Overview

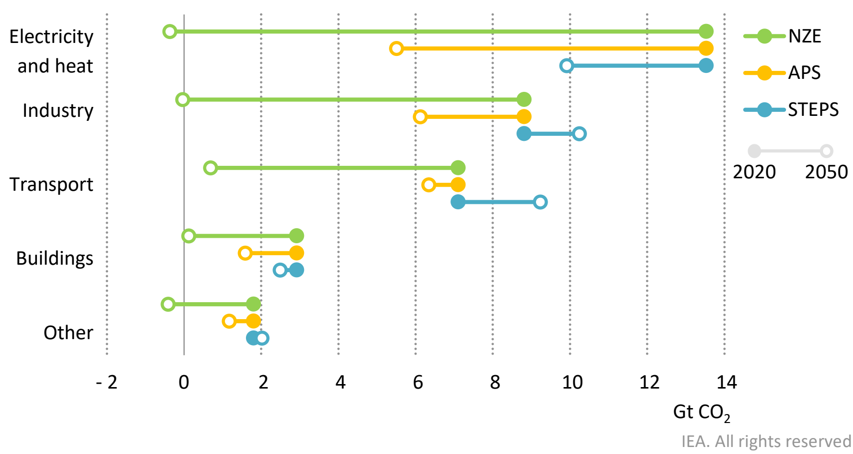
Key themes of WEO-2021

SUMMARY

- In the run-up to a crucial COP26 meeting in Glasgow, this *World Energy Outlook-2021* (*WEO-2021*) provides a detailed picture of how far countries have come in their clean energy transitions, and how far they still have to go. A new global energy economy is emerging, but will need to take shape much more quickly to avoid severe impacts from a changing climate.

- An outlook based on today's policy settings, the Stated Policies Scenario (STEPS), shows aggregate fossil fuel demand slowing to a plateau in the 2030s and then falling slightly by 2050, the first time this has been projected in this scenario. Almost all of the net growth in energy demand comes from low emissions sources. Nonetheless, the global average temperature rise in this scenario passes the 1.5 degrees Celsius (°C) mark around 2030 and would still be climbing as it reaches 2.6 °C in 2100.

Figure 1.1 ⊳ CO_2 emissions by sector and scenario



Clean electricity can do a lot of the heavy lifting, but it is harder to bend the emissions curve in industry and transport

- Announced net zero pledges and enhanced Nationally Determined Contributions, if implemented in full as in the Announced Pledges Scenario (APS), start to bend the curve and bring the temperature rise in 2100 down to around 2.1 °C. In the APS, oil demand peaks soon after 2025, and a more rapid ramp up in low emissions sources brings emissions down to 21 gigatonnes (Gt) in 2050. However, a much greater global effort will be essential to reach the relative safety of the Net Zero Emissions by 2050 Scenario (NZE). Announced pledges close less than 20% of the emissions gap in 2030 between the STEPS and the NZE.

- Actions in four key areas over the next decade are essential to keep the door to a 1.5 °C stabilisation open: a massive push for clean electrification; a renewed focus on realising the full potential of energy efficiency; concerted efforts to prevent leaks from fossil fuel operations; and a boost to clean energy innovation.
- Many emerging market and developing economies face a continued public health crisis from Covid-19, and the pandemic has set back efforts to improve access to electricity and clean cooking fuels. Funds for sustainable recovery are scarce and capital remains up to seven-times more expensive than in advanced economies, at a moment when their economies are entering what has historically been an energy- and emissions-intensive process of urban expansion and infrastructure development.
- An international catalyst will be essential to accelerate clean energy deployment and to allow developing economies – where per capita emissions are often very low – to chart a new lower emissions path for development; as things stand, emissions from emerging market and developing economies (excluding China) increase more than 5 Gt to 2050 in the STEPS, with the largest growth from industry and transport.
- Transitions are accompanied by marked shifts in energy sector employment, but clean energy jobs expand faster than other sectors fall. The downside risks for jobs are concentrated in the coal sector, where retirements of coal-fired capacity approach 100 gigawatts (GW) per year over the coming decade in the NZE, almost double the figure in the Announced Pledges Scenario (APS). Phasing out coal requires an accelerated scale up of new low emissions generation and infrastructure, as well as a sustained commitment by governments and the international community to manage the impacts on communities, assets, land and the local environment.
- Price volatility is an ever-present feature of commodity markets, but well-managed transitions offer ways to dampen the impacts on household energy bills. Compared with the situation in STEPS, the effect of a large price shock in 2030 in the NZE is reduced by efficiency gains and lower direct consumption of oil and gas.
- Getting the world on track for net zero emissions by 2050 requires transition-related investment to accelerate from current levels to around USD 4 trillion annually by 2030, but only a minority of these investments immediately deliver zero emissions energy or energy services. Ensuring that other investments are financed, for example those that aid transitions in emissions-intensive sectors, is a key challenge for financiers, investors and policy makers.
- If the world gets on track for net zero emissions by 2050, then the cumulative market opportunity for manufacturers of wind turbines, solar panels, lithium-ion batteries, electrolysers and fuel cells amounts to USD 27 trillion. These five elements alone in 2050 would be larger than today's oil industry and its associated revenues.

