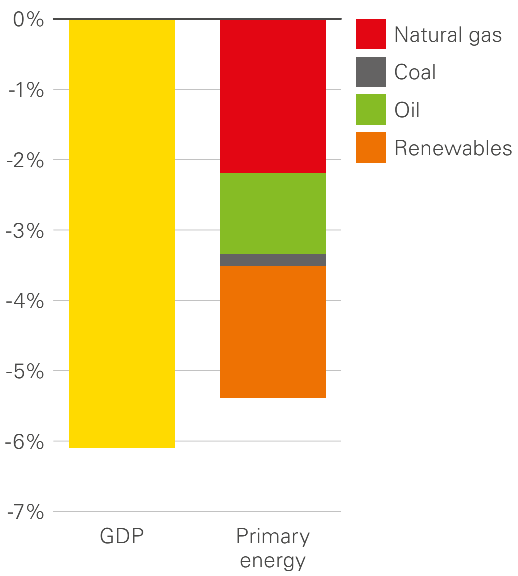
Key points

- The global energy system is highly interconnected, with huge international flows of traded energy. In 2018, almost three-quarters of global oil production was traded internationally and around a quarter of natural gas.
- These trade flows are associated with large energy imbalances (surpluses and deficits) as countries with large resource endowments export energy to countries with less natural energy resources.
- For example, in 2018, China imported around 70% of the oil it consumed and a little over 40% of its natural gas. The corresponding numbers for India were a little above 80% and 50%.
- These oil and gas deficits in China and India persist in *Rapid*, although to varying degrees. China's combined net imports of oil and gas decline slightly by 2050, helped by a 50% fall in Chinese oil demand (see pp 66-67). In contrast, India's combined oil and gas imports more than double by 2050, driven in part by increased coal-to-gas switching which leads to a marked deepening in India's dependence on imported LNG.
- On the other side of the trade balance, exports of oil and gas over the Outlook continue to be dominated by the Middle East and Russia.
- The expansion in US oil and gas production associated with the shale revolution, together with falling domestic consumption, means the US becomes a sizeable net exporter of oil and especially gas in *Rapid*. US exports of oil and gas peak in the 2030s before gradually declining as production of US tight oil and unconventional NGLs falls back (see pp 70-71).
- The disruptions associated with Covid-19, together with the increase in trade disputes and sanctions in recent years, may lead to rising concerns about energy security, particularly in countries which are highly dependent on energy imports.
- The potential impact of a shift towards deglobalization and increased concerns about energy security on the global energy system is explored on the next page.

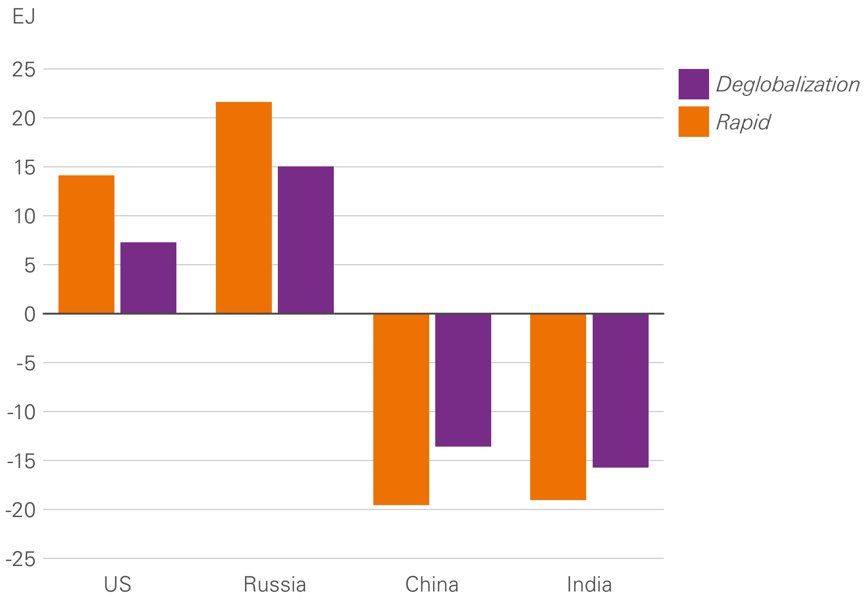
Alternative scenario: *Deglobalization*

Covid-19 may lead to deglobalization and increased concerns about energy security

Deglobalization versus *Rapid*: Global GDP and energy in 2050



Net exports of oil and gas in 2050



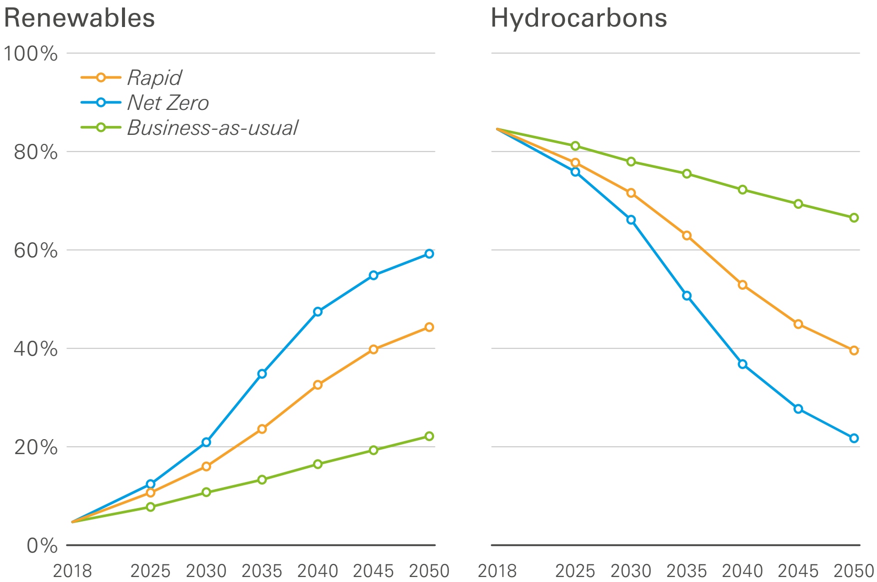
Key points

- The disruptions associated with Covid-19 may lead to a process of deglobalization, as countries seek to increase their resilience by becoming less dependent on imported goods and services, and companies reshore certain activities and move supply chains closer to home. One manifestation of these trends is that concerns about energy security may increase, particularly in countries which are highly dependent on energy imports.
- The impact of these possible changes on *Rapid* is explored in an alternative *Deglobalization* case in which:
  - the reduced openness of the global economy is assumed to lead to a slight reduction (0.2 percentage points) in trend global GDP growth; and
  - increased concerns about energy security lead countries to attach a small risk premium (10%) on imported sources of energy.
- The slower trend GDP growth results in the level of world GDP by 2050 being 6% lower in *Deglobalization* than in *Rapid* and energy demand around 5% lower, with those falls concentrated in countries and regions most exposed to reduced foreign trade.
- The risk premia on imported energy means that the fall in energy is concentrated in traded fuels, especially in oil and natural gas given the relatively low level of coal consumption remaining towards the end of the Outlook in *Rapid*. These falls lead to a pronounced narrowing in energy deficits and surpluses around the world. For example, China's net imports of oil and gas in *Deglobalization* are 30% lower than in *Rapid* by 2050. Likewise, US net exports of oil and gas are around 50% lower by 2050.
- The fall in traded fossil fuels relative to domestically produced energy, especially renewable energy, means that the carbon-intensity of the global fuel mix by 2050 is slightly lower in *Deglobalization* than in *Rapid*.

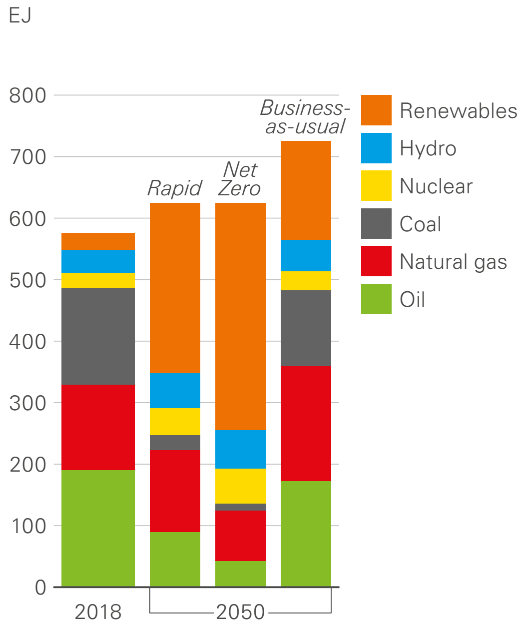
Demand and supply of energy sources

Renewables lead the transition to a lower-carbon energy mix

Shares of primary energy



Primary energy consumption by source



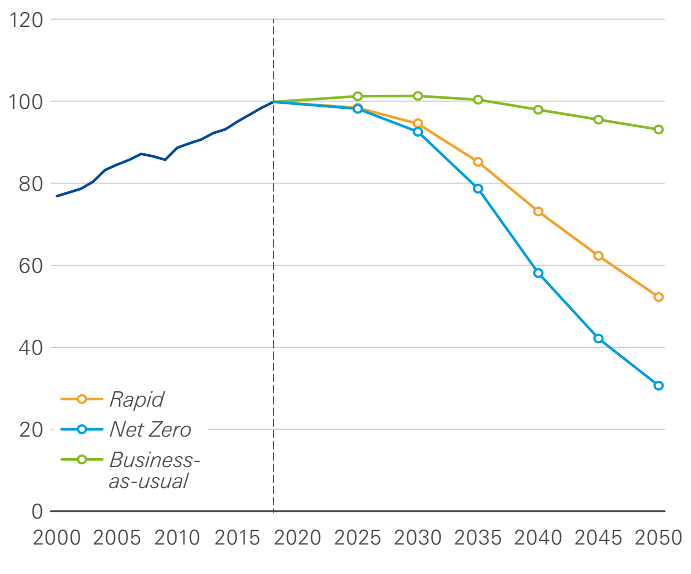
Key points

- The growth in primary energy over the Outlook is dominated by renewable energy, as the world shifts towards lower-carbon energy sources.
- Renewable energy – including wind, solar, geothermal and bioenergy but excluding hydroelectricity (see pp 84-87) – increases more than 10-fold in both *Rapid* and *Net Zero*, with its share in primary energy rising from 5% in 2018 to over 40% by 2050 in *Rapid* and almost 60% in *Net Zero*. Although the growth of renewables is less pronounced in *BAU*, they still account for around 90% of the overall increase in primary energy over the next 30 years (pp 84-85).
- The increasing importance of renewable energy comes at the expense of hydrocarbons whose share of primary energy declines from close to 85% in 2018 to around 40% by 2050 in *Rapid* and 20% in *Net Zero*.
- Within hydrocarbons, natural gas has the most durable outlook, with its level in *Rapid* in 2050 broadly unchanged from its current level and around 35% higher in *BAU*. Consumption of natural gas falls by around 40% by 2050 in *Net Zero* (pp 76-77).
- The level of oil demand in both *Rapid* and *Net Zero* does not fully recover from the sharp drop caused by Covid-19, with demand falling by around 50% by 2050 in *Rapid* and almost 80% in *Net Zero*. The outlook for oil is more resilient in *BAU*, with demand in 2050 declining slightly from its current level (pp 66-67).
- Coal consumption declines significantly in all three scenarios, particularly in *Rapid* and *Net Zero* in which it falls by well over 80% by 2050 (pp 88-89).
- The way in which the pronounced falls in the demand for oil, natural gas and coal in *Net Zero* are matched on the supply side by the countries and regions which produce these forms of energy is very uncertain and not explored in detail in this section.

Global market for liquid fuels adjusts to changing patterns of demand and production

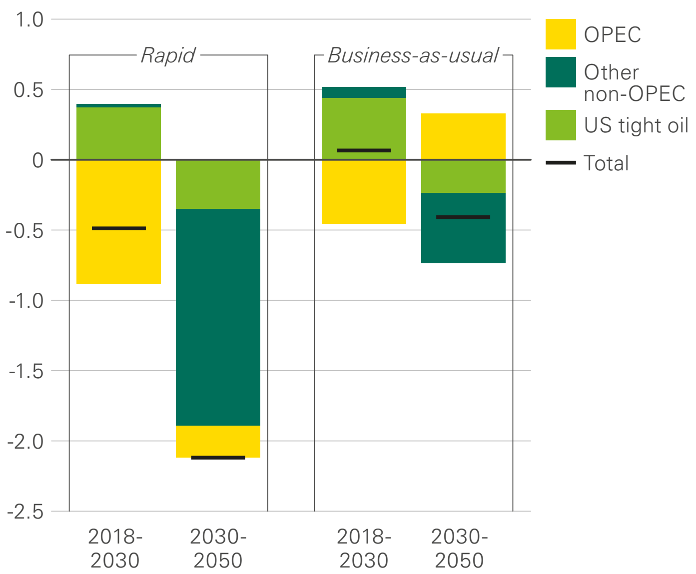
Liquid fuels consumption

Mb/d



Liquid fuels supply growth

Mb/d, average annual growth



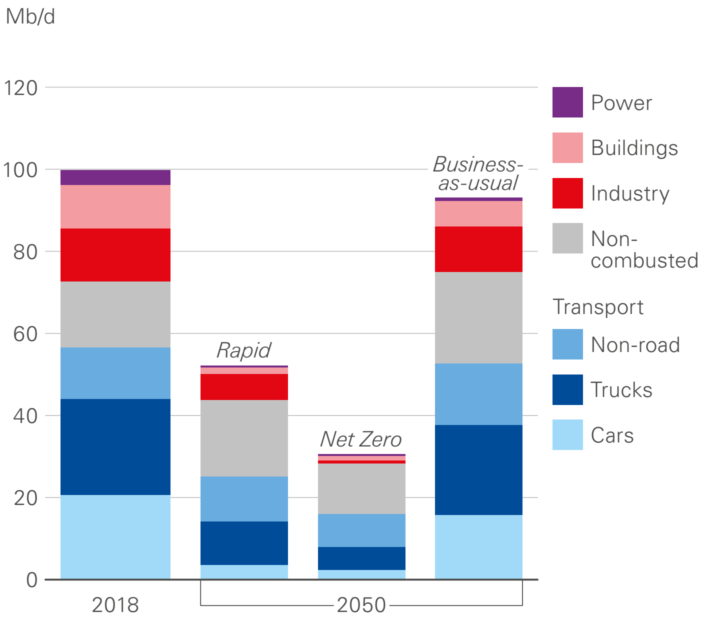
Key points

- The global market for liquid fuels (oil, biofuels and other liquids) transitions as oil demand peaks and supplies shift.
- The demand for liquid fuels in *Rapid* and *Net Zero* never fully recovers from the fall caused by Covid-19, implying that oil demand peaked in 2019 in both scenarios.
- The consumption of liquid fuels falls significantly over the Outlook in both scenarios, declining to less than 55 Mb/d and around 30 Mb/d in *Rapid* and *Net Zero* respectively by 2050. The falling demand is concentrated in the developed world and China, with consumption in India, Other Asia and Africa broadly flat over the Outlook as a whole in *Rapid*, but falling below 2018 levels from the mid-2030s onwards in *Net Zero*.
- In contrast, after recovering from the impact of Covid-19, the consumption of liquid fuels in *BAU* is broadly flat at around 100 Mb/d for the next 20 years, before edging lower to around 95 Mb/d by 2050. Demand for liquid fuels continues to grow in India, Other Asia and Africa, offset by the trend decline in consumption in developed economies.
- Despite the weakness in oil demand, US tight oil* in *Rapid* recovers from the impact of Covid-19 and expands until the early 2030s, with this increase in output more than offset by falls in OPEC production. Thereafter, OPEC production broadly stabilizes as declines in global demand are broadly matched by falls in US tight oil and other non-OPEC supplies. By 2050, non-OPEC supplies account for around two-thirds of the total decline in liquids supply in *Rapid*.
- US tight oil also grows over the next 10 years or so in *BAU* offset by declining OPEC production. Declines in US tight oil and other non-OPEC output from the mid-2030s onwards provides scope for OPEC to increase its production despite the backdrop of gradually declining demand. By 2050, the level of OPEC production in *BAU* is broadly unchanged from its level in 2018.

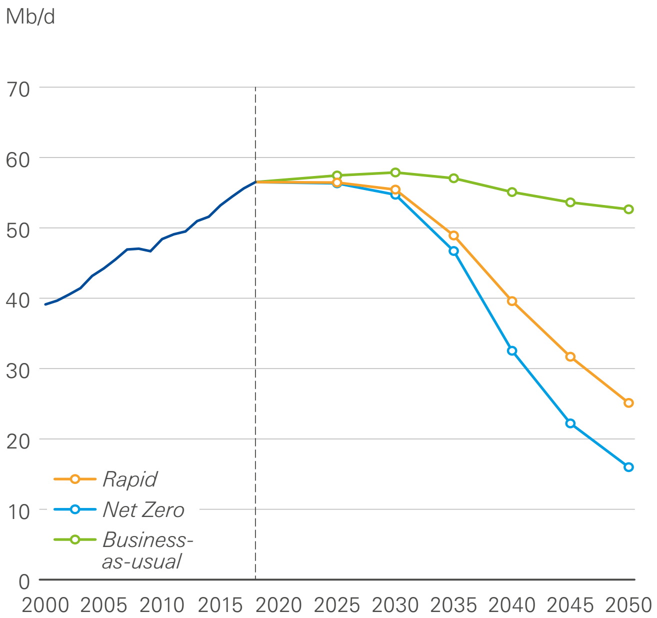
*US tight oil include crude, condensate and natural gas liquids from onshore tight formations

The outlook for liquid fuels demand is dominated by changes in the transport sector

Liquid fuels demand by sector



Consumption of liquid fuels in transport

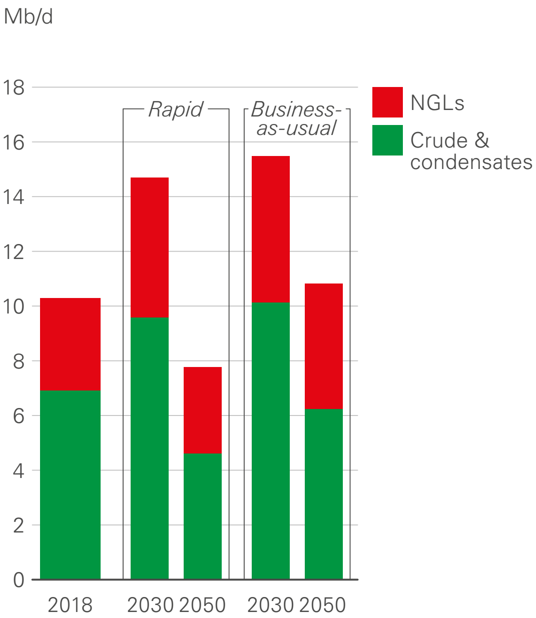


Key points

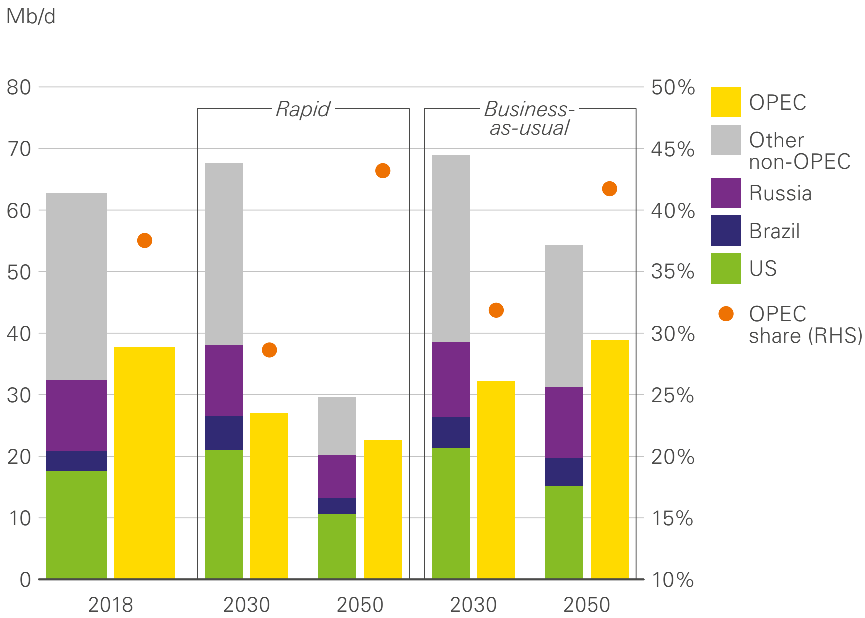
- The outlook for liquid fuels demand is dominated by the impact of Covid-19 in the near-term and by their declining use in the transport sector further out.
- Global liquids demand in all three scenarios is significantly affected by the impact of Covid-19, which disproportionately impacts economic activity and prosperity in emerging economies which are the main growth markets for liquid fuels. The experience of coronavirus also triggers some lasting changes in behaviour, especially increased working from home (see pp 28-29).
- Liquids demand in *Rapid* and *Net Zero* does not fully rebound from this near-term hit to demand and subsequently falls substantially over the Outlook to around 55 Mb/d and 30 Mb/d by 2050 respectively.
- The scale and pace of these falls are driven primarily by the changing use of liquid fuels in the transport sector, which declines sharply in the second half of the Outlook in both *Rapid* and *Net Zero*, driven by the increasing efficiency and electrification of road transportation (see pp 44-47). The transport sector accounts for around two-thirds of the decline in the use of liquid fuels by 2050 in *Rapid* and almost 60% in *Net Zero*.
- The pace of decline in liquids demand in the second half of the Outlook – during which it falls by an average of over 2 Mb/d per annum in *Rapid* and 3 Mb/d in *Net Zero* – is unprecedented and has significant implications for other parts of the oil industry, including refining (see pp 74-75).
- Liquids fuel demand in *BAU* is more resilient, with broadly stable use in transport helping to support global demand at around 100 Mb/d for much of the next 20 years, before it edges lower in the final 10 years of the Outlook as the use of liquid fuels within transport begins to decline.
- The non-combusted use of liquid fuels, largely as a feedstock in the petrochemicals sector, provides some degree of support to overall liquids demand, increasing in both *Rapid* and *BAU*, and declining below 2018 levels only in the final 10 years of the Outlook in *Net Zero*.