Introduction

In a momentous period for the future of energy and emissions, this *World Energy Outlook* uses several long-term scenarios to illustrate the choices that face the world's decision makers in the run-up to the crucial 26th Conference of the Parties (COP26) in November and beyond. A key variable in determining where the world goes from here is action taken by governments. They do not hold all the levers: individuals, communities, civil society, companies and investors can all make a major difference. But none have the same capacity as governments to shape the future of energy by setting the framework conditions that channel investment to energy projects, by supporting innovation, by giving clear signals about their long-term ambitions and by taking the necessary steps to realise them.

This *Outlook* takes into consideration the full diversity of country circumstances, resources, technologies and potential policy choices in its examination of the scenario projections. Countries are not starting this journey from the same place. Many developing economies, in particular, are facing a continued public health crisis and the impacts of the Covid-19 pandemic on their economies and energy sectors will be felt for years to come. By contrast, more rapid progress with mass vaccination campaigns leaves most advanced economies and the People's Republic of China (hereafter China) with a clearer near-term pathway to recovery, though many uncertainties and risks remain.

The main scenarios in this *Outlook* are:

- **Net Zero Emissions by 2050 Scenario** (NZE), which sets out a narrow but achievable pathway for the global energy sector to achieve net zero CO_2 emissions by 2050.
- **Announced Pledges Scenario** (APS), which assumes that all climate commitments made by governments around the world, including Nationally Determined Contributions (NDCs) and longer term net zero targets, will be met in full and on time.
- **Stated Policies Scenario** (STEPS), which reflects current policy settings based on a sector-by-sector assessment of the specific policies that are in place, as well as those that have been announced by governments around the world.

There are also references to the Sustainable Development Scenario (SDS), which, like the NZE, achieves key energy-related United Nations Sustainable Development Goals related to universal energy access and major improvements in air quality, and reaches global net zero emissions by 2070 (with many countries and regions reaching net zero much earlier). The Announced Pledges and New Zero Emissions by 2050 scenarios are introduced for the first time this year. Updates have been incorporated into the STEPS (Box 1.1) and to the SDS since the *WEO*-2020. All the scenarios are described in detail in Chapter 2.

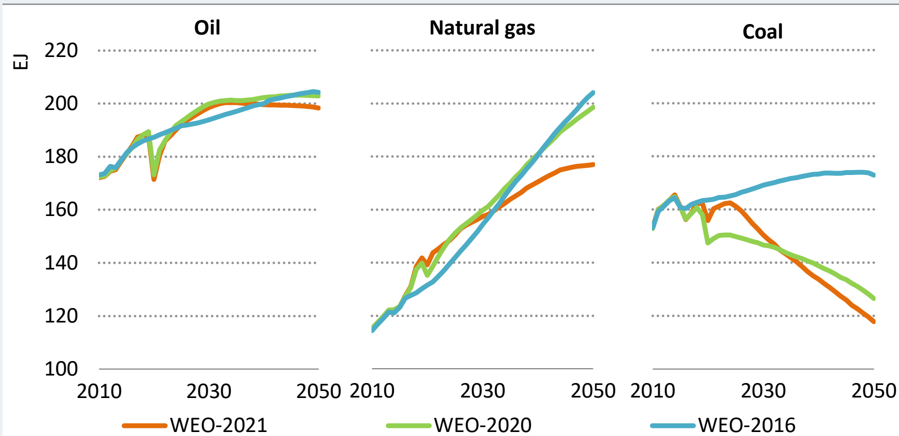
This Overview chapter explores ten key themes covering the risks, trade-offs and benefits of different courses of action. The *Outlook* is based on rigorous modelling and analysis, reflecting the latest energy data, policy announcements, investment trends and technology developments, but it keeps in mind two core tenets: the crucial role of energy in human well-being and social and economic development; and the responsibility of the energy sector for nearly three-quarters of the emissions that are causing climate change.

Box 1.1 ▻ One STEPS beyond…

The Stated Policies Scenario (STEPS) is based on prevailing policy settings and so provides a useful barometer of the strength and impact of these policies over time. Compared with the *WEO-2020*, some of the largest changes in the STEPS in this *Outlook* are:

- Total fossil fuel demand is higher in the near term than in the *WEO-2020* STEPS. However, it is also markedly lower after 2030. For the first time, aggregate fossil fuel demand slows to a plateau in the 2030s and then falls slightly by 2050 (Figure 1.2).
- Natural gas demand is around 600 billion cubic metres (bcm) (or 10%) lower in 2050 than in the *WEO-2020* STEPS, mainly reflecting lower projected consumption in the power and industry sectors in emerging market and developing economies in Asia.
- Oil demand starts to decline in the 2030s for the first time in the STEPS as a result of more muted growth in petrochemicals and faster reductions elsewhere.
- Coal use rebounds more rapidly in the near term and stays above last year's projections until around 2030, but its subsequent decline is faster than projected in 2020 (and much faster than projected five years ago).
- Total CO_2 emissions are around 2 Gt lower in 2050 than in last year's STEPS. Most of the difference is in the power sector, where emissions fall by more than 25% between 2020 and 2050 (compared with a decline of less than 10% in the *WEO-2020*). Generation from solar photovoltaics (PV) and wind in 2050 is around 15% and 20% respectively higher in this *Outlook*.

Figure 1.2 ▻ Oil, natural gas and coal demand in the Stated Policies Scenario in *World* Energy *Outlook 2021*, *2020* and *2016*



Oil demand peaks for the first time in the WEO-2021 STEPS; natural gas has been revised down from the WEO-2020; coal use is a lot lower than projected five years ago

Note: *WEO-2016* numbers are the New Policies Scenario extrapolated to 2050.

1.1 A new energy economy is emerging

There are unmistakeable signs of change. In 2020, even as economies sank under the weight of Covid-19 lockdowns, additions of renewable sources of energy such as wind and solar PV increased at their fastest rate in two decades, and electric vehicle sales set new records. A new energy economy is coming into view, ushered forward by policy action, technology innovation and the increasing urgency of the need to tackle climate change. There is no guarantee that the emergence of this new energy economy will be smooth, and it is not coming forward quickly enough to avoid severe impacts from a changing climate. But it is already clear that tomorrow's energy economy promises to be quite different from the one we have today.

Electricity is taking on an ever-more central role in the lives of consumers and, for an increasing number of households, it promises to become the energy source on which they rely for all their everyday needs: mobility, cooking, lighting, heating and cooling. The reliability and affordability of electricity is set to become even more critical to all aspects of people's lives and well-being.

Electricity's share of the world's final consumption of energy has risen steadily over recent decades, and now stands at 20%. Its rise accelerates in future years as the pace of transitions picks up. In the NZE, electricity accounts for around 50% of final energy use by 2050 (around 30% in the APS). Given that electricity delivers useful energy services with better efficiency than other fuels, the contribution of electricity is even higher than these numbers would suggest.

The rise of electricity requires a parallel increase in its share of energy-related investment. Since 2016, global investment in the power sector has consistently been higher than in oil and gas supply. The faster that clean energy transitions proceed, the wider this gap becomes, and as a result electricity becomes the central arena for energy-related financial transactions. In the NZE, investment in power generation and infrastructure is six-times higher than in oil and gas supply by 2030.

Clean technologies in the power sector and across a range of end-uses have become the first choice for consumers around the world, initially due to policy support but over time because they are simply the most cost-effective. In most regions, solar PV or wind already represents the cheapest available source of new electricity generation. Based on total costs of ownership, the case for electric cars in many markets is already a compelling one.

In the new energy economy, the huge market opportunity for clean technology becomes a major new area for investment and international competition; countries and companies jostle for position in global supply chains. We estimate that, if the world gets on track for net zero emissions by 2050, then the annual market opportunity for manufacturers of wind turbines, solar panels, lithium-ion batteries, electrolysers and fuel cells grows tenfold to USD 1.2 trillion by 2050, around 3.5-times larger than in the STEPS (Spotlight). These five elements alone would be larger than today's oil industry and its associated revenues.

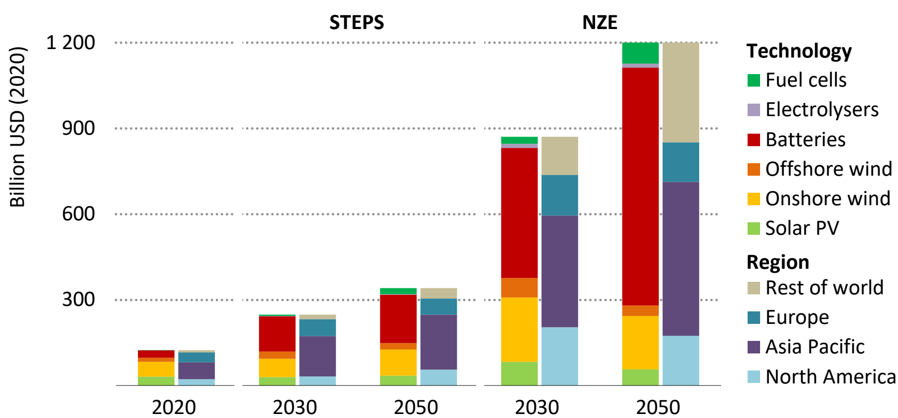
S P O T L I G H T

Sizing the market opportunity for clean energy

Achieving net zero emissions requires an unparalleled increase in clean energy investment. In the NZE, annual investment in clean energy rises to USD 4 trillion by 2030, more than tripling from current levels. Mobilising such a large investment will be challenging, but the investment required to secure clean energy transitions offers an unprecedented level of market opportunities to equipment manufacturers, service providers, developers and engineering, procurement and construction companies along the entire clean energy supply chain.

In the NZE, the combined size of the market for wind turbines, solar panels, lithium-ion batteries, electrolysers and fuel cells represents a cumulative market opportunity to 2050 worth USD 27 trillion. At over 60% of the total, batteries account for the lion's share of the estimated market for clean energy technology equipment in 2050 (Figure 1.3). With over 3 billion electric vehicles (EVs) on the road and 3 terawatt-hours (TWh) of battery storage deployed in the NZE in 2050, batteries play a central part in the new energy economy. They also become the single largest source of demand for various critical minerals such as lithium, nickel and cobalt (IEA, 2021a).