The supply of liquid fuels is initially driven by US tight oil, with OPEC's share recovering later

US tight oil production



Liquid fuels supply by region



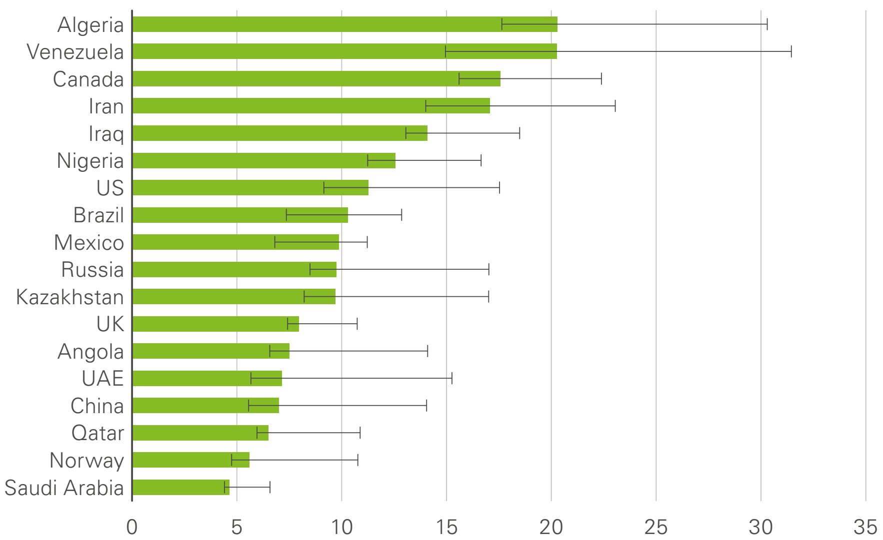
Key points

- The composition of global liquids supply is initially dominated by a rebound in US tight oil, with OPEC's share of production recovering in the second half of the Outlook.
- In *Rapid*, US tight oil recovers from the falls caused by the impact of Covid-19, increasing to close to 15 Mb/d in the early 2030s. Brazilian production also grows over the same period. But as US tight formations mature and OPEC adopts a more competitive strategy against a backdrop of accelerating declines in demand, US production and non-OPEC output more generally fall from the early 2030s onwards.
- OPEC production declines over the next 10 years or so before broadly stabilizing thereafter, with its share of total liquids production recovering from a low of close to 25% in the early 2030s to around 45% by 2050. The higher cost structure of non-OPEC production means around two-thirds of the total fall in liquids production in *Rapid* by 2050 is borne by non-OPEC supplies.
- Non-OPEC supplies follow a similar pattern in *BAU*, expanding in the first half of the Outlook, led by increases in US tight oil and Brazil, before declining in the second half as US tight oil peaks in the early 2030s. This reduction provides scope for OPEC to increase its production from the mid-2030s onwards, with its level of output by 2050 back close to 2018 levels and its market share rising to over 40%.
- As well the overall demand for liquid fuels falling, the transition to a lower-carbon energy mix also prompts a shift in the composition of liquid fuels. In *Rapid*, the overall decline in liquids supply over the Outlook is more than accounted for by a sharp fall in crude and condensates, while the production of biofuels increases by over 2 Mb/d. Similarly, although total liquids supply by 2050 in *BAU* is only slightly lower than 2018 levels, this is more than accounted for by a larger fall in crude and condensates, partially offset by growing supplies of natural gas liquids (NGLs) and biofuels.

Differences in operational carbon intensity of crudes have an increasing impact as carbon prices increase

Average carbon intensity of crude production by country, 2015

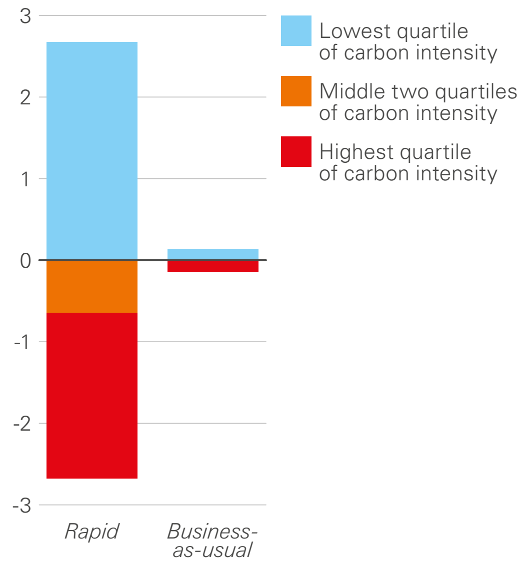
g of CO_2e/MJ



Source: Masnadi et al. (2018), Global carbon intensity of crude oil production graph includes countries with crude and condensates above 1 Mb/d in 2018. Error bars include 5-95th percentile of fields

Carbon intensity: impact on volumes*

Mb/d



*Difference in crude and condensate supplies relative to a counterfactual in which supplies have the same carbon intensity

Key points

- The carbon emissions associated with the production and transportation of crude oil and condensates accounted for around 5% of total carbon emissions from energy use in 2015.

- There is a significant variation in these operational emissions – measured by the carbon intensity of crude supplies – across (and within) different countries, reflecting differences in the nature and location of the operations. These differences in carbon intensity affect the exposure of different types of production to carbon prices.

- At low levels of carbon prices, these differences in carbon intensity have relatively little impact on overall costs and competitiveness and hence on the pattern of aggregate supplies. For example, in *BAU* in which carbon prices remain relatively low over the entire Outlook, the shift in the pattern of supplies between those in the highest and lowest quartiles of carbon intensity is less than 0.5 Mb/d by 2050 compared with a counterfactual case in which all supplies are assumed to have the same carbon intensity.

- In contrast, the higher level of carbon prices in *Rapid* increases the additional cost levied on supplies with higher levels of carbon intensity and so has a more material impact on their competitiveness. In particular, in *Rapid*, the increasing carbon price causes highest quartile intensity supplies by 2050 to be around 2 Mb/d lower than in the counterfactual case (a decline of almost 25%), with correspondingly greater volumes of lower quartile intensity supplies.

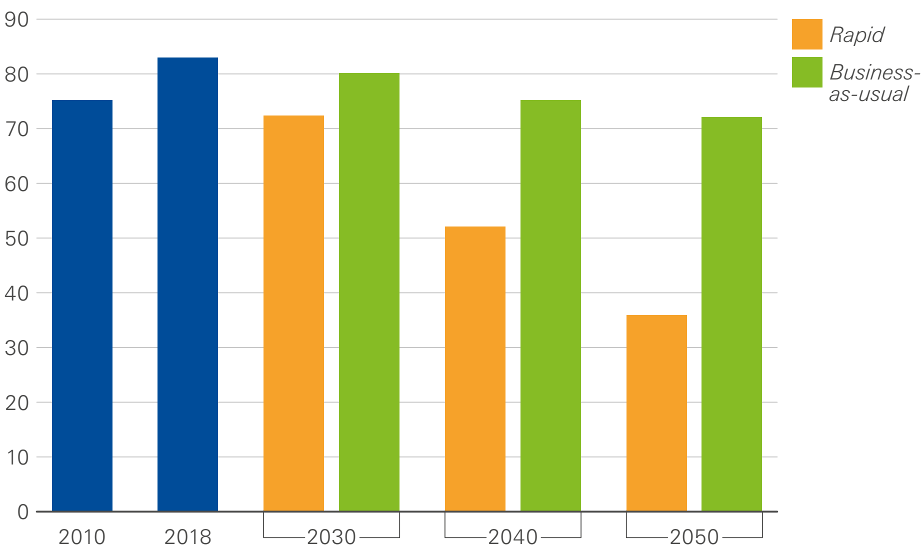
- The precise extent of this shift between high and low carbon intensity supplies depends on the extent the carbon intensity of different crudes and condensates can be reduced and at what cost. For example, it might be possible to reduce operational emissions of some onshore production via electrification at relatively little cost. But it seems likely that some of the differences in intensity is likely to persist and so have a bearing on the future pattern of supplies if carbon prices increase materially.

- A similar set of issues applies to differences in the carbon intensity of natural gas supplies, which in addition to differences in the carbon intensity of production, also depend on whether the gas is transported via pipelines or as LNG, which adds to its carbon intensity.

The outlook for refining is challenging, with declining demand and capacity shutdowns

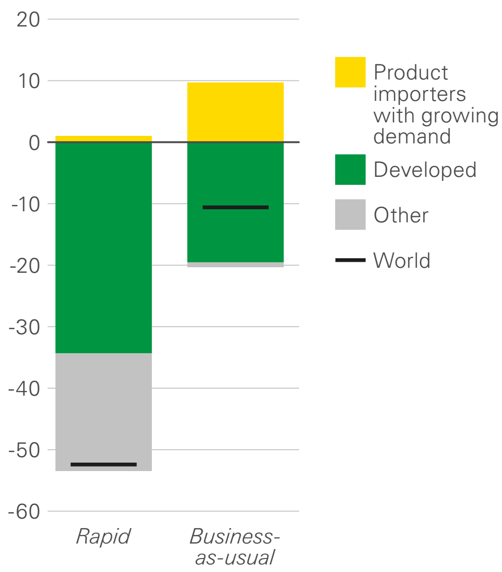
Refinery throughput

Mb/d



Refining capacity changes, 2018-2050

Mb/d

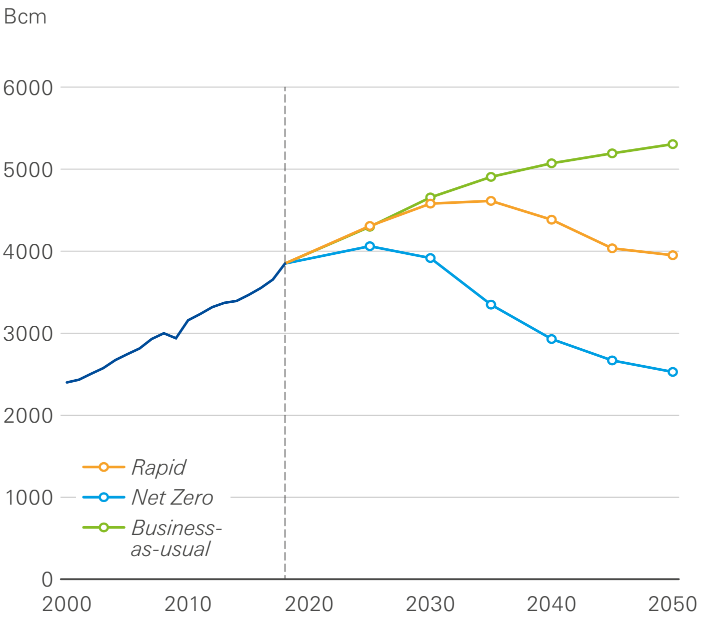


Key points

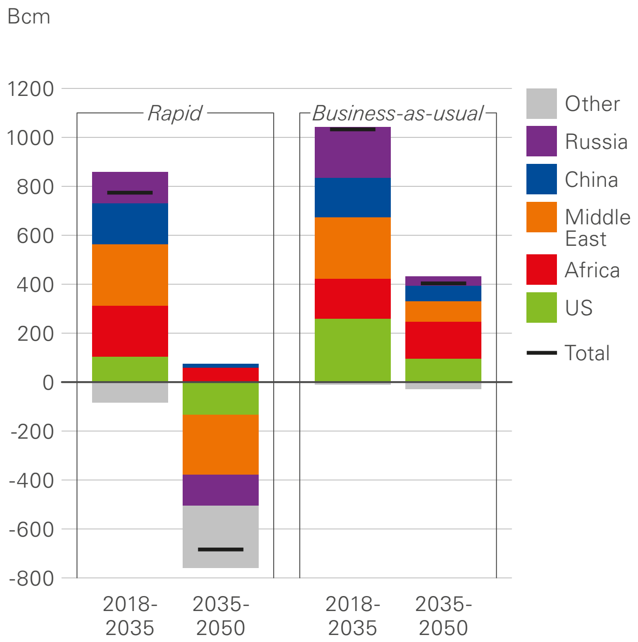
- The outlook for refining is downbeat, reflecting the impact of Covid-19 in the near term and a combination of declining liquid fuels demand and increasing competition from alternative feedstocks further out.
- Refinery throughputs in both *Rapid* and *BAU* are significantly lower in the near term as a result of Covid-19 reducing the demand for refined products, especially in the transport sector (see pp 68-69).
- As with the overall demand for liquids fuels, refinery runs in *Rapid* never fully recover to pre-Covid levels and fall by more than 45 Mb/d to less than half of their 2018 levels by 2050. The outlook for refining is a little less challenged in *BAU*, with refining runs recovering close to pre-Covid-19 levels over the next few years and remaining around these levels until the early 2030s, before gradually declining to around 10 Mb/d below 2018 levels by 2050.
- This outlook for falls in refining throughput contrasts with previously announced plans to build roughly 9 Mb/d of new refining capacity over the next 5 years or so. The scale of excess refining capacity could be even greater if emerging economies in which product demand continues to increase – such as India and Africa – build additional capacity to limit any increase in import dependency for refined products.
- The excess refining capacity that emerges in both *BAU* and *Rapid* leads to increasing competition and the eventual shutdown of the least competitive refineries. The shutdowns in *BAU* are concentrated in the developed economies – particularly Europe, OECD Asia and parts of North America – where falling domestic demand increases refineries' exposure to the highly competitive product export market.
- The degree of market rationalization required in *Rapid* is more pronounced and widespread, with around 50 Mb/d of current (or planned) capacity surplus to requirements by 2050. The refining capacity that is most resilient to these pressures in *Rapid* is aided by: resilient domestic demand, access to advantaged feedstock, high levels of upgrading, integration with petrochemicals and, in some regions, government support.

Outlook for gas is more resilient than for either coal or oil

Gas consumption



Gas production growth by region



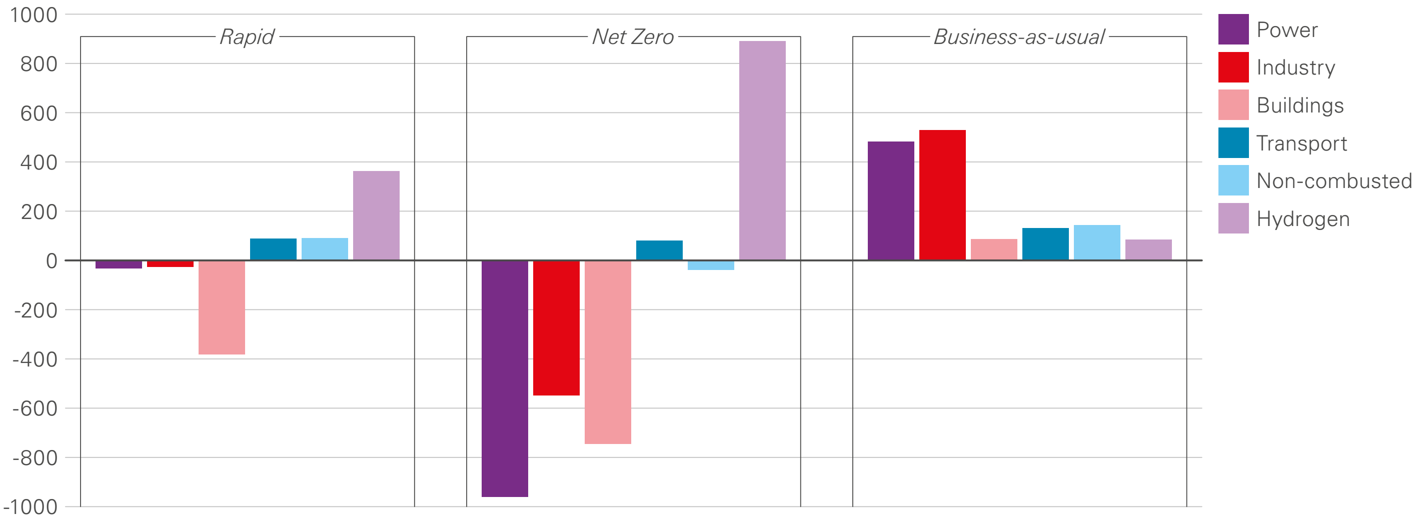
Key points

- The outlook for gas is more durable than for coal or oil, helped by broad-based demand and the increasing availability of global supplies.
- In *Rapid*, the global demand for gas – natural gas plus biomethane - recovers from the near-term dip associated with Covid-19 and grows relatively robustly over the next 15 years or so, driven primarily by economies in developing Asia (China, India, Other Asia) as they switch away from coal towards lower-carbon fuels, including gas (this potential supporting role for natural gas is explored on pp 80-81). Global gas consumption declines in the subsequent 15 years as the impetus from developing Asia fades, compounded by increasing falls in the developed world, such that global gas demand by the end of the Outlook falls back close to its 2018 levels at around 4000 Bcm.
- The growth of global gas demand in *Net Zero* is shorter lived, peaking in the mid-2020s, followed by a far faster decline, such that demand by 2050 is around 35% below 2018 levels.
- In contrast, gas demand increases throughout the next 30 years in *BAU*, increasing by a third to around 5300 Bcm by 2050. This growth in gas consumption is relatively widespread, with particularly strong increases across developing Asia, Africa and the Middle East.
- Biomethane increases in all three scenarios, reaching around 250 Bcm in *Rapid* and *Net Zero*, and 100 Bcm in *BAU*, which is around 6-10% and 2% respectively of total gas demand.
- The main areas of increasing gas production in *Rapid* are China and Africa, supported by rising domestic consumption. US and Middle Eastern gas production by 2050 are largely unchanged from their 2018 levels, with marked falls in domestic demand offset by increased exports. Much of the exports are in the form of liquefied natural gas (LNG), which roughly doubles over the Outlook in *Rapid*, increasing the competitiveness and accessibility of natural gas around the globe (see pp 82-83).
- The much stronger demand growth in *BAU* is largely met by increases in output in the US, Middle East and Africa, which together account for around two-thirds of the increase in global supplies in *BAU*.

The pattern of gas demand differs significantly across the scenarios

Change in gas demand by sector, 2018-2050

Bcm



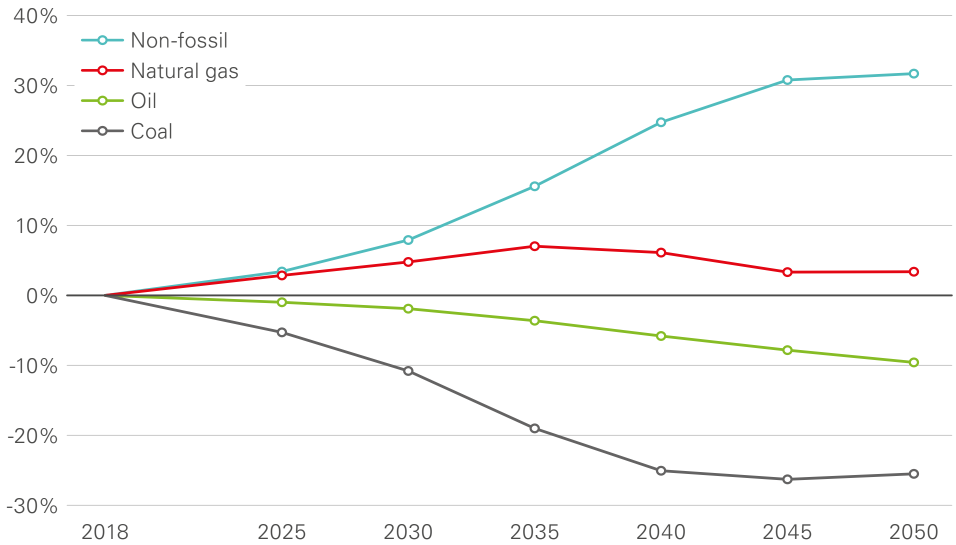
Key points

- The pattern of changes in global gas consumption varies markedly across the three scenarios reflecting differences in the pace and extent of the low-carbon transition.
- In *Rapid*, the shift to lower carbon energy sources, combined with significant gains in energy efficiency, means gas used in the industrial and power sectors – the two main sources of growth in gas consumption over the past 20 years – is largely unchanged over the Outlook, and falls materially in buildings. Instead, the main source of strength over the Outlook is the growing use of natural gas to produce blue hydrogen, which accounts for almost 10% of global gas demand by 2050 in *Rapid* (see pp 102-105 for a discussion of the outlook for hydrogen).
- These shifts in the pattern of gas demand are even more pronounced in *Net Zero*, with the use of gas in the power sector and buildings falling by around 65% and 90% respectively, partially offset by a substantial increase in the use of gas to produce blue hydrogen.
- In contrast, growth in global gas demand in *BAU* is broadly based across all sectors of the economy, led by the industrial and power sectors, which together account for around two-thirds of the increase. The growth in industrial demand stems entirely from emerging economies as they continue to industrialize, supported by significant coal-to-gas switching within China's industrial sector.