Figure 1.3 ▷ Estimated market size for selected clean energy technologies by technology and region, 2020-2050



There is explosive growth in clean energy technologies over the next decade in the NZE, leading to a clean energy market worth a cumulative USD 27 trillion by 2050

Note: Market share estimates are the product of anticipated average market prices and sales of tradeable units of the core technologies: solar PV modules; wind turbines; lithium-ion batteries (for EVs and grid storage); electrolysers and fuel cells. This differs from investment or spending estimates that include, for example, installation costs.

Advanced economies and China have been building up their research and development (R&D) programmes and increasing spending on clean energy innovation, but patterns of spending will change as deployment expands everywhere in the world. In the NZE, the Asia Pacific region is home to 45% of the estimated market for clean energy technologies by 2050, and the share of the market accounted for by North America and Europe is lower than it was earlier in the period.

Many countries are seeking to develop manufacturing expertise and capabilities that would allow them to use some locally produced products to meet domestic demand, and also to participate in global supply chains and to license related intellectual property. Energy start-up companies have an important part to play in this. Despite the pandemic, record-breaking levels of capital have flowed to clean energy technology start-ups, with investment in 2021 expected to surpass the USD 4 billion in early-stage equity raised in 2019, which was the previous peak year. The United States still accounts for around half of the capital being invested, but Europe was the only major region to increase investment in 2020 and China's share of the market has risen from 5% in the 2010-14 period to over 35% in the last three years.

Governments everywhere are also actively seeking to attract additional talent. India and Singapore have launched government initiatives to support international clean energy entrepreneurs. China, Japan and United States have recently made high-level commitments to energy R&D and innovation, framing it as a critical area of technological competition in coming years. In Europe, public initiatives like the European Battery Alliance are actively seeking to create new value chains. There is a momentous opportunity for the best innovators to capture a share of emerging value chains that have huge future potential.

The new energy economy involves varied and often complex interactions between electricity, fuels and storage markets, creating fresh challenges for regulation and market design. A major question is how to manage the potential for **increased variability** on both the demand and supply sides of the energy equation. The variability of electricity supply will be affected by rising shares of wind and solar PV, putting a huge premium on robust grids and other sources of supply flexibility. The variability of demand will be shaped by increasing deployment of heat pumps and air conditioners (the latter especially in developing economies, where current ownership levels are low), and could be exacerbated by poorly sequenced recharging of EV fleets or by cold snaps, heat waves or other extreme weather events. Without effective policies to prepare for and manage these fluctuations, the daily variation of demand could increase on the basis of announced pledges to 270 gigawatts (GW) in the European Union (from 120 GW today) and over 170 GW in India (from 40 GW) by mid-century.

Digital technologies play crucial roles in integrating different aspects of the new energy system. Sectors that have hitherto operated largely independently (such as electricity and transport) become connected in new ways with the rise of electric mobility, and grids need to cope with a much greater diversity and complexity of flows as many new players, including households, enter the arena as producers. Managing the platforms and data required to keep this system operating effectively becomes a central part of the new energy economy, as does mitigating associated cybersecurity and data privacy risks.

Clean electrification is the dominant theme in the early phases of the transformation of the global energy economy together with the quest for improvements in efficiency. Over time, however, continued rapid deployment in these areas needs to be accompanied by **clean energy innovation** and the widespread use of technologies that are not yet readily available on the market. These technologies are vital to decarbonise areas such as heavy industry and long-distance transport that are not readily susceptible to electrification for one reason or another, and they include advanced batteries, hydrogen electrolysers, advanced biofuels, and new technologies for the capture and use of CO_2, including direct air capture. Building these additional pillars of the new energy economy requires early and sustained investment in energy R&D and an accelerated programme of demonstration projects.

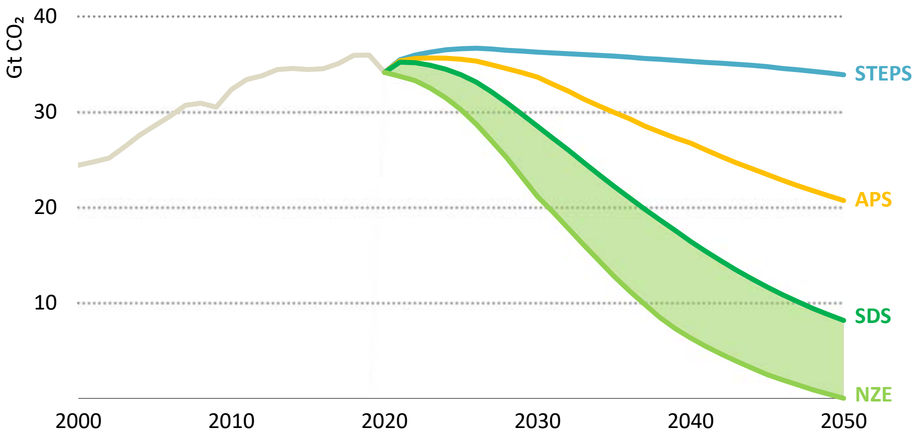
These changes redirect global **flows of trade and capital**. The combined share of hydrogen and critical minerals (such as lithium, cobalt, copper and rare earths elements) in global energy-related trade rises to one-quarter of the total in the APS, and takes a dominant share in the NZE as the value of fossil fuels trade declines significantly (see section 1.9). This completely upends the present dynamics of international energy-related trade, and it is accompanied by a major shift in energy-related financial flows: the decline in the value of trade in fossil fuels causes the dollar-denominated revenues accruing to producer economies from oil and gas exports to decline significantly over time.

The new energy economy depicted in the NZE is a collaborative one in which countries demonstrate a shared focus on securing the necessary reductions in emissions, while minimising and taking precautions against new energy security risks. However, the APS highlights the **possibility of new divisions and fragmentation** as countries proceed at different speeds through energy transitions. By the 2030s, for example, the APS sees the production of "green" steel in economies that have pledged to reach net zero alongside the continuing use of traditional emissions-intensive methods elsewhere, deepening tensions around trade in energy-intensive goods. There could be a gulf too in international investment and finance: increasingly stringent disciplines applicable to financial flows may mean that capital from the "net zero" world does not flow very freely to countries undergoing slower transitions. Successful, orderly and broad-based transitions in which countries enjoy the benefits of global trade will depend on finding ways to lessen and manage the potential tensions in the international system that are highlighted in the APS.

1.2 Scenario trajectories and temperature outcomes

This *World Energy Outlook* provides a detailed stocktake of how far nations have come in their energy transitions, and a sobering picture of how far there still is to go. In the STEPS, global energy-related and industrial process CO_2 emissions rebound quickly in 2021 and rise to 36 gigatonnes (Gt) in 2030. In the APS, emissions peak in the mid-2020s and return to just under 34 Gt in 2030, close to current levels. In the NZE, by contrast, emissions fall to 21 Gt in 2030, marking a decisive change of direction (Figure 1.4).

Figure 1.4 ▻ CO_2 emissions in the *WEO-2021* scenarios over time



The APS pushes emissions down, but not until after 2030; the SDS goes further and faster to be aligned with the Paris Agreement; the NZE delivers net zero emissions by 2050

Note: APS = Announced Pledges Scenario; SDS = Sustainable Development Scenario; NZE = Net Zero Emissions by 2050 Scenario.

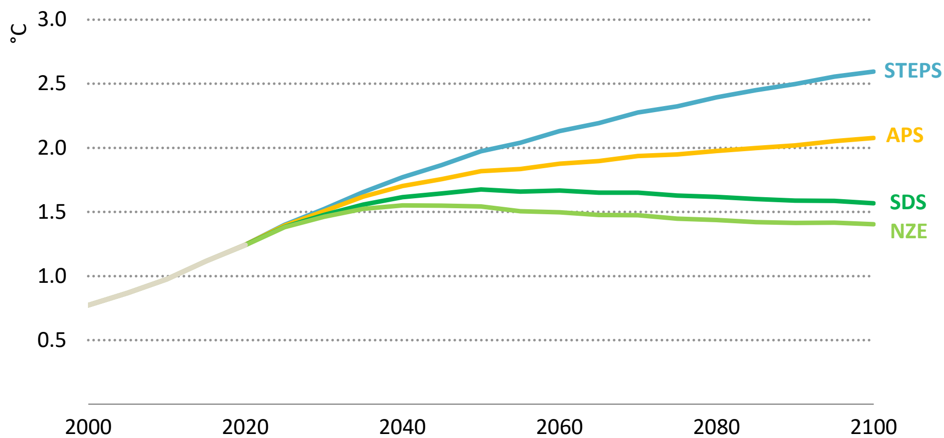
The 2.6 Gt difference in emissions between the STEPS and the APS in 2030 highlights the "implementation gap" that exists between announced net zero pledges and the policy frameworks and specific measures that they require: pledges need to be underpinned by strong, credible policies and long-term plans to make them a reality. However, realising these pledges in full would fill less than 20% of the total gap between the STEPS and the NZE. This leaves a 12 Gt "ambition gap" between the APS and the NZE in 2030 that requires countries to go beyond existing pledges to be on course to achieve net zero emissions by 2050. In the NZE, methane emissions also reduce far more quickly than in the APS. If methane is also counted, then the ambition gap in 2030 would be around 14 Gt CO_2-eq.[1] If the world is off course in 2030, it will be extremely difficult to make up the lost ground later.

There are large differences in emissions trajectories in the APS: emissions decline by around one-third (or 3.5 Gt) in advanced economies by 2030, but rise by just over 10% (or 2.5 Gt) in emerging market and developing economies. The APS highlights the risk of a two-speed world emerging, in which a narrow focus on achieving national net zero pledges in some countries is coupled with limited efforts to prioritise emissions reductions in others, and little

[1] One tonne of methane is considered to be equivalent to 30 tonnes of CO_2 based on the 100-year global warming potential (IPCC, 2021).

attention is given to technological spill-overs or to the scope for working in partnership. That could easily be a recipe for trade and other tensions to emerge, and it would militate against net zero emissions being achieved as cost-effectively as possible. Delivering the NZE is heavily dependent on all governments working together in an effective and mutually beneficial manner.

Figure 1.5 ▷ Global median surface temperature rise over time in the *WEO-2021* scenarios



The temperature rise is 2.6 °C in the STEPS and 2.1 °C in the APS in 2100 and continues to increase. It peaks at 1.7 °C in the SDS and 1.5 °C in the NZE around 2050 and then declines

Source: IEA analysis based on outputs of MAGICC 7.5.3.