The role of natural gas in a low-carbon energy transition

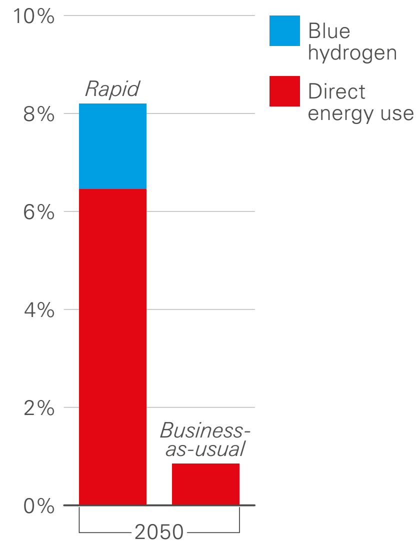
Rapid vs. *Business-as-usual*: India and Other Asia*

Differences in shares of primary energy



*Other Asia excludes China and OECD Asia

Natural gas with CCUS as a share of primary energy

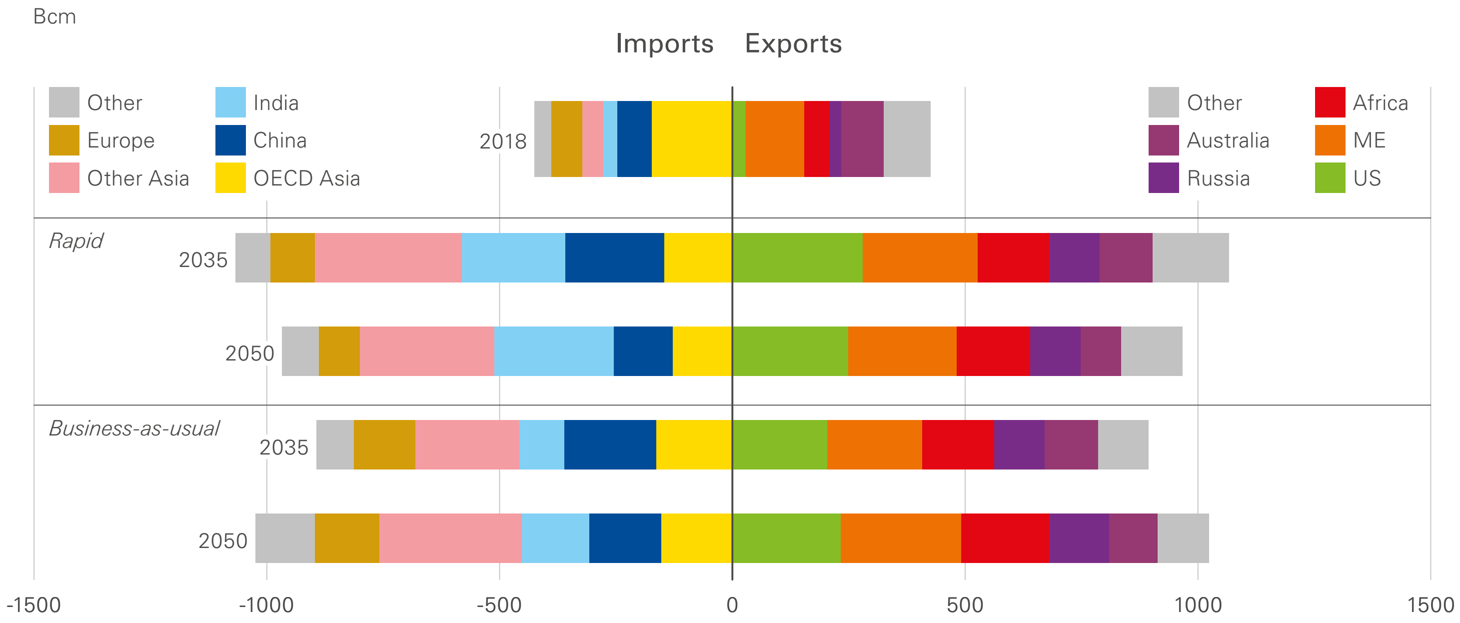


Key points

- Natural gas can potentially play two important roles in an accelerated transition to a low-carbon energy system:
  - supporting a shift away from coal in fast growing, developing economies in which electricity demand and other uses of coal are growing quickly, and renewables and other non-fossil fuels may not be able to grow sufficiently quickly to replace coal on their own; and
  - as a source of (near) zero-carbon power when combined with CCUS, either as a direct source of energy to the power and industrial sectors or to produce blue hydrogen.
- These two roles can be highlighted by contrasting the role of natural gas in the slow transition envisaged in *BAU* with the more accelerated decarbonization in *Rapid*.
- The role of natural gas supporting a shift away from coal can be seen most clearly in India and Other Asia. The greater fall in the share of coal in *Rapid* compared with *BAU* is mainly offset by fast growth in non-fossil fuels, led by renewable energy and supported by a larger increase in the share of gas. This supporting role fades towards the end of the Outlook as the growth of non-fossil energy sources gather pace.
- There is less need for this supporting role in developed countries, where the slower growth in energy demand makes it easier for the reduction in coal consumption to be largely matched by the increasing use of non-fossil fuels.
- The role of natural gas as a greater source of (near) zero-carbon energy in *Rapid* relative to *BAU* is clear, with gas combined with CCUS accounting for around 8% of primary energy by 2050 in *Rapid*, compared with just 1% in *BAU*. The majority of natural gas with CCUS in *Rapid* is used as a direct energy source in industry and power, with the residual used to produce blue hydrogen.

LNG grows substantially, increasing the accessibility of gas around the globe

LNG imports and exports



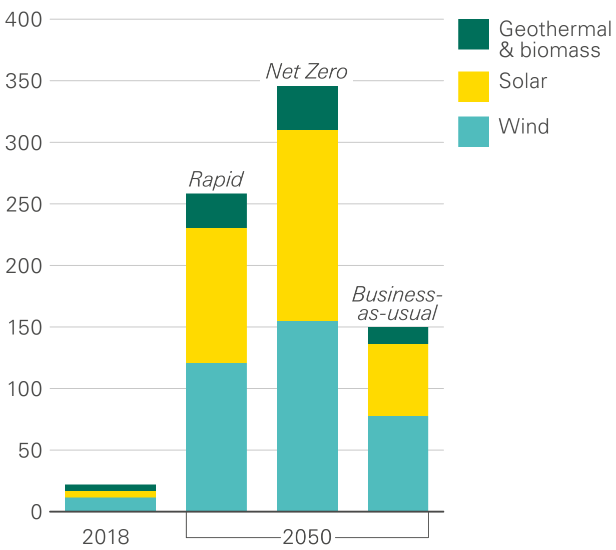
Key points

- LNG expands significantly in both *Rapid* and *BAU*, leading to a more competitive, globally integrated gas market.
- LNG trade in *Rapid* bounces back strongly from the near-term fall associated with Covid-19, more than doubling over the first half of the Outlook, increasing from 425 Bcm in 2018 to around 1100 Bcm by the mid-2030s.
- This fast growth is driven by increasing gas demand in developing Asia (China, India and Other Asia) as gas is used to aid the switch away from coal and LNG imports are the main source of incremental supply. This surge in LNG demand is met by increasing supplies from the US, Africa and the Middle East, which emerge as the three main hubs for LNG exports.
- Global LNG imports fall back in the second half of *Rapid* as import demand in developing Asia starts to decline. These falls are most pronounced in China, as overall demand declines and domestic production (including biomethane) increases. LNG trade by 2050 falls to around 970 Bcm. The pace of this decline in LNG exports after the mid-2030s is greater than the speed of depreciation of liquification facilities, implying that towards the end of the Outlook some facilities need to be operated at less than full capacity or shutdown prematurely.
- LNG trade in *BAU* grows more slowly than in *Rapid*, reaching a little over 1000 Bcm by 2050. However, even in *BAU*, around 60% of that growth occurs over the next 10 years or so. As in *Rapid*, US, Africa and the Middle East are the main source of incremental supply, with developing Asia the dominant destination for these increasing exports, along with the EU which remains an important balancing market for LNG in both scenarios.

Renewable energy in power grows quickly, driven by wind and solar power

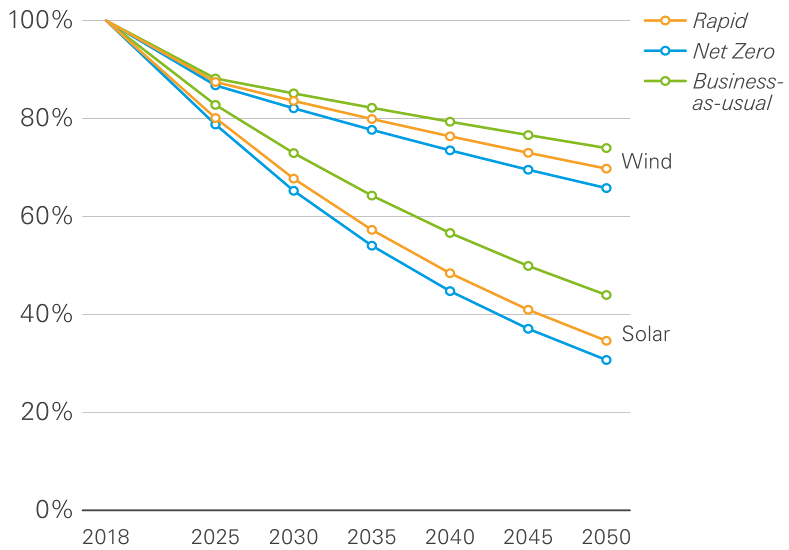
Renewable energy used in power sector

EJ



Cost of wind and solar energy by scenario

100% = 2018 price

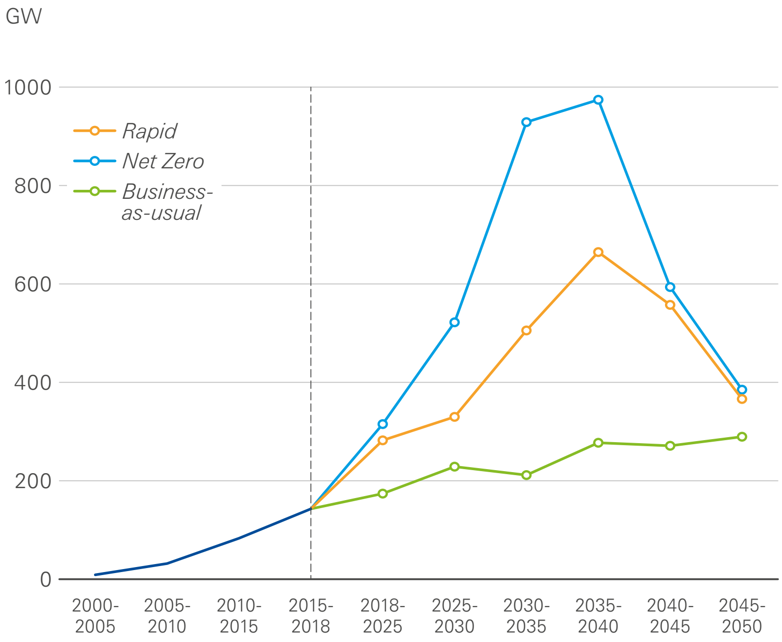


Key points

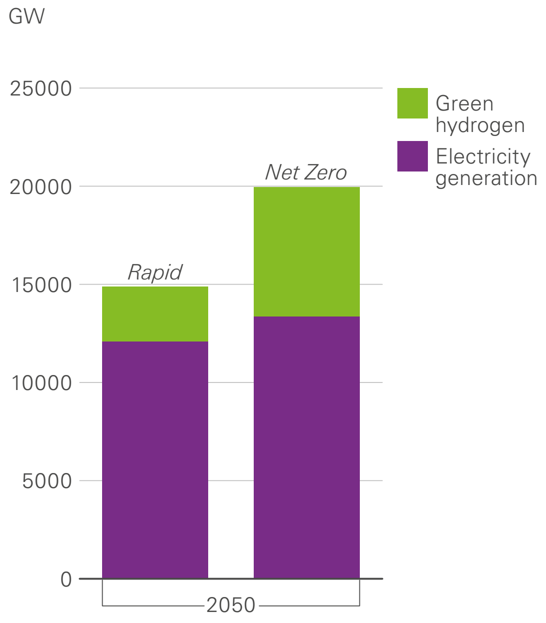
- Renewable energy used in the power sector – wind, solar, biomass and geothermal – grows quickly in all three scenarios, aided by falling costs of production and policies encouraging a shift to lower-carbon energy sources.
- The expansion of renewable energy in power in *Rapid* and *Net Zero* far outpaces the growth of primary energy, increasing by around 250 EJ and 350 EJ respectively over the Outlook – around five and seven times greater than the overall increase in primary energy.
- The fast pace of growth eases slightly from the late 2030s onwards as the costs of balancing the intermittency associated with adding increasing amounts of wind and solar power rise. Even so, the share of renewables in primary energy grows from around 5% in 2018 to 45% by 2050 in *Rapid* and 60% in *Net Zero*.
- The growth in renewable energy is dominated by wind and solar power, underpinned by continuing falls in development costs as they move down their 'learning curves'. Over the next 30 years, wind and solar costs fall by around 30% and 65% in *Rapid* respectively and by 35% and 70% in *Net Zero*.
- In both *Rapid* and *Net Zero*, wind and solar power account for broadly similar absolute increases in power generation. This equates to a significantly faster rate of expansion in solar power, supported by (and driving) the greater cost declines.
- The growth of renewables in power is less fast in *BAU*, although they still grow seven-fold and contribute around 90% of the growth in primary energy over the Outlook.
- In all three scenarios, emerging economies account for the majority of the growth in renewable energy, driven by stronger growth in power generation and by the increasing share of renewables in power, especially at the expense of coal.

The build out of wind and solar power capacity accelerates sharply

Annual average increase in wind and solar capacity



Installed capacity of wind and solar energy

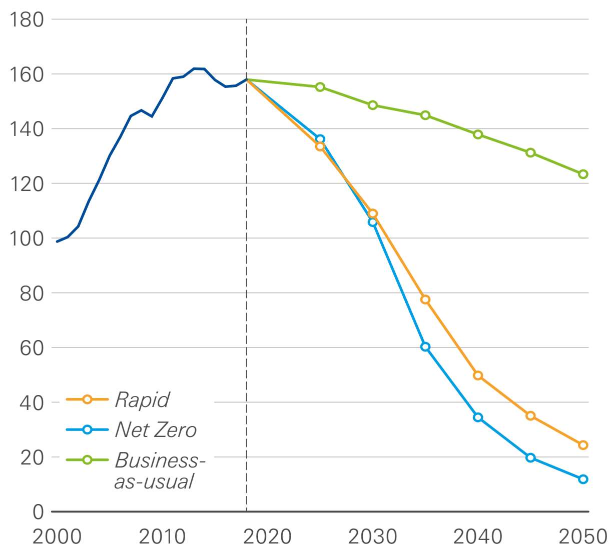


Key points

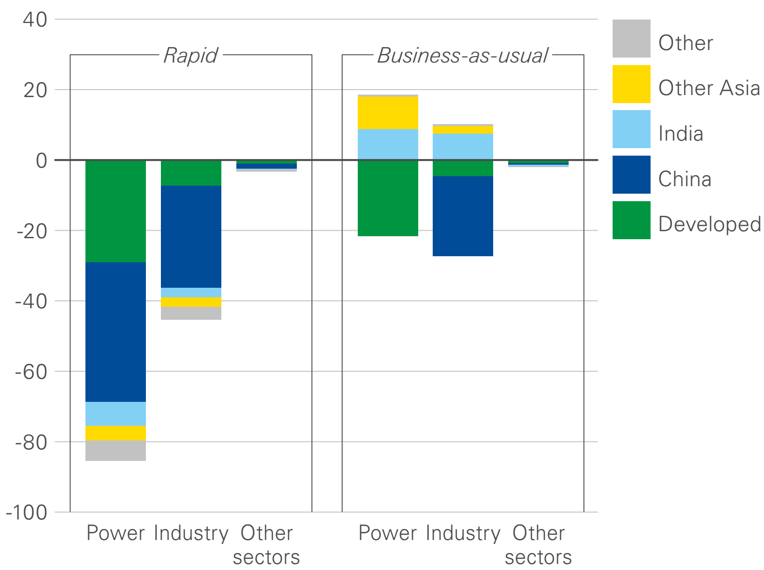
- The growth of wind and solar power generation in all three scenarios requires a significant acceleration in the build out of renewable capacity.
- The average annual increase in wind and solar capacity in *Rapid* and *Net Zero* over the first half of the Outlook is around 350 GW and 550 GW respectively, between 6 and 9 times faster than the annual average of around 60 GW since 2000.
- Although such an acceleration in wind and solar capacity requires a significant increase in investment spending, the extent of that increase is partially offset by the falling development costs of wind and solar energy. The implications for investment in wind and solar energy are considered on pp 132-133.
- The fast growth in wind and solar power generation in *Rapid* and *Net Zero* followed by a subsequent slowing as the costs of intermittency build is reflected in the pattern of capacity additions, which peak around 2035 in *Rapid* and *Net Zero* before slowing sharply. This hump in the pattern of new additions raises the risk of excess capacity within the renewables supply chain towards the end of the Outlook.
- The acceleration in the build out of wind and solar capacity in *BAU* is more gradual and steadier, although the average annual rate of capacity construction (235 GW) over the Outlook is still considerably faster than past rates of expansion
- In *Rapid* and *Net Zero*, developed countries represent around 25% of total deployment of wind and solar, China accounts for broadly another 25%, with the rest accounted for by other emerging economies. In *BAU*, developed economies have a larger role - accounting for around a third of total deployment.
- A significant share of wind and solar energy is used to produce green hydrogen in *Rapid* and *Net Zero*, with this share increasing to around 20% of total installed capacity by 2050 in *Rapid* and to around a third in *Net Zero*.

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

Coal consumption



Change in coal demand by sector and region, 2018-2050

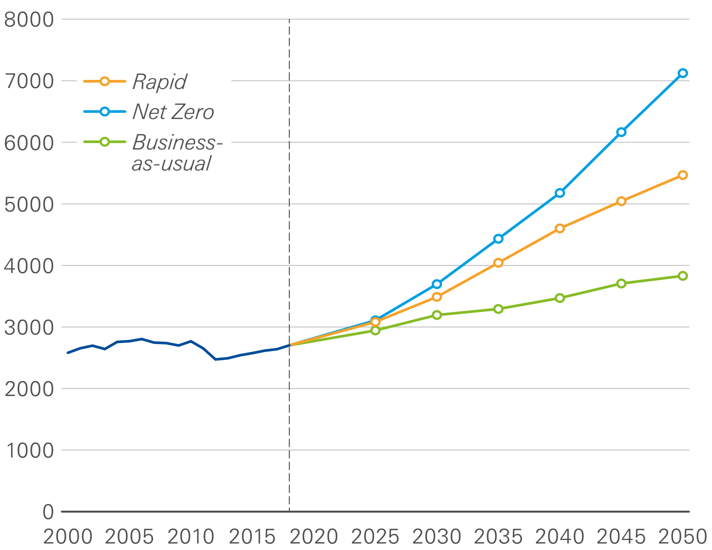


Key points

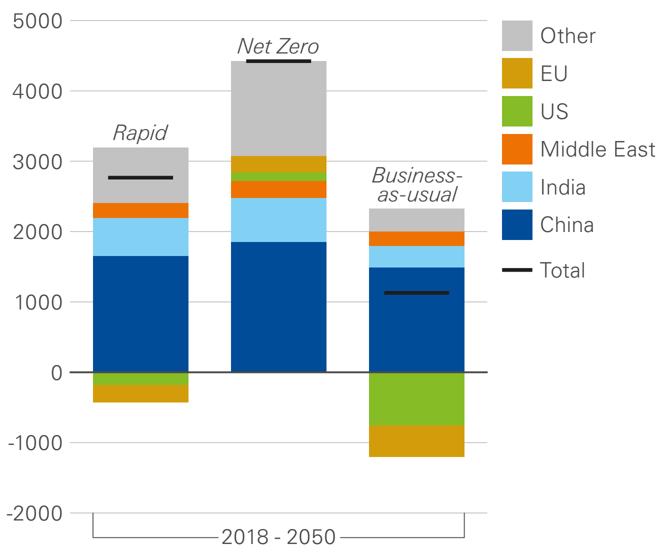
- Global coal consumption declines consistently over the next 30 years in all three scenarios, never recovering back to its peak level of 2013.
- The scale of the decline is particularly pronounced in *Rapid* and *Net Zero*, in which coal is almost entirely eliminated from the global energy system over the next 30 years, falling between 85-90%, with the share of coal in primary energy dropping to less than 5% by 2050 in both scenarios.
- The fall in coal demand in *Rapid* and *Net Zero* is dominated by China as it shifts to a more sustainable pattern of growth and a lower-carbon fuel mix. Declines in Chinese coal consumption account for around half of the overall fall in global demand in these two scenarios, supported by declines in OECD, India and Other Asia.
- The contraction in coal consumption is less pronounced in *BAU*, falling by around 25% by 2050, with the speed of that decline accelerating through the Outlook. China accounts for the vast majority of the fall, followed by the US and the EU. The overall fall in global coal consumption is partially mitigated by continuing increases in India and Other Asia. By 2050, developing Asia (China, India and Other Asia) accounts for over 80% of total coal consumption in *BAU*.
- The falls in coal consumption are concentrated in the power and industrial sectors. In *Rapid* and *Net Zero*, the power sector accounts for around two-thirds of the decline as power generation is largely decarbonized; whereas in *BAU*, the falls are distributed roughly evenly between the two sectors. By 2050, the power sector accounts for around two-thirds of the remaining use of coal in *BAU* (see pp 100-101 for a discussion of the prospects for coal-fired power generation in India).
- In both *Rapid* and *Net Zero*, most of the coal consumption remaining in 2050 is used in conjunction with CCUS, concentrated in the power sector and the production of blue hydrogen.
- The falls in global coal demand are matched on the supply side by significant falls in Chinese coal production, which accounts for the vast majority of the production declines in both *Rapid* and *BAU*.