We have carried out new detailed analysis using the Model for the Assessment of Greenhouse Gas Induced Climate Change ("MAGICC") to assess the impacts of these emissions trajectories on the average global surface temperature rise (Figure 1.5).[2] In the STEPS, the global average surface temperature rise would exceed 1.5 degrees Celsius (°C) around 2030.[3] Emissions in 2050 are around 32 Gt CO_2: if emissions continue their trend after 2050, and if there are similar changes in non-energy-related greenhouse gas (GHG) emissions, the rise in temperature in 2100 would be around 2.6 °C (Table 1.1). In the APS,

[2] MAGICC climate models have been used extensively in assessment reports written by the Intergovernmental Panel on Climate Change. MAGICC 7, the version used in this analysis, is one of the models used for scenario classification in the IPCC's 6th Assessment Report (IPCC, 2021). Emissions of all energy-related GHG from the *WEO-2021* scenarios are supplemented with commensurate changes in non-energy-related emissions based on the scenario database published as part of the IPCC Special Report on Global Warming of 1.5 °C (IPCC, 2018). All changes in temperatures are relative to 1850-1900 and match the IPCC 6th Assessment Report definition of warming of 0.85 °C between 1995-2014.

[3] Unless otherwise stated, temperature rise estimates quoted in this section refer to the median temperature rise, meaning that there is a 50% probability of remaining below a given temperature rise.

the faster reduction in CO_2 emissions to around 21 Gt in 2050 has little impact on the year in which 1.5 °C is exceeded, but the rise in temperature in 2100 would be restricted to around 2.1 °C. The temperature would continue to rise in both the STEPS and APS after 2100 because total CO_2 emissions are still well above zero in 2100 in these scenarios.

In the NZE, CO_2 emissions are net zero in 2050 globally and there are rapid reductions in all non-CO_2 emissions (such as methane). The rise in temperature reaches a maximum level of just over 1.5 °C around 2050. The temperature then starts to decline slowly as a result of continued reductions in non-CO_2 emissions, and by 2100 the rise in temperature has fallen to around 1.4 °C. In the SDS, CO_2 emissions drop to zero around 2070 and there are rapid reductions in non-CO_2 emissions. The 1.5 °C level is exceeded in the early 2030s and the rise in temperature peaks at just under 1.7 °C around 2050.[4] The SDS is in line with the Paris Agreement objective of "holding the increase in the global average temperature to well below 2 °C", while the NZE goes further to be in line with the Paris Agreement objective of "pursuing efforts to limit the temperature increase to 1.5 °C".

Table 1.1 ⊳ Temperature rise in the *WEO-2021* scenarios (°C)

Scenario	2030		2050		2100	
Confidence level:	50%	33% – 67%	50%	33% – 67%	50%	33% – 67%
Stated Policies	1.5	1.4 – 1.6	2.0	1.8 – 2.1	2.6	2.4 – 2.8
Announced Pledges	1.5	1.4 – 1.6	1.8	1.7 – 2.0	2.1	1.9 – 2.3
Sustainable Development	1.5	1.4 – 1.6	1.7	1.5 – 1.8	1.6	1.4 – 1.7
Net Zero Emissions by 2050	1.5	1.4 – 1.5	1.5	1.4 – 1.7	1.4	1.3 – 1.5

Note: Shows the maximum temperature rises with 33%, 50% and 67% confidence levels.

Source: IEA analysis based on outputs of MAGICC 7.5.3.

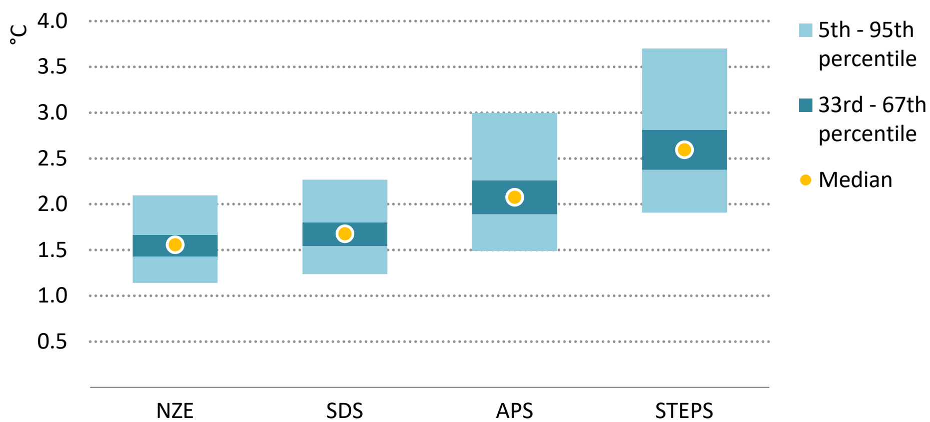
The difference in temperature rise between the scenarios has stark consequences for global ecosystems and human well-being. The higher the temperature rise, the greater the risks of severe weather events such as extreme heat, drought, river and coastal flooding and crop failures. Even during the last decade, with an average temperature rise of 1.1 °C above pre-industrial levels, extreme heat events occurred almost three-times more frequently than in pre-industrial times. In the STEPS, around 2050, there would be a 100% increase in the frequency of extreme heat events compared to today and these would be around 120% more intense; there would also be a 40% increase in ecological droughts that would be around 100% more intense. In the NZE, the increase in frequency of extreme heat events would be lower at around 45% and ecological droughts would be less than 20% more frequent.

By 2100, as the temperature trajectories of the scenarios diverge, differences in the frequency and intensity of extreme weather events would become even more stark. There

[4] All scenarios in the *WEO-2021* have a similar temperature rise over the 2021-2030 period and a similar year in which 1.5 °C warming is exceeded. This results from a balance between reductions in emissions of gases that have a large near-term warming effect on the climate (such as methane) and reductions in aerosols and gases that have a large near-term cooling effect on the climate (such as sulphur dioxide).

is around a 10% chance that the rise in temperature in the STEPS would exceed 3.5 °C in 2100 (Figure 1.6). This would lead to an 80-130% increase in the frequency of ecological droughts and a two-to-threefold increase in their intensity. Extreme rainfall would happen up to twice as often as today and be three-to-four-times more intense (IPCC, 2021). The risk of ice sheet collapse and disruptions to ocean circulation currents would also be substantially higher.[5] This in turn could precipitate irreversible changes in the permafrost, boreal forests and the Amazon rain forest, potentially accelerating warming.

Figure 1.6 ▷ Peak temperature rise in the *WEO-2021* scenarios



The NZE limits the maximum median temperature rise to just over 1.5 °C. There is a small chance that the temperature rise in 2100 could exceed 3.5 °C in the STEPS

Note: Shows the temperature rise around 2050 for the NZE and SDS, and in 2100 for the APS and STEPS.

Source: IEA analysis based on outputs of MAGICC 7.5.3.

1.3 Keeping the door to 1.5 °C open

Announced net zero pledges and updated NDCs, reflected in full in the Announced Pledges Scenario, represent an important boost to the world's efforts on climate but, as they stand, they close less than 20% of the gap in 2030 between the STEPS and the NZE. An additional 12 Gt CO_2 emissions need to be abated in 2030 in order to get the world on track for the NZE, and this needs to be accompanied by reductions of almost 90 million tonnes (Mt) in methane emissions from fossil fuel operations (equivalent to another 2.7 Gt of CO_2 emissions). That is the task before the world's decision makers as they assess how to keep a 1.5 °C stabilisation in global average temperatures within reach.

[5] The uncertainty ranges associated with temperature rises shown in do not take into account the possibility of these low likelihood, high impact events, which could generate feedbacks and cause additional atmospheric warming.