Growth in nuclear power is dominated by China

Nuclear generation



Change in nuclear generation by region, 2018-2050

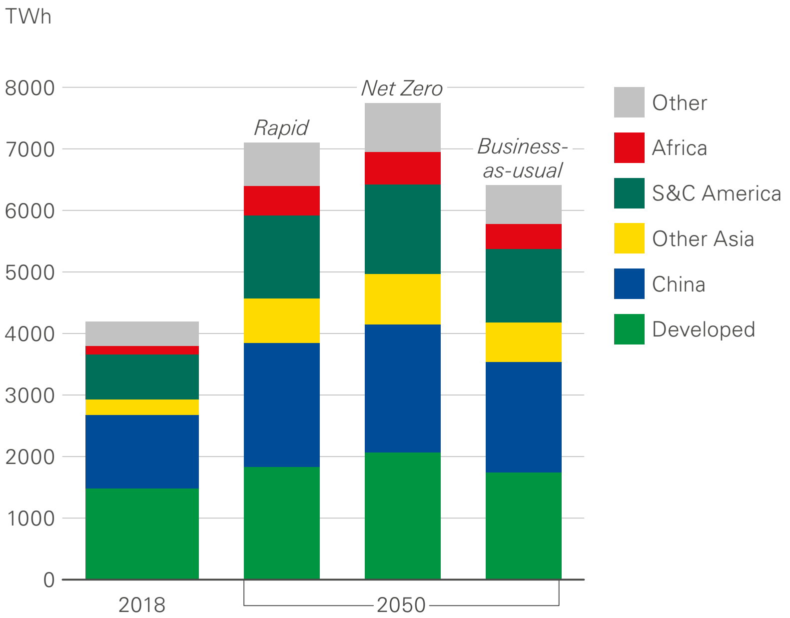


Key points

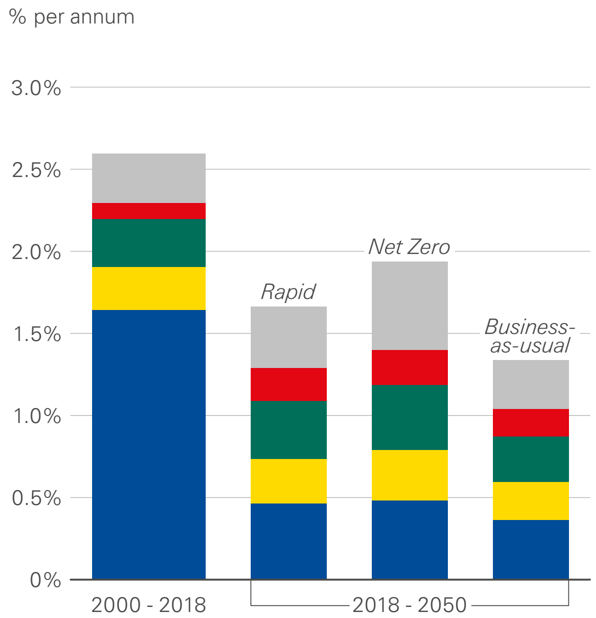
- Nuclear energy grows throughout the Outlook in all three scenarios, as strong growth in China offsets weak or falling nuclear power generation in the developed world.
- Nuclear generation grows robustly in *Rapid* and *Net Zero*, increasing by around 100% and 160% respectively by 2050. China accounts for around 60% of this growth in *Rapid* – and 40% in *Net Zero* – as China continues to diversify away from coal towards a lower-carbon fuel mix in the power sector. The share of nuclear power in China's power generation increases from around 4% in 2018 to more than 15% by 2050 in both scenarios. Nuclear power generation also increases in India, Other Asia and Africa.
- Nuclear power in the developed economies falls slightly in *Rapid* and edges higher in *Net Zero*. In both scenarios, the pressure to decarbonize the power sector more quickly than other zero-carbon energy sources and balancing technologies can be deployed is partially met by extending the operating lifetimes of nuclear power plants in the US and Europe, many to 60 years or more.
- The pace of build out of new capacity additions in *Rapid* is comparable to that seen in the heyday of nuclear power in the 1980s – and even quicker in *Net Zero* – with the pace of construction in *Rapid* increasing more than two-fold relative to recent rates of expansion.
- The growth of nuclear generation is slower in *BAU*, increasing by around 40% by 2050, with its share in primary energy edging lower. The pattern of growth in *BAU* is even more lopsided, with China accounting for more than the entire growth of nuclear power generation, partially offset by declines in the US and Europe as aging nuclear plants are retired and a combination of economic and political factors means they are not replaced by new capacity. The level of nuclear generation in China by 2050 in *BAU* is around twice that of the entire developed world.

Hydroelectricity grows over the next 30 years but at a slower pace than in the past

Hydroelectricity generation by region



Hydroelectricity growth by region



Key points

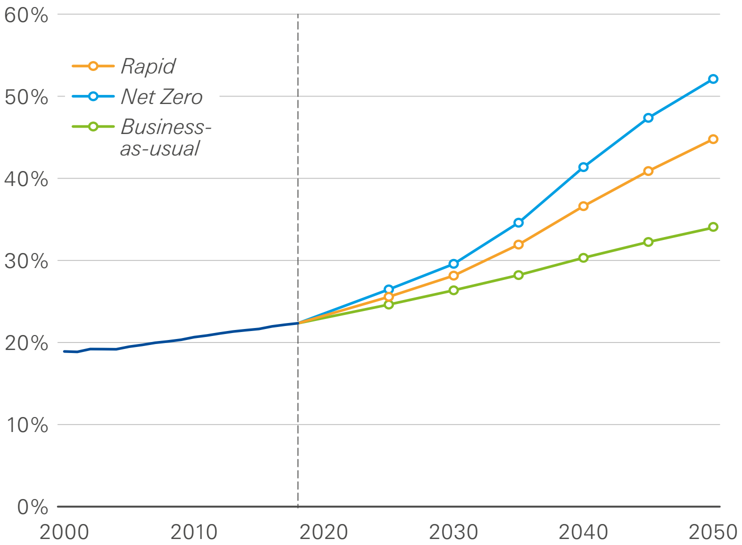
- Hydroelectricity expands throughout the Outlook, but the pace of growth slows in the second half of all three scenarios as the availability of the most advantaged sites gradually wanes.
- The greater pressure to decarbonize the energy system in *Rapid* and *Net Zero* helps to support stronger growth of hydro energy than in *BAU*, even so the growth of hydro power in all three scenarios over the Outlook – ranging from 1.3% to 1.6% p.a. – is slower than the past 20 years (2.6 p.a.). The share of hydro in global power generation is broadly stable in all three scenarios at around 15%.
- The slowing in hydroelectricity relative to past trends is dominated by China, where the robust build out of hydro facilities over the past 20 years accounted for around three-quarters of global growth in hydroelectricity. But as the most productive and advantaged sites in China are exploited, the growth of Chinese hydro power slows, averaging between 1.3-1.7% p.a. in the three scenarios, down from an average annual rate of almost 10% over the past 20 years.
- Some of this slowing in the growth of Chinese hydro power generation is offset by an acceleration in Other Asia, Latin America, and Africa, where growing economic prosperity and accelerating power demand increase the economic viability of developing the abundant geographical sites available in these regions.

Other energy carriers

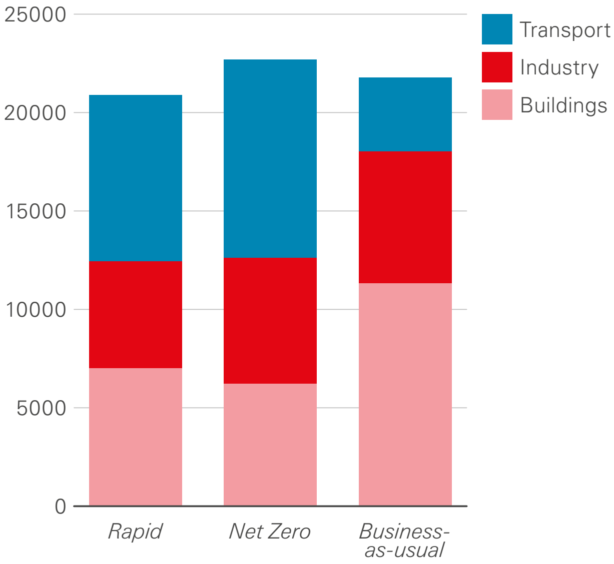
Electricity and power generation
Hydrogen

Electricity demand grows robustly as the world continues to electrify

Share of electricity in total final consumption



Change in electricity demand by sector, 2018-2050

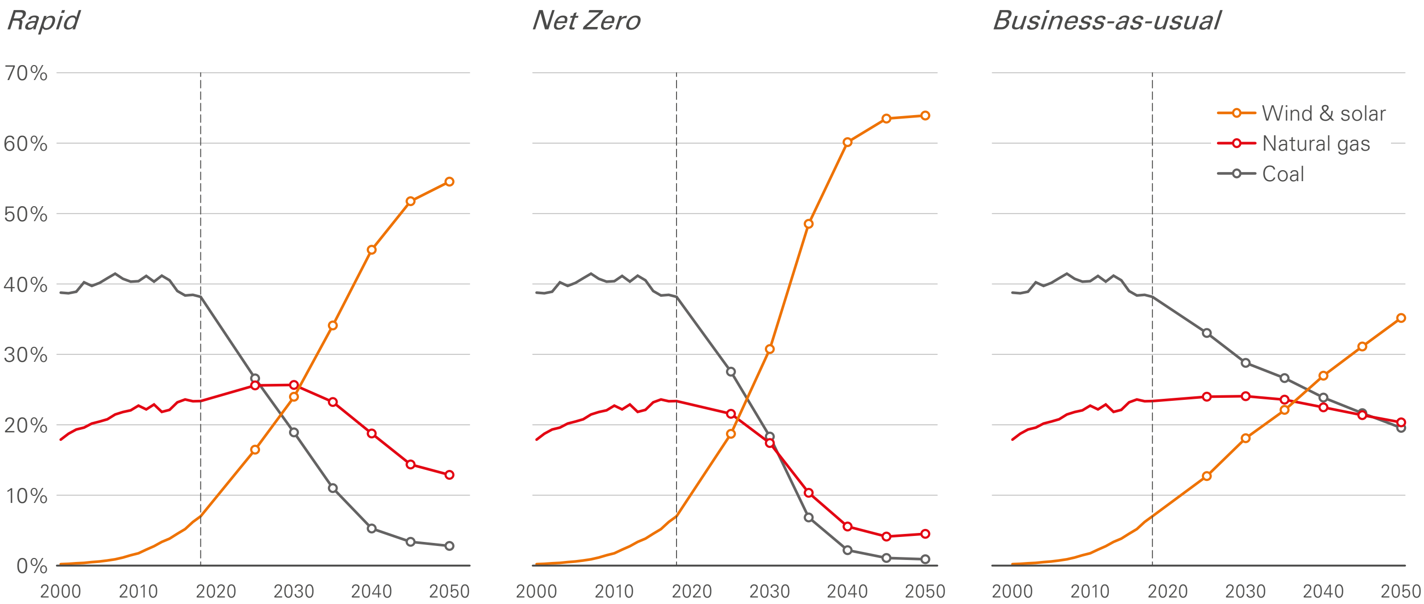


Key points

- The world continues to electrify, leading the power sector to play an increasingly central role in the global energy system.
- The growth in final electricity demand is similar in all three scenarios, growing by just under 2% p.a., such that demand expands by around 80% by 2050.
- The extent to which the energy system electrifies is greatest in *Rapid* and *Net Zero* as the progressive decarbonization of the energy system leads to increasing amounts of final energy use being electrified. The share of electricity in total final consumption increases from a little over 20% in 2018 to 45% in *Rapid* by 2050 and over 50% in *Net Zero*, compared with just 34% in *BAU*. The growth of electricity demand in *BAU* is supported by stronger overall growth in energy consumption than in the other two scenarios.
- The energy required to meet the growing use of electricity for final consumption is the dominant source of incremental demand for primary energy in all three scenarios. As a result, the share of primary energy that is absorbed by the power sector increases from 43% in 2018 to around 60% by 2050 in *Rapid* and *Net Zero* and to a little over 50% in *BAU*.
- The vast majority of the growth in electricity demand in all three scenarios is driven by emerging markets, led by developing Asia (China, India, and Other Asia) and Africa, as increasing prosperity and living standards underpin higher electricity consumption.
- The increase in electricity use in *Rapid* and *Net Zero* is broadly based across all three sectors (industry, transport and buildings) of the economy, with electricity used in the transport sector rising most strongly as increasing amounts of road transportation are electrified (see pp 42-45).
- In contrast, the slower gains in energy efficiency in buildings and industry in *BAU* means these sectors account for around 80% of the growth in power demand, with a more subdued increase in transport.

Growth in power generation is led by wind and solar power as coal loses share

Share of global power generation by energy source

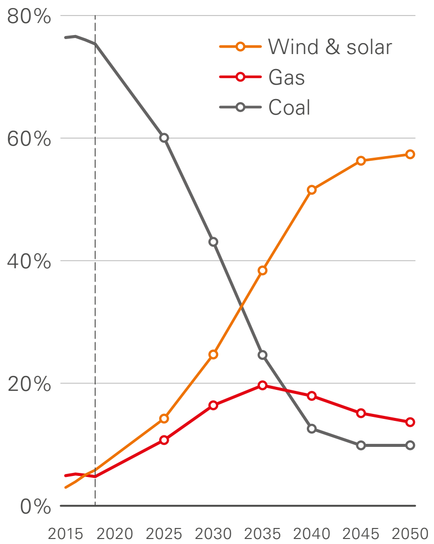


Key points

- The growth of global power generation is dominated by renewable energy.
- Renewable energy, led by wind and solar power (and including biomass and geothermal), more than accounts for the entire growth in global power generation in *Rapid* and *Net Zero* and for around three-quarters of the growth in *BAU*.
- The increasing cost of balancing the intermittency associated with the use of wind and solar power as their share rises causes the pace at which they penetrate the power sector to slow in the 2040s in *Rapid* as their share of global power rises above 50%. Similarly, the share of wind and solar power in *Net Zero* begins to flatten out in the 2040s as it rises above 60%.
- The main fuel to lose ground is coal, with the share of coal-fired power generation in global power falling from 38% in 2018 to less than 3% in 2050 in *Rapid* and *Net Zero*, and to around 20% in *BAU*.
- The use of gas in the power sector increases during the first half of the Outlook in *Rapid* as it gains share from coal but falls back close to its 2018 level by 2050 as the use of renewables accelerate. The initial growth of gas in *Net Zero* is shorter lived and the subsequent decline sharper. In contrast, the use of gas in *BAU* increases broadly in line with overall power demand, with its share in global power generation edging down only slightly. By 2050, roughly half of the natural gas used to generate power in *Rapid* and around 90% in *Net Zero* is used in conjunction with CCUS.
- The changes in the fuel mix, combined with the increasing use of CCUS, means the carbon intensity of power generation falls by over 90% in *Rapid*, compared with just 50% in *BAU*. As a result, despite the substantial increase in power generation, carbon emissions from the power sector decrease by over 80% in *Rapid*, compared with just 10% in *BAU*. In *Net Zero*, the use of bioenergy combined with CCUS (BECCS) means that net CO_2 emissions from the power sector are negative by 2050.

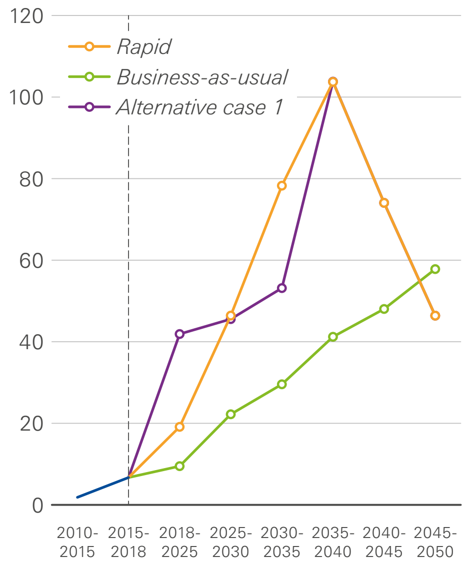
The challenge of decarbonizing the Indian power sector

Share of Indian power generation by energy source in *Rapid*



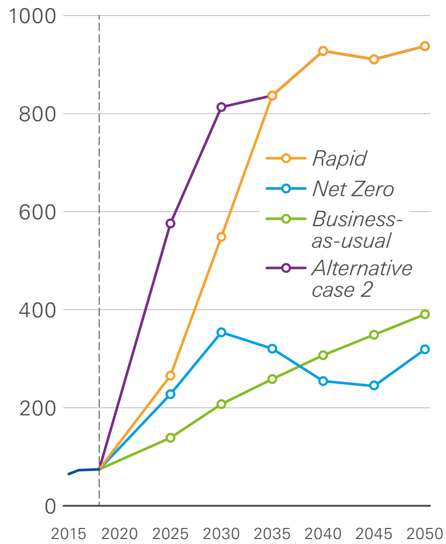
Annual average net capacity additions in wind and solar in India

GW



Generation from gas in India

TWh

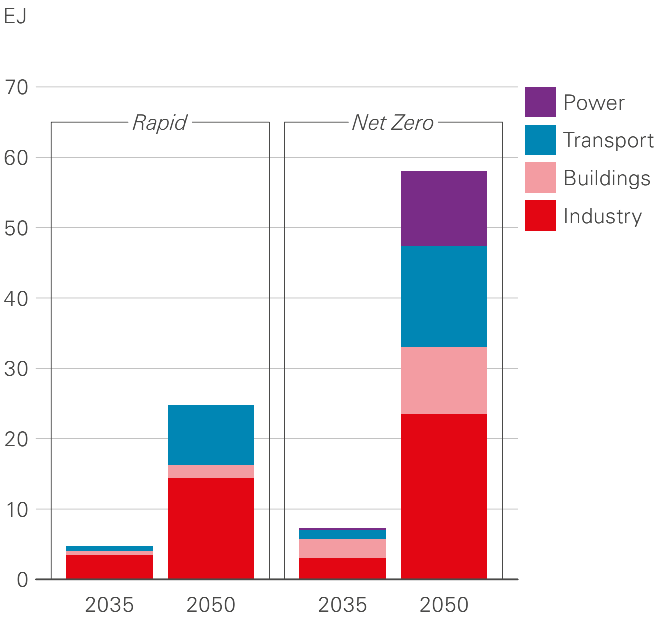


Key points

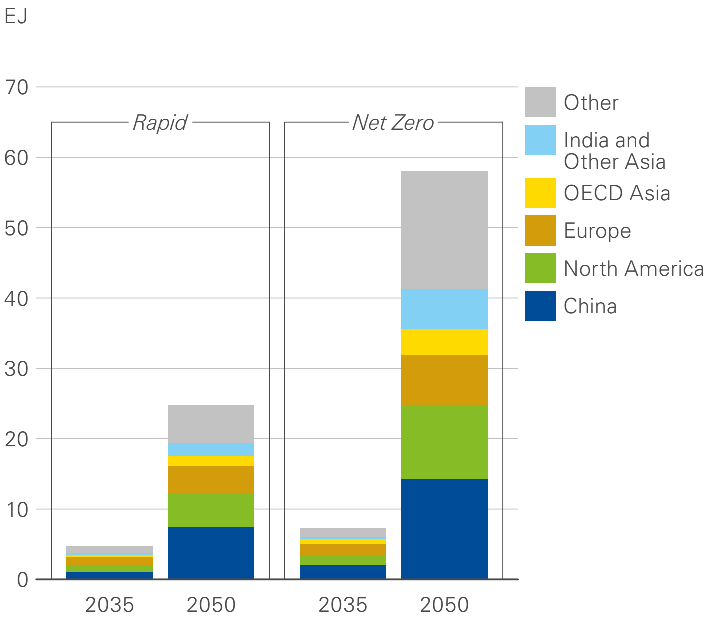
- The challenge of decarbonizing the power sector in economies and regions in which there is strong growth in electricity demand is illustrated by the outlook for the Indian power sector.
- Electricity consumption in India increases robustly in all three scenarios, growing between 4.0-4.6% p.a. over the Outlook, as improving prosperity and living standards boost industrial and residential demand.
- In *BAU*, wind and solar power generation increase more than 20-fold by 2050, growing at an average rate of 10% p.a.. Despite that, Indian coal-fired power generation doubles over the Outlook in *BAU*, requiring more than 100 new coal-fired power plants to be built over the next 15 years.
- The pace and extent of the decarbonization of power is greater in *Rapid*, with coal power generation falling by around 40% by 2050. Wind and solar power generation grow by around 30-fold and 60-fold respectively, and gas over 13-fold.
- However, even in *Rapid*, Indian coal-fired power generation increases by around a third over the next 10 years or so before subsequently declining. This requires around 50 new coal-fired power stations to be built in the 2020s, with the likelihood that some of these power stations become uneconomic as coal generation subsequently declines. A similar near-term increase in coal generation, albeit less pronounced, is apparent in *Net Zero*.
- One option to avoid any increase in Indian coal-fired power generation would be for wind and solar power to accelerate even more quickly over the next 10 years, averaging around 45 GW per year, compared with 30 GW in *Rapid* and an average of 3 GW since 2000. This is illustrated by 'Alternate case 1' above.
- Another alternative (as shown by Alternate case 2) would be to bring forward some of the growth of gas-fired power generation that happens later in the Outlook. If gas power generation is increased sufficiently to prevent any increase in coal generation, this would reduce carbon emissions by around 2 Gt CO_2 over the next decade relative to *Rapid*.

Hydrogen plays an increasing role as the world transitions to a low-carbon energy system

Hydrogen use by sector



Hydrogen use by region



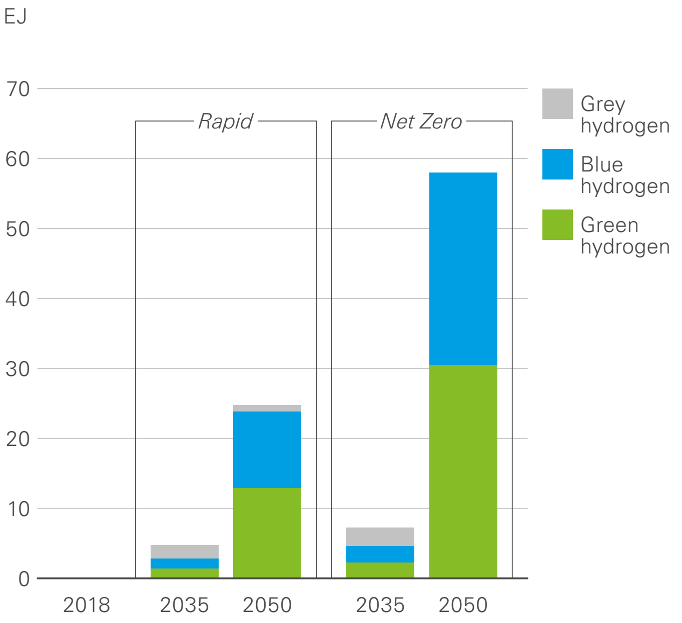
Key points

- The use of hydrogen as an energy carrier* increases significantly in *Rapid* and *Net Zero* as the world transitions to a lower-carbon energy system. The hydrogen can be used either directly or combined with (bio) carbon or nitrogen to make it easier to transport.
- The growth of hydrogen is concentrated in the second half of the Outlook as falling technology and input costs, combined with rising carbon prices, allow it to compete increasingly against incumbent fuels. By 2050, hydrogen accounts for around 7% of (non-combusted) total final energy consumption (excluding the non-combusted use of fuels) in *Rapid* and around 16% in *Net Zero*.
- Hydrogen complements the growing role of electricity in *Rapid* and *Net Zero* because it can be used for some activities which are difficult or costly to electrify, especially in industry and transport, and because it can be more easily stored than electricity.
- Hydrogen has a particular advantage in industry as a source of energy for high-temperature processes, such as those used in steel, cement, refining and petrochemicals sectors. By 2050, hydrogen accounts for around 10% of total final energy consumption in industry in *Rapid* and 18% in *Net Zero*.
- The use of hydrogen in transport is concentrated in long-distance transportation, particularly heavy-duty trucks in which 7% of VKM in *Rapid* by 2050 are powered by hydrogen and 10% in *Net Zero*.
- The use of hydrogen in *Rapid* is most pronounced in China and the developed economies which lead the world in its adoption, supported by rising carbon prices and increasing deployment of infrastructure and other policies supporting its use. This adoption is more broadly-based in *Net Zero*, with significant increases also in India and other parts of developing Asia.
- In contrast, the role of hydrogen within *BAU* is far more limited, mirroring the minimal progress made in decarbonizing the energy system.

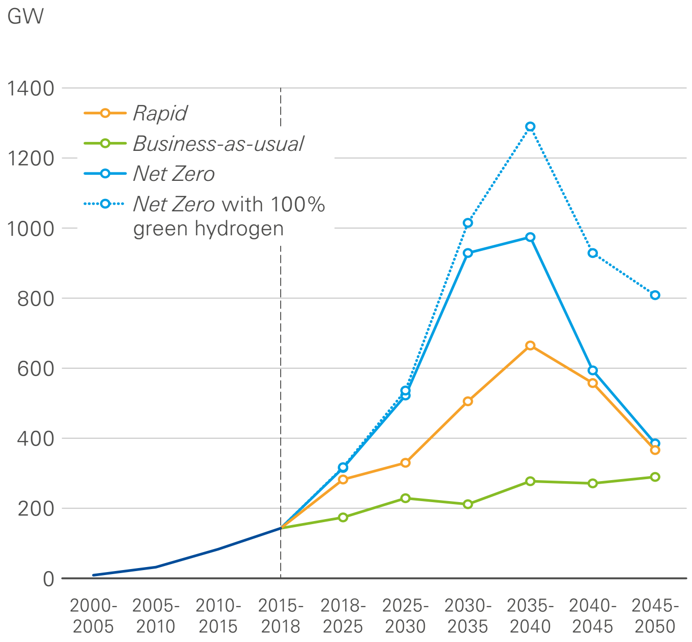
*The *Outlook* does not include the role of hydrogen as a feedstock in industry

Most hydrogen production by 2050 is a combination of green and blue hydrogen

Hydrogen production by type



Annual average increase in wind and solar capacity



Key points

- The production of hydrogen in *Rapid* and *Net Zero* is dominated by green and blue hydrogen.
- Green hydrogen is made by electrolysis using renewable power; blue hydrogen is extracted from natural gas (or coal) and the displaced carbon is captured and stored (CCUS).
- The ability of many countries to produce either green or blue hydrogen, combined with relatively high transport costs, means that the majority of hydrogen is produced relatively locally, with a mix of blue and green hydrogen depending of local conditions. By 2050, over 95% of hydrogen in *Rapid* and *Net Zero* comes from green and blue hydrogen in broadly equal amounts. The remainder comes from legacy facilities which produce hydrogen using natural gas or coal without CCUS (so-called grey hydrogen).
- The production of blue hydrogen helps supplies of hydrogen to grow relatively quickly in *Rapid* and *Net Zero* without relying only on renewable energy. This is important for two reasons.
- First, relying exclusively on green hydrogen would require an even faster expansion in wind and solar capacity. To achieve the same level of hydrogen production as in *Net Zero* using only green hydrogen, would require an average build out of wind and solar capacity of around 800 GW per year over the Outlook, compared with less 600 GW in *Net Zero* and around 60 GW over the past 20 years.
- Second, production of green hydrogen diverts renewable energy that could potentially be used to decarbonize further the power sector. Given that the vast majority of domestic power sectors over the Outlook are not fully decarbonized in either scenario, only renewable energy which cannot be used within the domestic power sector can strictly be used to produce green hydrogen. This would be the case if the renewable energy is curtailed at certain points in time or because its location means it is not economic for it to be connected to the central grid.

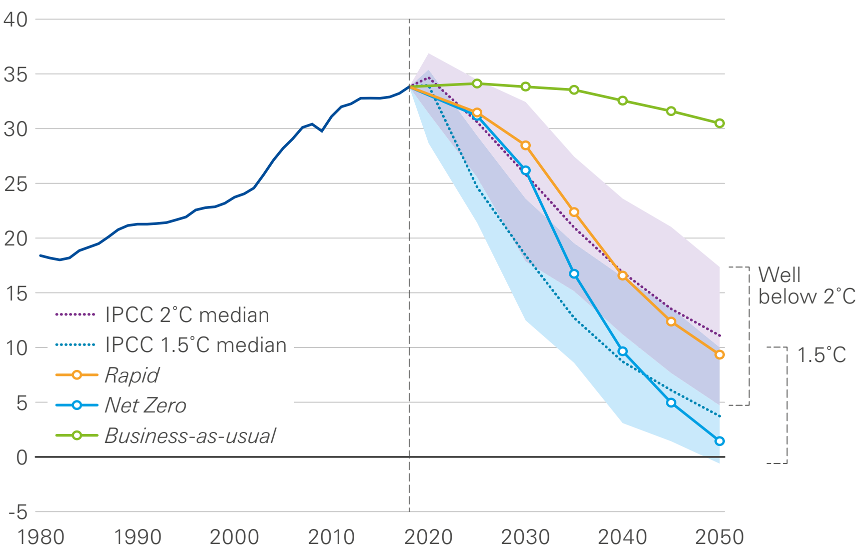
Carbon emissions from energy use

Summary
Carbon pathways
Alternative scenario: *Delayed and Disorderly*

Carbon emissions fall significantly in *Rapid* and *Net Zero*; little progress in *Business-as-usual*

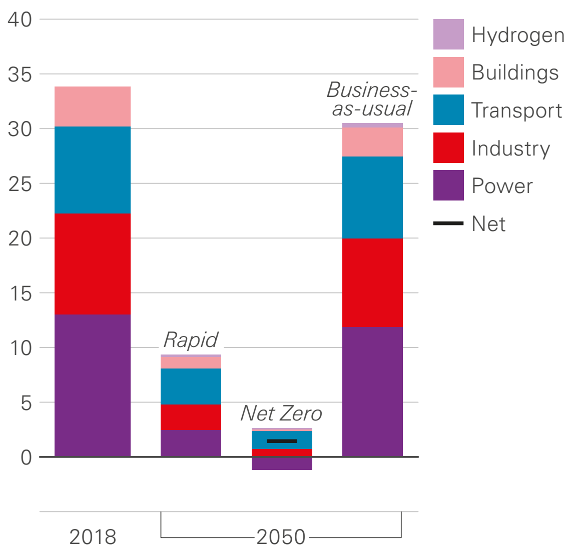
Global carbon emissions from energy use

Gt of CO_2



Carbon emissions by sector

Gt of CO_2



Ranges show 10th and 90th percentiles of IPCC scenarios, see pp 150-151 for more details

Key points

- The impact of Covid-19 causes carbon emissions from energy to fall sharply in the near-term. Although emissions subsequently pick up as the global economy recovers, the level of carbon emissions in *Rapid* and *Net Zero* do not return to their pre-pandemic levels.

- Carbon emissions from energy use in *Rapid* fall by around 70% by 2050 to a little over 9 Gt CO_2. This fall in emissions is broadly in the middle of the range of 'well below 2-degree' scenarios contained in the 2019 IPCC Report. See pages 150-151 for details on the construction of the IPCC scenario ranges.

- In *Net Zero*, carbon emissions fall by over 95% from their 2018 levels to around 1.5 Gt CO_2 by 2050. The initial pace of decline is slower than the range of IPCC 'below 1.5-degree' scenarios, but by the second half the Outlook the emissions pathway in *Net Zero* is close to the middle of the IPCC range.

- The carbon emissions remaining in 2050 in *Net Zero* could be reduced further by either additional changes in the energy system or using negative emissions technologies (NETs). Alternatively, the emissions could be offset by increased deployment of natural climate solutions (NCS) (see pp 130-131). This will partly depend on the costs of NETs and of abating GHGs emitted from outside the energy system, neither of which are explicitly considered in this Outlook.

- The extent of the decline in carbon emissions from energy use in *BAU* is far more limited. Emissions peak around the mid-2020s and decline only gradually, falling to around 10% below 2018 levels by 2050.

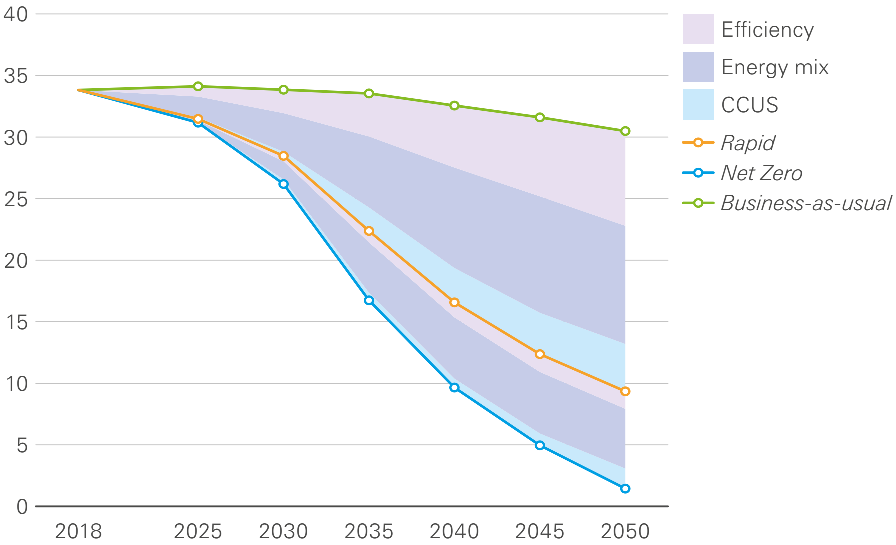
- The composition of the carbon emissions remaining in 2050 in *Rapid* provide a sense of the hardest-to-abate emissions. The largest source of emissions is the transport sector which accounts for around third of the remaining emissions, with the industrial and power sectors each accounting for around a quarter.

- The transport and industrial sectors account for the majority of the remaining emissions in *Net Zero* in 2050. These emissions are partially offset by net negative emissions from the power sector, stemming from the use of biomass combined with CCUS (BECCS), which reduce net carbon emissions by around 1.5 Gt CO_2 by 2050.

The fall in emissions in *Rapid* and *Net Zero* driven by switch to low-carbon energy

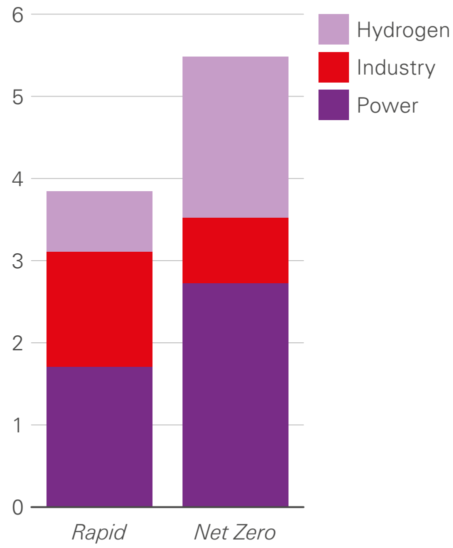
Carbon emissions from energy use

Gt of CO_2



Carbon capture utilization and storage in 2050

Gt of CO_2



Key points

- The reduction in carbon emissions in *Rapid* and *Net Zero* reflect a combination of increased switching to low-carbon fuels, greater gains in energy efficiency, and growing use of carbon capture technologies (CCUS).

- The most important factor accounting for the reduction in carbon emissions in *Rapid*, relative to the *BAU* emissions pathway, is the additional degree of switching to low-carbon fuels which accounts for around 45% of the difference by 2050. This is driven by significant reductions in the use of coal, especially in developing Asia, with much of this replace by faster penetration of renewable energy and, to a lesser extent, gas.

- The rest of the difference between the carbon pathways in *Rapid* and *BAU* reflects stronger gains in energy efficiency and greater use of CCUS. By 2050, CCUS is used to capture and store around 4 Gt CO_2 of potential emissions in *Rapid*, with around three quarters of the captured emissions emanating from the industrial and power sectors and the remainder from the production of blue hydrogen.

- The additional reductions in carbon emissions in *Net Zero* relative to *Rapid* are partly enabled by changes in the behaviour and preferences of companies and households, with increased focus on using energy more efficiently, greater switching to zero or low-carbon fuels and adjusting their consumption patterns towards lower-energy activities. These changing societal preferences accentuate the impact of government low-carbon policies.

- The largest factor contributing to the greater declines in carbon emissions in *Net Zero* relative to *Rapid* is the further switching away from fossil fuels into zero-carbon energy sources, especially renewable energy.

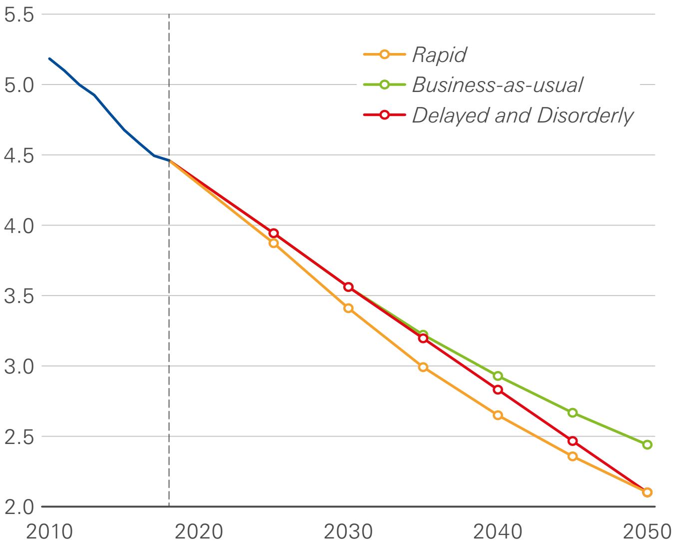
- There are also contributions from faster gains in energy efficiency and greater use of CCUS. By 2050, the amount of carbon captured and stored in *Net Zero* is around 5.5 Gt CO_2, with the majority employed in the production of blue hydrogen and the power sector.

Alternative scenario: *Delayed and Disorderly*

A delayed transition may lead to a disorderly adjustment path

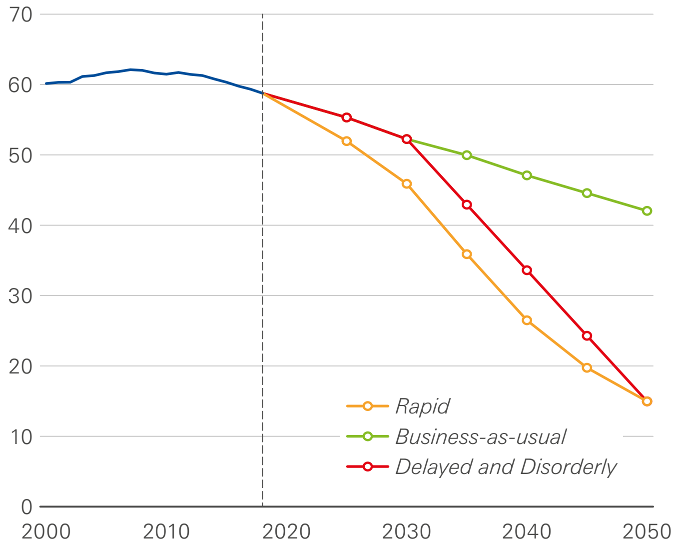
Energy intensity

MJ per $US of GDP



Carbon intensity of energy

Mt of CO_2 per EJ



Key points

- *Rapid* and *Net Zero* assume that government and society begin to change policy and behaviour relatively quickly, such that carbon emissions from energy use start to fall over the next few years. But it is possible that there is an extended delay before these types of changes take place, with an increasing likelihood of a sharp tightening in climate policies the longer the world remains on an unsustainable path.

- This possibility is explored in an alternative *Delayed and Disorderly* scenario in which the global energy system is assumed to move in line with *BAU* until 2030, after which sufficient policies and actions are undertaken to limit cumulative carbon emissions over the Outlook (2018-50) to be the same as in *Rapid*.

- *Delayed and Disorderly* is highly stylized - the nature of any delayed transition path will depend on the factors triggering the eventual change and the response of government and society. The scenario is predicated on the assumption that there are costs to delaying action. In particular, it assumes that it is not possible to make greater progress in energy efficiency or fuel switching by 2050 than is achieved in *Rapid*. As such, for illustrative purposes, it assumes that from 2030 onwards the:
  - degree of energy efficiency (including recycling, reuse and reduce) improves linearly and reaches the same level as *Rapid* by 2050;
  - carbon intensity of the fuel mix improves linearly and reaches the same level (including CCUS) as *Rapid* by 2050;

- Given these constraints on the speed and extent to which energy efficiency and fuel switching can improve, any further actions necessary to achieve the cumulative emissions target are assumed to take the form of energy 'rationing', that is, policies that stop or restrict various energy-using outputs or activities.

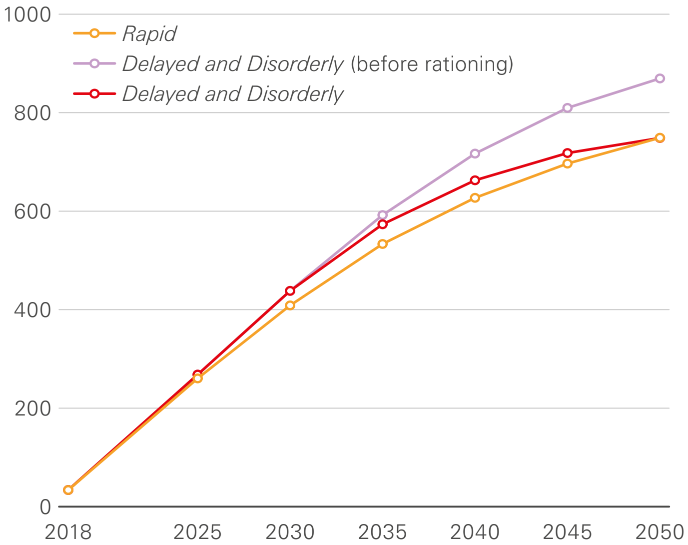
- For simplicity, *Delayed and Disorderly* assumes that the required energy rationing is imposed proportionality across the main sectors of the economy, with the degree of rationing increasing at a constant rate over the Outlook.

Alternative scenario: *Delayed and Disorderly*

A delayed and disorderly transition leads to significant economic costs

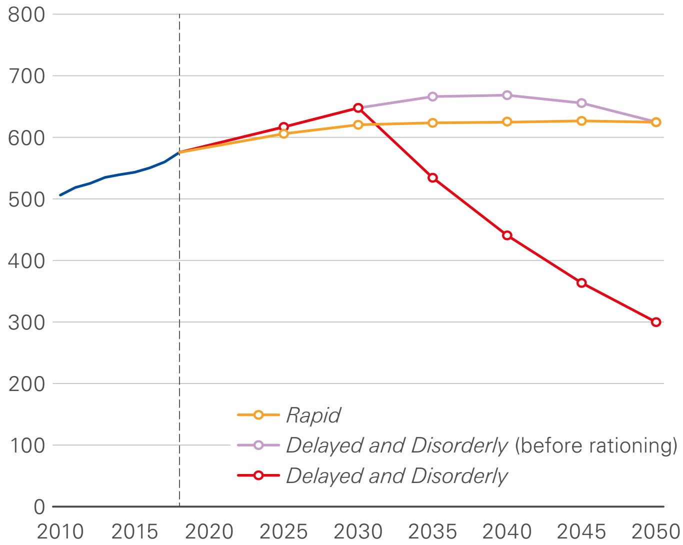
Cumulative carbon emissions

Gt of CO_2



Primary energy consumption

EJ



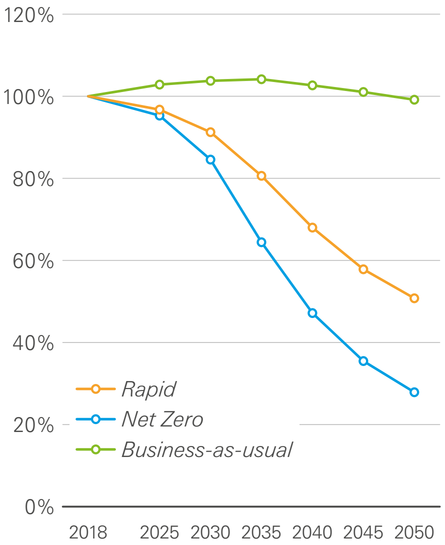
Key points

- Delaying the start of the decisive shift to a low-carbon energy system until 2030 significantly increases the scale of the challenge relative to *Rapid*: carbon emissions start from a higher level and there is less time to make the adjustments.
- This delay leads to significant economic cost and disorder in *Delayed and Disorderly*.
- Achieving the same improvements in energy efficiency and the fuel mix as in *Rapid* in two-thirds of the time is likely to require a significant diversion of investment from other productive activities and lead to the premature scrapping of productive assets.
- More significantly, the implied scale of energy rationing necessary to achieve the reduction in carbon is equivalent to around a quarter of the energy consumption between 2030 and 2050 in *Rapid*.
- Assuming this rationing is imposed proportionately across the main sectors of the economy, it is roughly equivalent to:
  - in industry – offsetting around 20 years of growth in industrial output;
  - in transport – reducing car travel by up to two-thirds and air travel by half relative to their 2050 levels in *Rapid*, together with similar scale reductions in commercial and marine transportation;
  - in buildings – a reduction in energy use relative to the 2050 level in *Rapid* roughly equivalent to the energy used to fuel the entire buildings sector in the EU today.
- Although not modelled explicitly, this rationing is likely to have a significant impact on economic activity and levels of well-being.

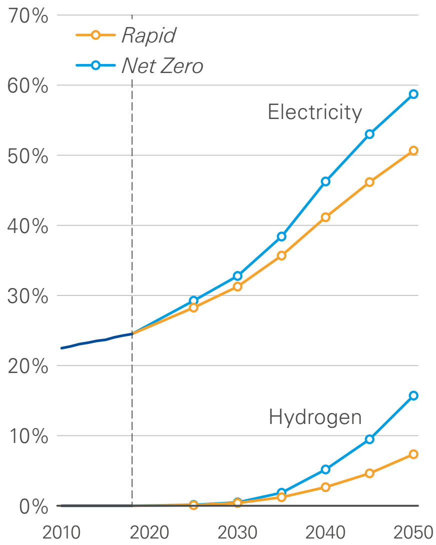
Low carbon transition leads to fundamental changes in the global energy system

Hydrocarbon use by scenario

100% = 2018 level

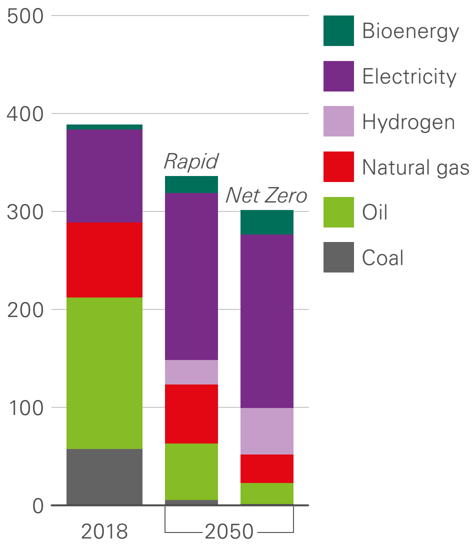


Share of electricity and hydrogen in total final consumption*



Total final consumption by carrier*

EJ



*Excluding non-combusted

Key points

- The transition to low-carbon energy system in *Rapid* and *Net Zero* leads to a fundamental restructuring of the global energy system.
- These changes are led by the declining importance of fossil fuels: oil, natural gas and coal. The use of hydrocarbons in both *Rapid* and *Net Zero* peak in the next few years, falling by around 50% and 70% respectively by 2050. Within that, the combined use of oil and natural gas falls by around a third and two-thirds in *Rapid* and *Net Zero* respectively.
- These traditional forms of energy are replaced to a large extent by low-carbon energy carriers in the form of electricity and, to a lesser extent, hydrogen. By 2050, electricity accounts for around 50% of final consumption (excluding the non-combusted use of fuels) in *Rapid* and around 60% in *Net Zero*. This greater recourse to electricity is complemented by the increasing use of hydrogen which is used for activities which are harder or more costly to electrify. By 2050, hydrogen accounts for around 7% of final energy consumption in *Rapid* and 16% in *Net Zero*.
- The shift away from traditional hydrocarbons also leads to an increasing role for bioenergy. Bioenergy takes various forms including liquid biofuels used largely in transport; biomethane which can be used as a direct substitute for natural gas across all sectors of the economy; and biomass used predominantly in the power sector. By 2050, bioenergy accounts for around 7% of primary energy in *Rapid* and almost 10% in *Net Zero*.
- The uncertainties surrounding the eventual nature of the global energy system in a net-zero world are considered in the next section.

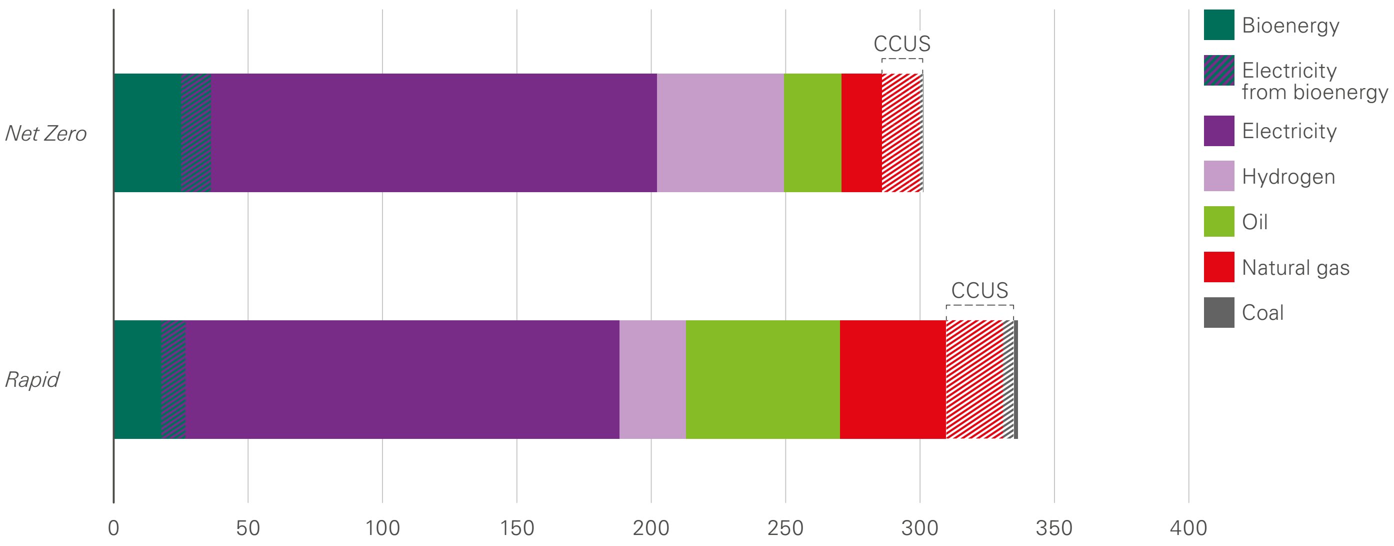
Global energy system at net zero

Summary
Energy demand
Electrification and the power sector
Oil and natural gas
Bioenergy and hydrogen
CCUS and negative emission technologies

Key uncertainties surrounding the global energy system in a net-zero world

Total final consumption by energy source in 2050*

EJ



*Excluding non-combusted

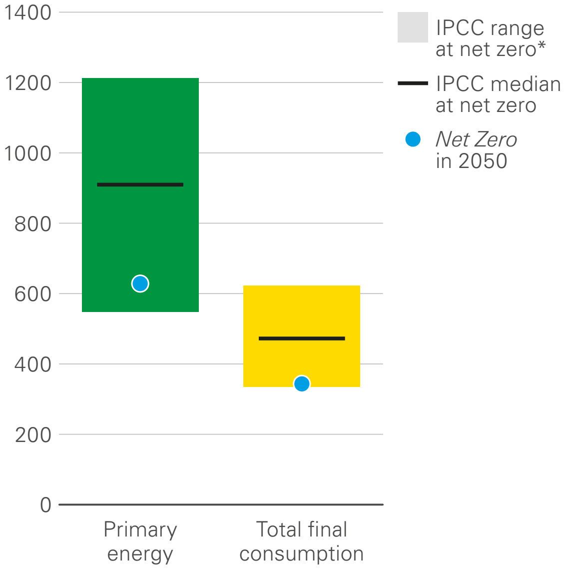
Key points

- There is significant uncertainty surrounding the structure of the global energy system in a net-zero world.
- The composition of energy in *Net Zero* in 2050 may provide some insight: total final energy consumption (excluding non-combusted energy) is close to 10% lower than in *Rapid*; electricity, hydrogen and bioenergy together account for around 85% of end energy use; and CCUS plays a significant role.
- But there are myriad transition paths to a net-zero world which will affect the eventual structure of the energy system and that structure is likely to continue to evolve even once it has reached net zero.
- There are (at least) five sources of uncertainty surrounding the size and structure of a net-zero energy system:
  - Energy demand: to what extent could efficiency improvements and changing consumption patterns cause energy demand to decouple from economic activity;
  - Electrification and the power sector: what proportion of final energy consumption might be electrified, and what different energy sources and technologies may be needed in a fully decarbonized power sector;
  - Other zero-carbon energy sources and carriers: what are the scope and limitations on the share of global energy use that could be provided by bioenergy and hydrogen;
  - Oil and natural gas: what role will oil and natural gas play as the energy system is decarbonized;
  - Carbon capture and negative emission technologies: how significant could CCUS be in reducing carbon emissions, and what is the potential for negative emission technologies and actions?
- These uncertainties are discussed in the rest of this section. The analysis is aided by considering the scenarios included in the IPCC Report which reach a net-zero energy system and considering the variation in outcomes across those scenarios (see pp 150-151 for more detail).

Net-zero energy system: how much energy will the world need?

Global energy demand in IPCC scenarios and *Net Zero*

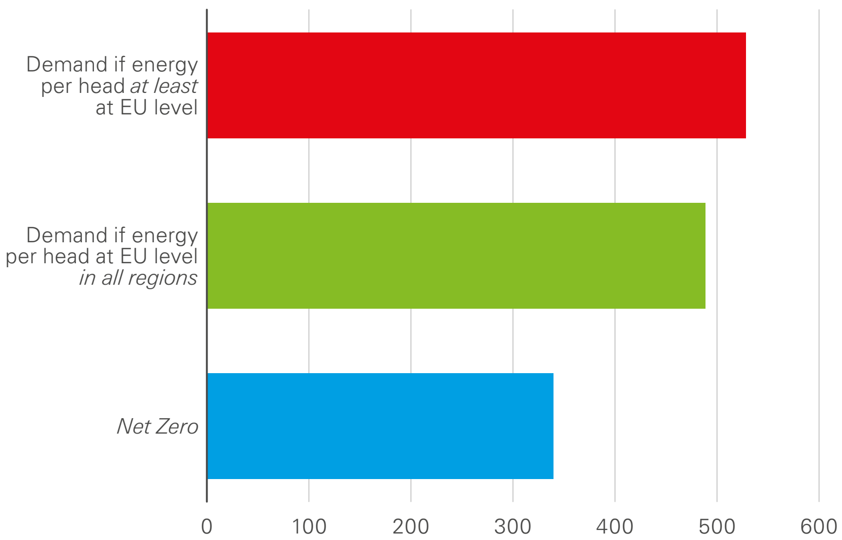
EJ



*Ranges show 10th and 90th percentiles of IPCC scenarios

Total final consumption in 2050

EJ

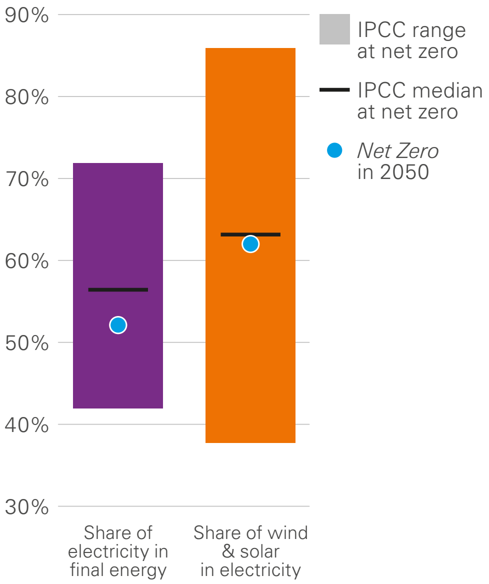


Key points

- The nature of a net-zero energy system will depend importantly on its overall size: how much energy is required for the global economy to continue to grow and prosper?
- This depends partly on the extent to which it is possible to decouple energy consumption from economic activity, through either improving energy efficiency – producing the same goods and services with less energy – or reduced energy use – changing production and consumption patterns to make less demands on the energy system, e.g. through the expansion of circular and sharing economies.
- The IPCC scenarios suggest a wide range for final end use of energy between 340-620 EJ in net zero. That compares with 425 EJ in 2018 and with 340 EJ in *Net Zero* in 2050 which is at the bottom of this range.
- Global energy demand will also depend on the equality of energy access and use globally. In *Net Zero*, average energy consumption per capita in the developed world by 2050 is still more than twice that in emerging economies, with billions of people living in energy deficient countries and regions. To reduce that inequality, either overall energy provision would need to increase or energy consumption in developed economies fall further.
- If regions with energy consumption per capita below EU levels increased to at least EU levels, global energy demand would be over 55% higher. This required increase falls to around 45% if regions with energy consumption per capital above EU levels reduced their average consumption levels to EU levels.
- The size of the energy system will also be affected by the relative importance of different energy sources and carriers. In particular, the conversion process used to produce energy carriers such as electricity and hydrogen boosts primary energy. The range of primary energy in the IPCC net-zero scenarios is 550-1210 EJ – considerably more than total final consumption of energy.
- Even if the vast majority of this primary energy is zero carbon, the overall footprint of the energy system is still likely to have wider implications due to the competing demands for (and environment impacts of) the materials, land and water it requires.

Net-zero energy system: significant increase in electrification and decarbonized power sector

Shares of electricity, wind and solar in IPCC scenarios and *Net Zero*



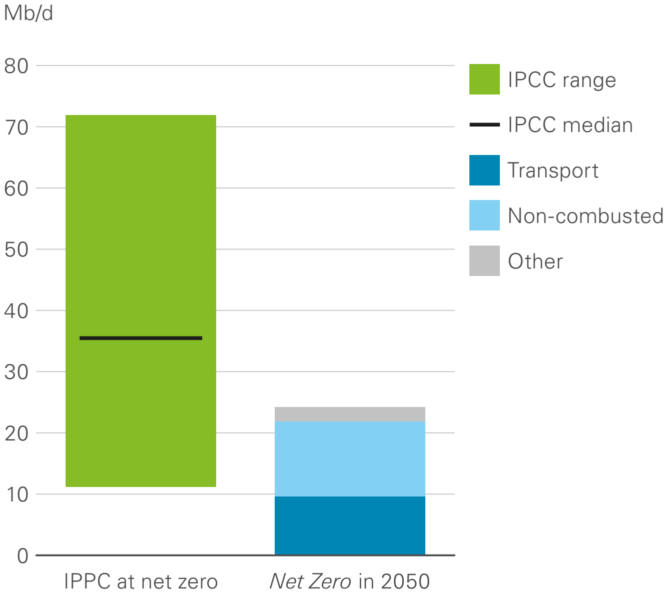
Technologies to help balance power system at different durations

Key points

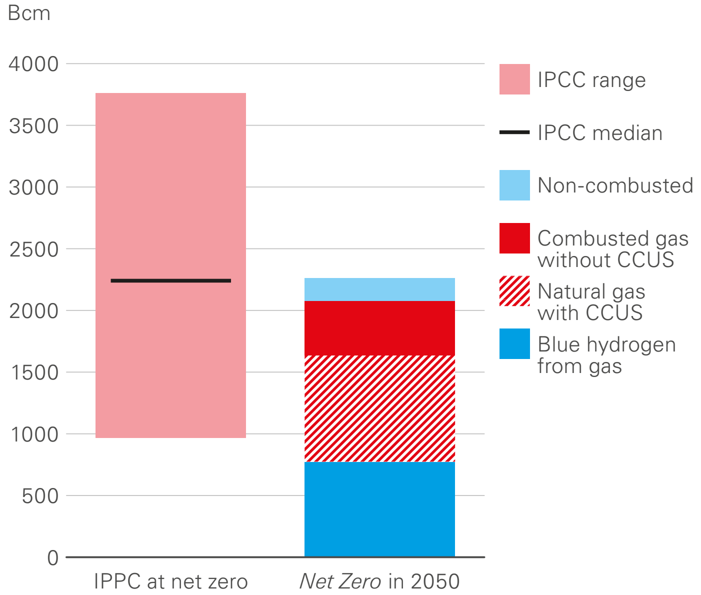
- A net-zero energy system is likely to be characterized by a substantial increase in the electrification of energy-consuming activities, with the electricity generated from a fully decarbonized (or net negative) power sector.
- But not all energy processes and uses can be technically or economically electrified, such as high-temperature industrial processes or long-distance transportation. In the IPCC net-zero scenarios, between 40-70% of end energy use is electrified; in *Net Zero*, a little over 50% of end energy use is electrified by 2050.
- A fully decarbonized power sector is likely to be dominated by zero- and near-zero carbon energy sources, led by wind and solar power, together with nuclear, hydro and bioenergy and other supporting technologies to ensure reliability. The intermittency of wind and solar power means the cost of balancing the power sector is likely to increase as the share of wind and solar power grows, slowing the extent to which they penetrate the power sector.
- In the IPCC net-zero scenarios, wind and solar power provides between 40-85% of global power generation. In *Net Zero*, the share of wind and solar reaches a little above 60% in the early 2040s after which it begins to plateau.
- A power system dominated by wind and solar power generation is likely to require a range of different energies and technologies to help balance their intermittency. For short-duration, high-frequency balancing, lasting from a few seconds to a few hours, this is likely to be met largely from a combination of batteries, pumped hydroelectricity and demand-side responses.
- But some of these technologies and actions are unlikely to be technically or economically feasible for longer-duration balancing across multiple days, weeks and seasons. This longer-term balancing is likely to be met by a combination of bioenergy; natural gas (or coal) combined with CCUS; hydrogen; and hydroelectricity combined with high-capacity reservoirs. In *Net Zero*, bioenergy, natural gas with CCUS, hydro and hydrogen collectively account for 30% of power generation in 2050.

Net-zero energy system: use of oil and natural gas falls substantially

Oil consumption in IPCC scenarios and *Net Zero*



Natural gas consumption in IPCC scenarios and *Net Zero*

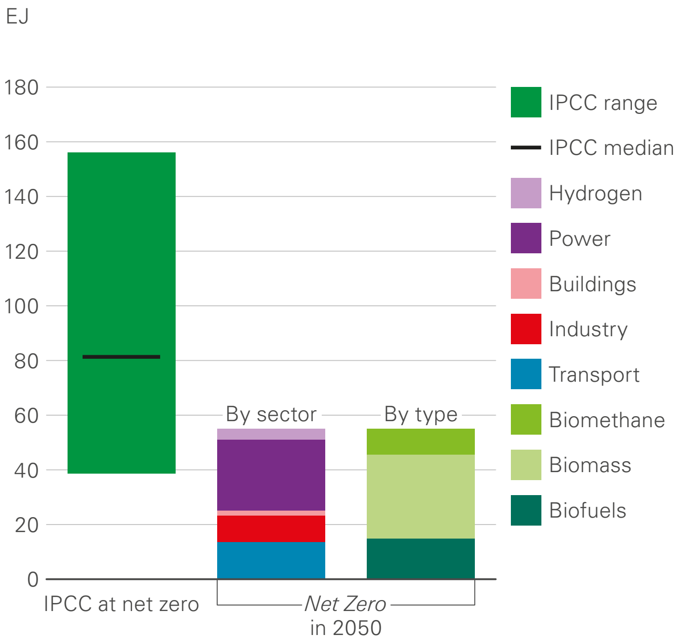


Key points

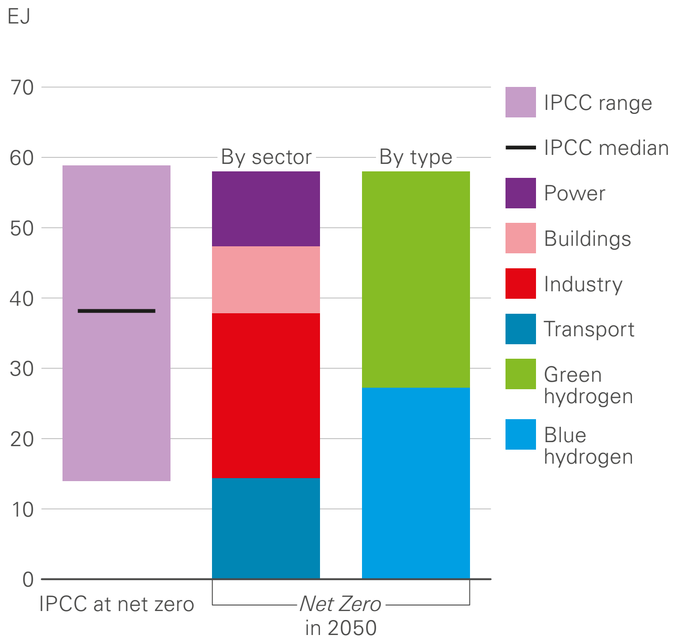
- The use of both oil and natural gas in a net-zero energy system is likely to decline substantially from current levels.
- Oil consumption in the IPCC net-zero scenarios declines to between 70-10 Mb/d, around 30-90% below current levels. Oil consumption falls to around 25 Mb/d in *Net Zero* by 2050, of which 10 Mb/d is used in the transport sector, mainly for long-distance transportation in trucking, aviation and marine. It is likely that this use in transport will decline further over time, as legacy vehicles and infrastructure are increasingly replaced with alternative technologies and energy sources.
- Outside of transport, most of the remaining oil in *Net Zero* in 2050 is used in the non-combusted sector for petrochemical feedstock and other industrial uses. Although this use of oil does not lead to carbon emissions at the point of use – since the oil is not combusted – the use and ultimate end of life consumption or disposal of the products which the oil is used to produce, such as plastics, may well generate carbon emissions over their life cycle. And, depending on how those activities are conducted, may also lead to other environmental issues. This may put further pressure on oil use over time.
- Natural gas consumption in the IPCC net-zero scenarios in 2050 varies between 3800 Bcm – similar to 2018 – and 1000 Bcm, a decline of 75% from current levels. In *Net Zero*, natural gas is around 2300 Bcm in 2050 providing energy across all the main sectors of the economy – either directly or via blue hydrogen.
- By 2050, around three-quarters of the natural gas which is combusted in *Net Zero* is used in conjunction with CCUS. This share is likely to grow further over time, either as the build out of CCUS expands or alternative low or zero-carbon energy sources become increasingly available and replace unabated natural gas.

Net-zero energy system: share of bioenergy and hydrogen increases

Bioenergy in IPCC scenarios and *Net Zero*



Hydrogen in IPCC scenarios and *Net Zero*



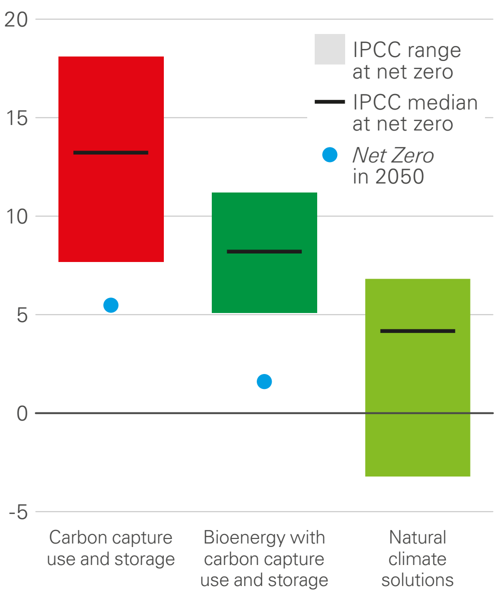
Key points

- Bioenergy and hydrogen – alongside electricity – are likely to play an increasing role in a net-zero energy system.
- The use of bioenergy in the IPCC net-zero scenarios ranges from 40-155 EJ; this compares with around 55 EJ in *Net Zero* by 2050, where it accounts for close to 10% of primary energy.
- A little over half of the bioenergy used in *Net Zero* is in the form of biomass, which is mainly used as a flexible feedstock in the power sector and to fuel high-temperature industrial processes. Biofuels account for almost another 30%, used largely in long-distance transportation, helped by their portability and high energy density. The remainder is biomethane which is consumed across all sectors as a replacement for natural gas.
- The use of bioenergy in a net-zero energy system will depend on the cost and feasibility of producing bioenergy at scale, together with other environmental and social factors, such as the extent of competition with other land uses and its impact on biodiversity.
- Hydrogen as an energy carrier reaches around 60 EJ in Net Zero by 2050, providing around 15% of total final consumption (excluding the non-combusted use of fuels). This is at the top of the range of IPCC net-zero scenarios (15-60 EJ), which may reflect that many of the IPCC scenarios were compiled before the increase in policy and private-sector interest in hydrogen over the past few years.
- The versatility of hydrogen means it is used in all sectors of the economy in *Net Zero* by 2050, especially in high-temperature industrial processes; long-distance road and marine transportation; and as a form of storage and flexible energy source in the power and buildings sectors.
- The production of hydrogen in *Net Zero* by 2050 is roughly even split between green and blue hydrogen (see pp 104-105).

Net-zero energy system: CCUS and negative emission technologies play a significant role

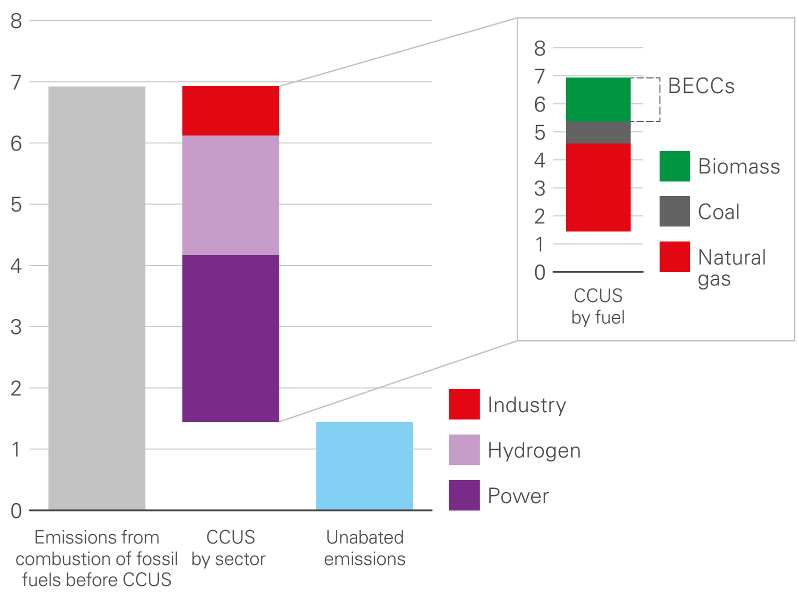
Carbon captured in IPCC scenarios and *Net Zero*

Gt of CO_2



CCUS by sector and fuel type in *Net Zero* in 2050

Gt of CO_2



Key points

- Technologies which capture carbon emissions or extract them from the atmosphere are likely to play a material role in a net-zero environment.
- In the IPCC net-zero scenarios, the use of CCUS ranges between 8-18 Gt CO_2, which is roughly equivalent to capturing and sequestering between a quarter and a half of all current carbon emissions from energy use. This range is higher than in *Net Zero*, where CCUS reaches a little over 5 Gt CO_2 by 2050.
- Although CCUS facilities capture a vast majority of carbon emissions, current technologies don't have a 100% capture rate. The average efficiency rate assumed in *Net Zero* is around 90%, implying residual carbon emissions from CCUS operations of around 0.5 Gt CO_2.
- CCUS can be combined with bioenergy (BECCS) in the power and industrial sectors to create a negative-emissions energy source. In the IPCC net-zero scenarios, the negative emissions produced using BECCS range from 5-10 Gt CO_2. Again, this is higher than in *Net Zero*, where the negative emissions from BECCS reach around 1.5 Gt CO_2 by 2050.
- There are a variety of other negative emission technologies (NETs). These technologies are not modelled explicitly in *Net Zero* which explores a possible pathway in which the energy system almost fully decarbonizes without significant use of NETs. Even so, these NETs may play an increasingly important role as the world seeks to reduce all GHG emissions to net zero, offsetting any continuing emissions from hard-to-abate sources in the energy system and the wider economy, such as agriculture, as well as any overshoots in the carbon budget.
- In particular, natural climate solutions (NCS), which includes forest and peat restoration and various forms of enhanced land management, generate emissions savings in the IPCC net-zero scenarios ranging from -3 to +7 Gt CO_2e (where the 'negative saving' reflect the risk that land use deteriorates over time adding to emissions).
- There are other NETs, such as direct air capture and biochar which, although not explicitly included in *Net Zero*, may also play a material role in balancing total GHGs as the world moves to net zero.

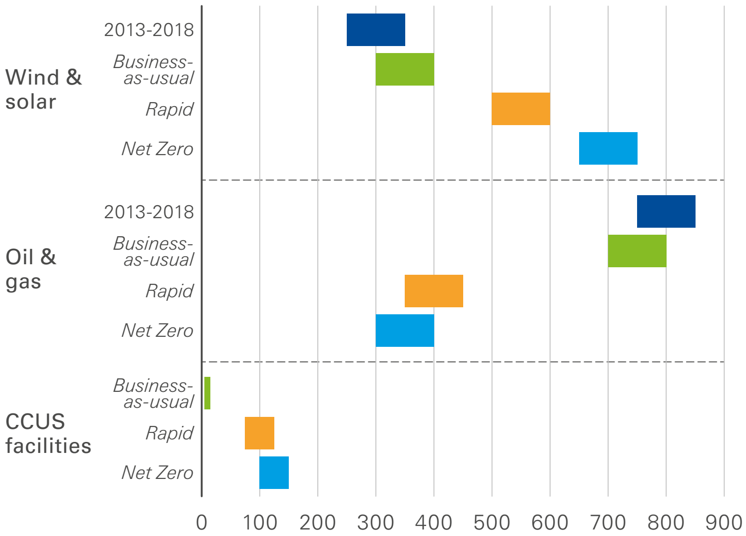
Investment

Summary
Upstream oil and gas investment

The energy transition requires significant shifts in the pattern of investment

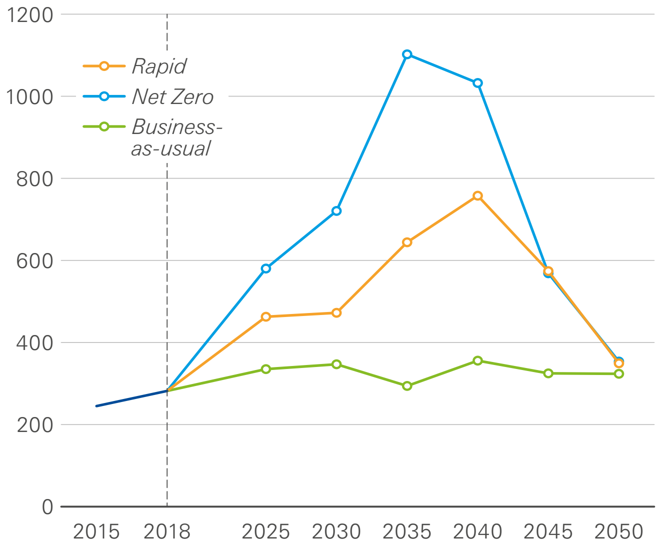
Average annual investment, history and 2020-2050

2018 US$ Billion



Average annual investment in wind and solar

Five-year rolling average, 2018 US$ Billion

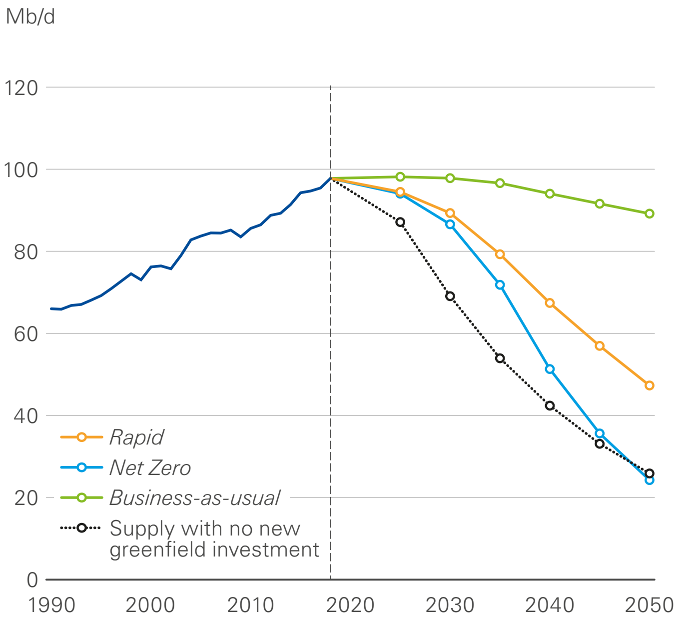


Key points

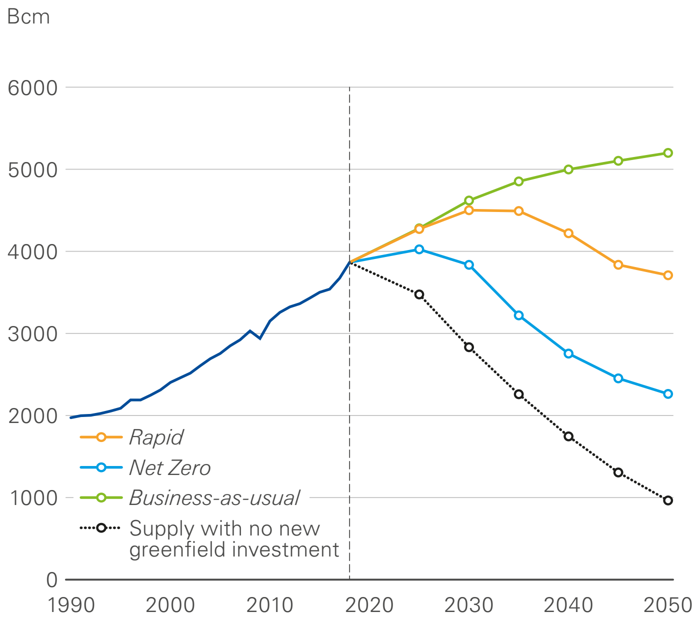
- The energy transition requires significant levels of investment, with material shifts in the pattern of that investment across different energy sources.
- Estimates of the investment paths implied by different scenarios are highly uncertain since they depend on assumptions concerning a range of factors that could affect the cost of energy investments over the next 30 years. The assumptions underlying the estimated investment requirements are discussed in more detail on pp 152-153. Investment estimates are in real $2018 prices.
- *Rapid* and *Net Zero* scenarios imply a significant increase in investment in wind and solar power capacity relative to the past. The average annual investment in wind and solar capacity implied by *Rapid* and *Net Zero* is between $500-750bn. This is two or three times greater than recent levels of investment, although is roughly equivalent to around only 3% of total business investment in 2018. *BAU* also implies an increase in investment in wind and solar capacity to around $300-400bn per year.
- The hump-shaped pattern of wind and solar investment in *Net Zero* – reflecting the quick build-out of new capacity in the 2020s and 30s before slowing markedly – may lead to issues of excess capacity in the supply chain supporting this build-out.
- The marked decline in oil and natural gas demand in *Rapid* and *Net Zero* is reflected in a sharp slowing in the pace of upstream investment relative to the past and is significantly lower than the investment in wind and solar capacity implied by these scenarios. The pattern of investment in oil and natural gas production in the different scenarios is discussed in more detail on pages 136-137.
- The level of investment required to support the build-out of CCUS facilities is relatively small compared to that required for wind and solar capacity and upstream oil and gas production. This is the case even in *Rapid* and *Net Zero* in which CCUS capacity is increased substantially.

Significant investment in new oil and natural gas production is still required

Consumption and production of oil



Consumption and production of natural gas



Key points

- Even though the demand for oil and natural gas peaks and falls in nearly all the scenarios, the faster rate of decline in existing production means that significant amounts of new upstream investment in oil and natural gas production is required in all three scenarios.

- The scenarios are based on the assumption that, if oil producers over the next 30 years invested only in maintaining existing (brownfield) sites, as well as completing projects that have already been sanctioned, this would imply an average decline rate of oil production of a little above 4% p.a., with global oil supplies falling to around 25 Mb/d in 2050. The corresponding decline rate for natural gas is assumed to be slightly higher (4.5%), reflecting the greater proportion of natural gas production that comes from short-cycle unconventional plays.

- Closing the gap between these 'no new greenfield investment' supply profiles for oil and natural gas and the level of supply needed to meet the demand profiles in the three scenarios requires significant levels of new investment in upstream oil and gas production, totalling between $9 trillion and over $20 trillion over the next 30 years.

- The profile of oil demand in *Net Zero* highlights the increasingly difficult judgements concerning future investments in oil and gas as the world transition to a lower carbon energy system.

- The relative resilience of oil demand during the first half of the Outlook in *Net Zero* implies that several trillions of US dollars of new oil investment is needed over the next 15 years or so to ensure adequate supplies. But the pace at which oil demand falls in the second half of *Net Zero* is faster than the natural decline rate of production, implying that some of these investments by 2050 may not be fully utilized and so may become uneconomic.

- This risk may be able to be mitigated by investing in less capital intensive, shorter-cycle, scalable projects, such as unconventional tight oil and gas, brownfield redevelopments and subsea tiebacks.

- The uncertainty about the speed and nature of the energy transition, as highlighted for example by *Delayed and Disorderly*, means the option value associated with these types of projects could increase in coming years.

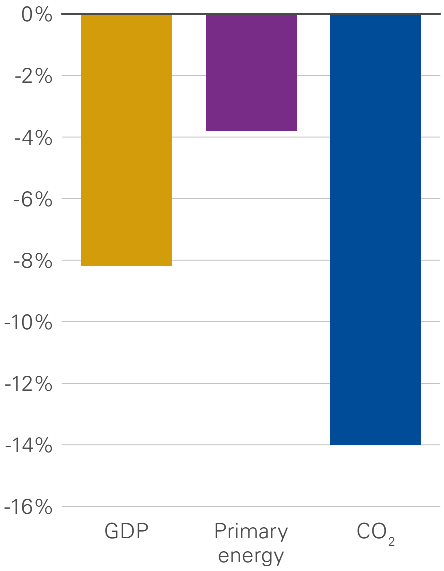
Comparisons

Revisions to *Rapid*
Comparing *Rapid* with external Outlooks

Main revisions to *Rapid*: lower energy demand and carbon emissions; higher share of renewable energy

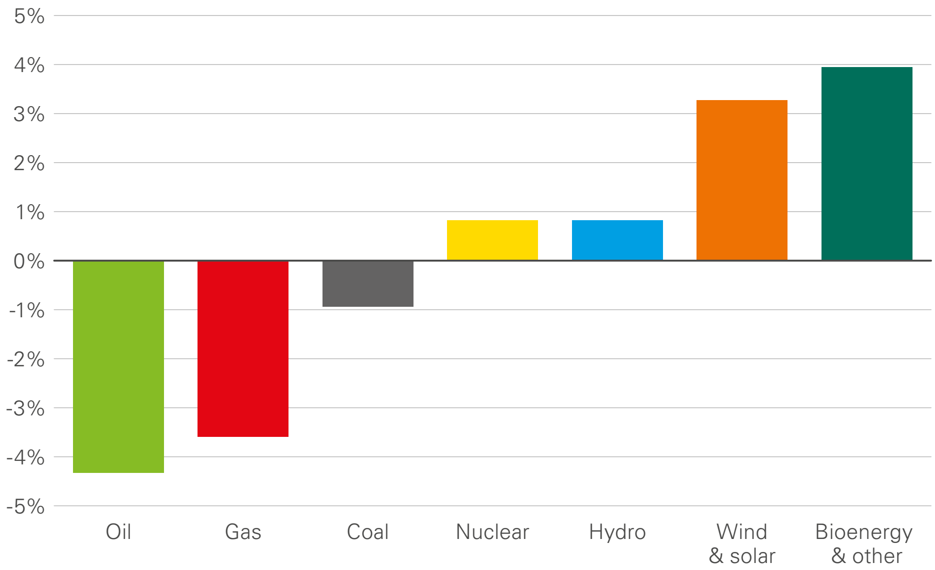
GDP, energy and carbon emissions

% change in 2040 vs previous Outlook



Shares of primary energy

Percentage point change in 2040 vs previous Outlook



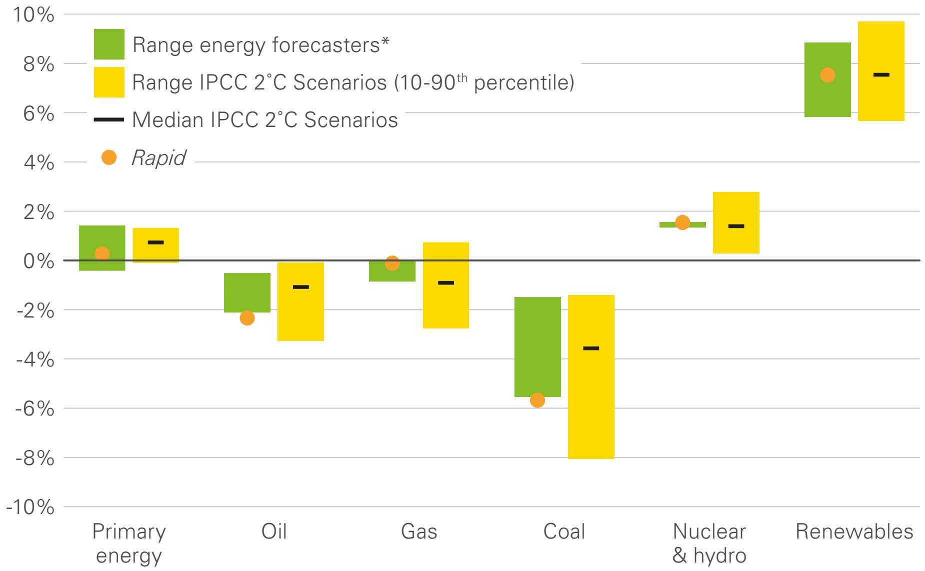
Key points

- Analysing how previous Outlooks have been revised over time helps identify key developments that may affect the future path of the energy system.
- The modelling assumptions used in *Rapid* differ from those used in last year's Rapid Transition scenario (RTS) in two main respects. First, *Rapid* includes a more comprehensive modelling of the role that hydrogen and bioenergy may play in the energy transition. Second, *Rapid* embodies a faster pace of decarbonization, such that the level of carbon emissions from energy use in *Rapid* in 2040 are around 15% lower than in 2019's RTS. The differences in *Rapid* relative to 2019's RTS reflect a combination of these modelling changes as well as the impact of recent developments.
- Global GDP in *Rapid* is 8% lower in 2040 than in last year's RTS. This largely reflects the impact from Covid-19 and new assumptions concerning the impact of climate change on economic activity (see pp 28-29, 148-149). The level of energy demand in 2040 in *Rapid* is around 4% lower, reflecting the weaker profile for economic growth partially offset by the increasing use of secondary energy carriers such as electricity and hydrogen, whose production tends to boost primary energy.
- The largest downward revision is to oil, whose share of primary energy in 2040 is 4 percentage points lower than in 2019's RTS. This diminished role for oil reflects the proportionally higher impact of Covid-19 on the transport sector, faster penetration of electricity and hydrogen in transport, and more stringent policy assumptions regarding the use of plastics (see pp 28-29, 44-45, 38-39).
- The share of natural gas in primary energy is also lower than in last year's RTS, squeezed by a more pronounced shift to renewable energy in power generation and a greater substitution by electricity and hydrogen in industry.
- The main counterpart is renewable energy, whose share of primary energy in 2040 is 7 percentage points higher than in last year's RTS. This upwards revision is split roughly equally between bioenergy – reflecting this year's more comprehensive analysis of bioenergy (see pp 128-129) – and wind & solar power, supported by green hydrogen production as well as continuing falls in development costs.

Rapid is broadly in line with external outlooks, although weaker oil and stronger natural gas

Growth in primary energy by source, 2018-2050

% per annum



*See pp 155 for more detail

CO_2 emissions and CCUS in 2050

Gt of CO_2

Key points

- It is also helpful to compare the scenarios in the *Energy Outlook* with projections published by other organizations to highlight differences of view and areas of uncertainty. *Rapid* can be compared with a sample of external outlooks which are broadly consistent with limiting global temperature rises to 'well below 2oC' as well as a range of corresponding IPCC scenarios (see pp 155 for details of the sample of external outlooks and pp 150-151 for more details on the IPCC scenarios).
- The average growth of primary energy over the next 30 years in *Rapid* is towards the bottom end of the range of both the sample of external outlooks and the IPCC scenarios. This may partly reflect the impact of Covid-19 on economic activity and energy demand since many of the scenarios have not been updated since the pandemic, as well as the assumed impact of climate change on GDP growth in *Rapid*.
- The comparative weakness of energy demand in *Rapid* is manifest in the profiles for oil and coal consumption, where *Rapid* is at or towards the bottom of the range of both the external projections and the IPCC scenarios.
- As with *Rapid*, both sets of comparator scenarios point to renewable energy being the fastest growing source of energy over the next 30 years, with the average annual rate of growth of renewable energy in *Rapid* broadly in line with the median IPCC scenario.
- The outlook for natural gas in *Rapid* is towards the top end of both scenario ranges, which may partly reflect *Rapid* having a brighter outlook for blue hydrogen than many of the other scenarios.
- In terms of carbon emissions in 2050, *Rapid* is towards the low end of the range of external scenarios and in line with the median IPCC scenario. Within that, the use of CCUS in *Rapid* is broadly in the middle of the spread of external outlooks, although below the bottom of the range of IPCC scenarios which embody a stronger view of the potential role of CCUS.

Annex

Key figures, definitions, methodology and data sources

Key figures

	Level in 2050				Shares of primary energy in 2018 and 2050				Change 2018 - 2050 (% p.a.)		
	2018	*Rapid*	*Net Zero*	*BAU*	2018	*Rapid*	*Net Zero*	*BAU*	*Rapid*	*Net Zero*	*BAU*
Primary energy by fuel (EJ)											
Total	576	625	625	725	100%	100%	100%	100%	0.3%	0.3%	0.7%
Oil	190	89	42	172	33%	14%	6.8%	24%	-2.3%	-4.6%	-0.3%
Natural gas	138	134	81	187	24%	21%	13%	26%	-0.1%	-1.6%	0.9%
Coal	158	24	12	123	27%	3.9%	1.9%	17%	-5.7%	-7.8%	-0.8%
Nuclear	24	44	57	31	4.2%	7.0%	9.1%	4.2%	1.9%	2.7%	0.7%
Hydro	38	57	62	51	6.5%	9.1%	9.9%	7.1%	1.3%	1.6%	1.0%
Renewables (incl. biofuels)	27	277	370	161	4.7%	44%	59%	22%	7.5%	8.5%	5.7%
Primary energy by sector											
Transport^	119	147	159	147	21%	24%	26%	20%	0.7%	0.9%	0.7%
Non-combusted^	38	44	28	53	6.5%	7.1%	4.4%	7.3%	0.5%	-1.0%	1.1%
Buildings^	169	179	177	234	29%	29%	28%	32%	0.2%	0.1%	1.0%
Industry^	250	254	261	291	43%	41%	42%	40%	0.1%	0.1%	0.5%
Of which:											
Inputs to power	245	423	483	388	43%	68%	77%	54%	1.7%	2.2%	1.5%
Primary energy by region											
Developed	240	179	186	218	42%	29%	30%	30%	-0.9%	-0.8%	-0.3%
US	95	67	69	92	17%	11%	11%	13%	-1.1%	-1.0%	-0.1%
EU	70	49	49	53	12%	7.8%	7.8%	7.3%	-1.1%	-1.1%	-0.8%
Other	75	64	68	73	13%	10%	11%	10%	-0.5%	-0.3%	-0.1%
Emerging	335	445	438	507	58%	71%	70%	70%	0.9%	0.8%	1.3%
China	136	141	139	155	24%	23%	22%	21%	0.1%	0.1%	0.4%
India	34	75	77	86	5.9%	12%	12%	12%	2.5%	2.6%	3.0%
Other Asia	41	66	68	76	7.1%	11%	11%	11%	1.5%	1.6%	2.0%
Middle East	38	40	31	53	6.6%	6.5%	5.0%	7.3%	0.2%	-0.6%	1.1%
Russia	30	27	28	30	5.2%	4.2%	4.5%	4.1%	-0.4%	-0.2%	0.0%
Brazil	12	20	20	20	2.1%	3.2%	3.1%	2.8%	1.5%	1.5%	1.6%
Other	45	76	75	87	7.8%	12%	12%	12%	1.7%	1.6%	2.1%

	Level in 2050				Change 2018 - 2050 (% p.a.)		
	2018	*Rapid*	*Net Zero*	*BAU*	*Rapid*	*Net Zero*	*BAU*
Primary energy by fuel (native units)							
Oil (Mb/d)	97	47	24	89	-2.2%	-4.2%	-0.3%
Natural gas (Bcm)	3845	3708	2263	5199	-0.1%	-1.6%	0.9%
Production							
Oil (Mb/d)	98	47		89	-2.2%		-0.3%
Natural gas (Bcm)	3865	3717		5200	-0.1%		0.9%
Coal (EJ)	165	30		120	-5.2%		-1.0%
Macro							
GDP (trillion US$ PPP)	129	297	297	297	2.6%	2.6%	2.6%
Population (billions)	7.6	9.7	9.7	9.7	0.8%	0.8%	0.8%
GDP per capita (thousand US$)	17	31	31	31	1.9%	1.9%	1.9%
Energy intensity (MJ per US$ of GDP)	4.5	2.1	2.1	2.4	-2.3%	-2.3%	-1.9%
Net CO_2 emissions (Gt)	33.8	9.4	1.4	30.5	-3.9%	-9.4%	-0.3%

EJ = exajoules

^Includes electricity and hydrogen; and their associated conversion losses.

Estimates of climate change on GDP growth

This year's *Energy Outlook* attempts to account explicitly for the impact of climate change on economic activity as well as the mitigation costs associated with decarbonizing the energy system. There is considerable uncertainty in the economic and scientific literature as to how to model these impacts and so any estimates of these effects, including those contained in the Outlook, are imperfect and almost certainly incomplete. That said, we have judged that it is better to use the research that is available than to make no attempt to include it in our analysis.

The economic literature on climate change has traditionally quantified the relationship between climate change effects and economic activity using climate-economy integrated assessment models (IAMs). A more recent strand of empirical literature analyses the economic impact of climate change based on estimates of how past changes in temperature in different parts of the world have affected GDP. One of the benchmark studies of this literature, Burke et al. (2015) uses the IPCC Representative Concentration Pathways (RCP) scenarios to assess the non-linear impact of temperature changes on GDP across 166 countries. They find that GDP per capita is a concave function of temperature, peaking at an annual average temperature of 13°C and declining strongly at higher levels.

The illustrative estimates of the impact from climate change on GDP contained in the *Outlook* are based on the models from Burke et al. The assumed temperature profiles implied by the three main scenarios are based on the RCP scenario which most closely approximate the trajectories for carbon emissions from energy use in each of the scenarios. For *Rapid* this is RCP 2.6; *Net Zero* – RCP 1.9; and *BAU* – RCP 4.5. The economic impacts from these implied temperature increases are computed relative to a counterfactual scenario, in which future temperatures are assumed to be held constant at recent (1980-2010) average levels.

The median climatic change impacts derived using Burke's methodology suggest that, for *BAU*, the implied increase in global temperatures would decrease global GDP by close to 5% by 2050. The estimated impacts for *Rapid* and *Net Zero* are somewhat smaller, reflecting the lower path of carbon emissions. The regional impacts are distributed according to the evolution of their temperatures relative to the concave function estimated by Burke et al. Regions that are already relatively warm are likely to experience negative impacts on GDP, while colder regions could potentially benefit from relatively warmer weather.

These climate change impacts are hugely uncertain and incomplete as the Burke et al framework focuses only on temperature changes on GDP, and does not incorporate other climate change effects (such as rising sea levels, more frequent and stronger storms, floods, droughts or loss of biodiversity) or other sources of economic disruption, such as large-scale human migration.

The mitigation costs of actions to decarbonize the energy system are also very uncertain, with significant variations across different external estimates. Most estimates, however, suggests that these costs increase with the stringency of the mitigation effort, suggesting that they are likely to be bigger in *Rapid* and *Net Zero*, than in *BAU*. Estimates published by the IPCC (AR5 – Chapter 6) suggest that for scenarios consistent with keeping global temperatures increases to well below 2°C, median estimates of mitigation costs range between 2-6% of global consumption by 2050.

Given the huge range of uncertainty surrounding estimates of the economic impact of both climate changes and mitigation, and the fact that all three of the main scenarios include both types of costs to a greater or lesser extent, the *Outlook* is based on the illustrative assumption that these effects reduce GDP in 2050 by around 5% in all three scenarios, relative to the counterfactual in which temperatures are held constant at recent average levels.

Importantly, if the scenarios were extrapolated beyond 2050, the Burke methodology would imply GDP growth and prosperity in *BAU* would get progressively worse, leading to significantly lower levels of well-being than in *Rapid* and *Net Zero*.

References

Burke, M., Hsiang, S. & Miguel, E. Global non-linear effect of temperature on economic production. Nature 527, 235–239 (2015)

The global aggregate mitigation cost estimates in terms of GDP losses are taken from IPCC AR5 – Chapter 6: *https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_chapter6.pdf*

Construction of IPCC scenario sample ranges

The world's scientific community has developed a number of "integrated assessment models" (IAMs) that attempt to represent interactions between human systems (the economy, energy, agriculture) and climate. They are "simplified, stylized, numerical approaches to represent enormously complex physical and social systems" (Clarke 2014). These models have been used to generate a large number of scenarios, exploring possible long-run trajectories for GHG emissions and climatic changes under a wide range of assumptions.

The Intergovernmental Panel on Climate Change (IPCC) carries out regular surveys of this scenario modelling as part of its assessment work. The most recent survey was carried out in support of the 2019 IPCC Special Report on Global Warming of 1.5°C (SR15). A total of 414 scenarios from 13 different modelling frameworks were compiled and made available via an online portal *(https://data.ene.iiasa.ac.at/iamc-1.5c-explorer)*.

Some of the scenarios are now quite dated and, in some cases, scenario results are already significantly out of line with recent historical data and so were excluded from our analysis. From the remaining model runs, we extracted 112 scenarios that were judged to be consistent with the Paris Agreement Long Term Temperature Goal. They were further divided into two subsets: "well below 2°C" (69 scenarios); and "1.5°C with no or low overshoot" (43 scenarios). A more detailed note on the scenario selection methodology is available at *www.bp.com/energyoutlook*. For each of these two subsets of scenarios, the ranges of outcomes for key variables are described in terms of medians and percentile distributions.

For each of these two subsets of scenarios, the ranges of outcomes for key variables are described in terms of medians and percentile distributions.

It is important to note that the scenario dataset represents "an ensemble of opportunity" – a collection of scenarios that were available at the time of the IPCC survey and which were produced for a variety of purposes. "It is not a random sampling of future possibilities of how the world economy should decarbonise" (Gambhir et al, 2019). That means that the distributions of IPCC scenarios cannot be interpreted as reliable indicators of likelihood of what might actually happen. Rather, the distributions simply describe the characteristics of the scenarios contained in the IPCC Report.

The sample ranges included in the section 'Global energy system at net zero' (see pp 119-131), are based on those IPCC scenarios in our sample which embody net carbon emissions from energy and industrial use falling below 1 Gt before 2100. This was the case for 84 of the scenarios from the sample of 112 scenarios. For each of these scenarios, the size and structure of the energy system is considered at the point at which carbon emissions fall below the 1 Gt threshold. The earliest point at which this 'net zero' state is reached in the sample of scenarios is around 2045 and the median scenario in 2070.

References

Clarke L. et al (2014). Assessing Transformation Pathways. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change

Gambhir A. et al (2019). Energy system changes in 1.5 °C, well below 2 °C and 2 °C scenarios Energy Strategy Reviews 23

Estimate of investment profiles

This year's *Energy Outlook* includes estimates of the investment requirements implied for each of the three main scenarios for upstream oil and natural gas, renewables and carbon capture use and storage (CCUS).

Oil and gas investment

Upstream oil and natural gas capital expenditure (excluding operating costs) profiles in each of the three main scenarios are calculated based on the investment required at an individual asset level to meet the shortfall between estimates of the demand for oil and natural gas and a hypothetical supply of oil and natural gas where no new investment is undertaken in new fields. Both the asset-level database and decline rates are derived from Rystad. The average base decline rate up to 2050 for oil and natural gas is estimated at 4.3% p.a. and 4.8% p.a., respectively. When including fields that have already been sanctioned, the decline rate is mitigated to 4.1% p.a. and 4.5% p.a., respectively.

The hypothetical supply baselines for oil and natural gas assume that no new investment is undertaken in new fields beginning with the 2020 supply baseline. It assumes that continuous investment at producing and sanctioned fields takes place including infill wells and costs related to maintaining the facility. Additionally, projects that have already been sanctioned (up to almost 7 Mb/d by 2025 and 400 Bcm by 2027 for oil and natural gas, respectively) are assumed to be completed in the next few years.

A set of non-producing, unsanctioned, dispatchable assets needed to meet the oil and gas shortfalls in our three main demand scenarios is defined. Based on Rystad data, the asset-level investments required to bring those assets online are estimated. Finally, the capital spending on new assets is added to the capex of the producing and under development assets. Investment in producing and under development assets are assumed to be equal in all scenarios.

Investment in wind and solar energy, and CCUS

For wind and solar energy, the deployment rate of each technology in each scenario is estimated. Investment costs are assigned to each based on their historical costs and learning curves. The investment costs of solar and wind energy are broadly aligned with their historical learning curves, around 8% for wind and 20% for solar.

For carbon capture and storage, the cost of investment in 2018 for different technologies – iron & steel, cement, hydrogen, power sector, chemical sector, fertilizers – is taken from a range of sources. It is assumed that the investment costs decline over time as a reflection of technology progress. The annual investment cost reduction varies from a minimum of 1.3% to a maximum of 1.9%, depending on the technology.

The total investment in CCUS is based on deployment and costs. These also include variables costs and, in particular, the cost of transportation and storage of carbon emissions which vary between regions and over time.

References

Rystad Energy's UCube global upstream database, August 2020

Definitions and data sources

Data

- Unless noted otherwise, data definitions are based on the BP Statistical Review of World Energy
- All comparison data, including scenarios from IPCC and other energy forecasters, have been rebased to be consistent with the bp Statistical Review
- Primary energy comprises commercially-traded fuels, and excludes traditional biomass
- The primary energy values of nuclear, hydro and electricity from renewable sources have been derived by calculating the equivalent amount of fossil fuel required to generate the same volume of electricity in a thermal power station, the thermal efficiency assumption is time varying, with the simplified assumption that efficiency will increase linearly to 45% by 2050. For more information see *https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/methodology-for-converting-non-fossil-fuel-primary-energy.pdf*
- Gross Domestic Product (GDP) is expressed in terms of real Purchasing Power Parity (PPP) at 2015 prices

Sectors

- Transport includes energy used in road, marine, rail and aviation
- Industry includes energy combusted in manufacturing; construction; the energy industry including pipeline transport; and for transformation processes outside of power generation
- Non-combusted includes fuel that is used as a feedstock to create materials such as petrochemicals, lubricant and bitumen
- Buildings includes energy used in residential and commercial building, plus agriculture, fishing and IEA's non-specified sector "Other"
- Power includes inputs into power generation (including combined heat and power plants)

Regions

- OECD is approximated as North America plus Europe plus OECD Asia
- China refers to the Chinese Mainland
- Other Asia includes all countries and regions in non-OECD Asia excluding mainland China and India

Fuels, energy carriers, carbon and materials

- Oil unless noted otherwise includes: crude (including shale oil and oil sands); natural gas liquids (NGLs); gas-to-liquids (GTLs); coal-to-liquids (CTLs); condensates; and refinery gains
- Liquids includes all of oil plus biofuels
- Renewables unless otherwise noted includes wind, solar, geothermal, biomass, biomethane and biofuels and excludes large-scale hydro
- Non-fossils includes renewables, nuclear and hydro
- Hydrogen demand includes its consumption in transport, industry, buildings and power, but does not include the demand as a non-combusted feedstock (such as use for fertilizer or methanol production)
- Gas includes natural gas and biomethane
- References to carbon emissions consider only CO_2 emissions from fuel combustion
- Plastics includes synthetic fibres

Data sources used to compare with *Rapid*

- Equinor: Renewal Scenario, *Energy Perspectives 2019*, June 2019
- IEA: Sustainable Development Scenario, *International Energy Agency, World Energy Outlook 2019,* Paris, France, November 2019
- IHS Markit: *Accelerated Carbon Capture and Storage and Multitech Mitigation: IHS Markit 2020 low emission cases,* January 2020
- Shell: *Sky Scenario,* February 2018

Other key data sources

- BP p.l.c., *bp Statistical Review of World Energy, London, United Kingdom,* June 2019
- International Energy Agency, *Energy Balances of Non-OECD Countries,* Paris, France, 2019
- International Energy Agency, *Energy Balances of OECD Countries,* Paris, France, 2019
- United Nations, Department of Economic and Social Affairs, Population Division (2019). *World Population Prospects 2019,* Online Edition. Rev. 1

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