Table 1.2 ▷ Selected indicators in the Net Zero Emissions by 2050 Scenario

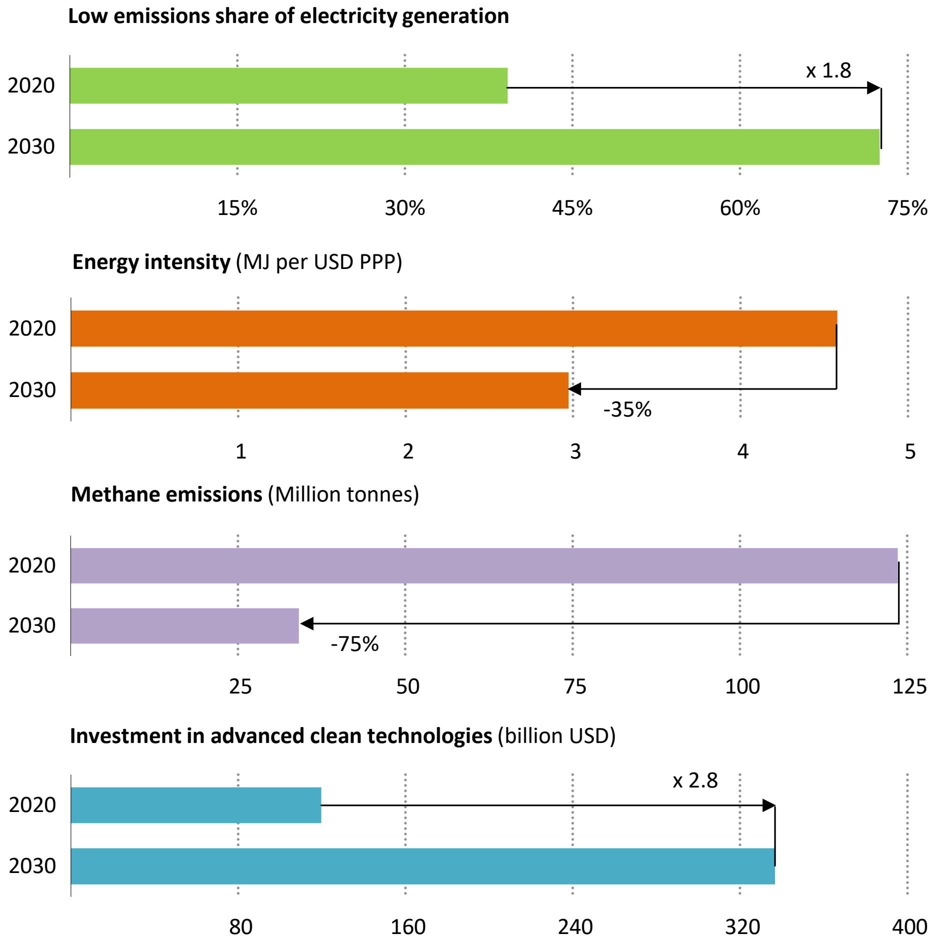
	2010	2020	2030	2040	2050
Global indicators					
CO_2 emissions per capita in AE (t CO_2 per capita)	10	8	4	1	0
CO_2 emissions per capita in EMDE (t CO_2 per capita)	3	4	2	1	0
CO_2 emissions per unit of GDP (t CO_2 per GDP PPP)	318	259	114	25	0
Energy intensity (MJ per USD PPP)	3.8	3.1	2.1	1.5	1.1
Share of electricity in TFC	17%	20%	26%	39%	49%
Share of fossil fuels in TES	81%	79%	62%	35%	22%
Share of population with access to electricity in EMDE	80%	90%	100%	100%	100%
Investment in clean energy (billion USD)	619	974	4 344	4 348	4 210
Carbon captured, stored or utilised (Mt CO_2)	90	139	1 799	5 766	7 740
Supply					
Emission intensity of oil and gas (kg CO_2-eq per boe)	91	93	40	35	31
Methane emission from fossil fuel operations (Mt CH_4)	104	117	28	14	10
Low-carbon share in total liquids	2%	2%	10%	21%	39%
Low-carbon share in total gases	0%	0%	13%	32%	61%
Low-carbon share in total solids	18%	21%	39%	55%	72%
Electricity generation					
CO_2 emissions intensity (g CO_2 per kWh)	575	506	156	-1	-5
Share of unabated coal	40%	35%	8%	0%	0%
Share of renewables	20%	28%	61%	84%	88%
Share of wind and solar PV	2%	9%	40%	63%	68%
Buildings					
CO_2 emissions intensity (g CO_2 per MJ)	27	25	17	7	1
Existing buildings retrofitted to be zero-carbon-ready level	< 1%	< 1%	20%	50%	85%
Share of new buildings that are zero-carbon-ready	< 1%	5%	100%	100%	100%
Appliance unit energy consumption (index 2020=100)	106	100	75	64	60
Industry					
CO_2 emissions intensity (g CO_2 per MJ)	59	55	44	23	3
Energy intensity (MJ per USD PPP)	4.8	4.0	3.0	2.3	1.7
Share of low-carbon fuels in heavy industry (excl. electricity)	1%	2%	9%	16%	23%
Share of electricity in TFC	18%	22%	28%	37%	46%
Transport					
CO_2 emissions intensity of passenger cars (g CO_2 per km)	231	200	106	34	4
CO_2 emissions intensity of heavy trucks (g CO_2 per km)	1 175	1 109	710	324	65
Share of low-carbon fuel use in aviation and shipping	0%	0%	17%	51%	81%
Share of PHEV, BEV and FCEV in total passenger car sales	0%	4%	64%	97%	100%
Share of electric and fuel cell trucks in total sales	0%	0%	5%	24%	31%

Note: AE = advanced economies; EMDE = emerging market and developing economies; t CO_2 per GDP PPP = tonnes of carbon dioxide per gross domestic production at purchasing power parity; MJ per USD PPP = megajoule per US dollar at purchasing power parity; TFC = total final consumption; TES = total energy supply; Mt CO_2 = million tonnes of CO_2; kg CO_2-eq per boe = kilogrammes of CO_2 per barrel of oil equivalent; Mt CH_4 = million tonnes of methane; g CO_2 per kWh = grammes of CO_2 per kilowatt-hour; g CO_2 per MJ = grammes of CO_2 per megajoule; g CO_2 per km = grammes of CO_2 per kilometre; PHEV = plug-in hybrid electric vehicle; BEV = battery electric vehicle; FCEV = fuel cell electric vehicle.

The four key priorities for action to close this gap over the next decade, and to prepare the ground for further rapid emissions reduction beyond 2030, are to:

- Deliver a surge in clean electrification.
- Realise the full potential of energy efficiency.
- Prevent methane leaks from fossil fuel operations.
- Boost clean energy innovation.

Figure 1.7 ▷ Four key priorities to keep the door to 1.5 °C open in the Net Zero Emissions by 2050 Scenario



Closing the emissions gap needs efforts to accelerate clean electrification, boost clean energy innovation, minimise methane leaks, and realise the potential of energy efficiency

Notes: MJ per USD PPP = megajoule per US dollar at purchasing power parity. Advanced clean technologies include CCUS, batteries, advanced biofuels, synthetic fuels and direct air capture.

The first three priorities require the application, at massive scale, of technologies and approaches that are mature today, using policies and measures that are tried and tested (Figure 1.7). Boosting clean energy innovation is essential to bring new technologies through the demonstration and prototype stages so that they are ready to scale up dramatically in the 2030s in areas where electrification is difficult to achieve, such as heavy industry and long-distance transport. Ensuring adequate financing for all of these priority areas is a crucial cross-cutting component.

There are strong synergies between all of these efforts. Clean electrification brings major efficiency gains, as well as helping to decarbonise end-use sectors, because many electric technologies are significantly more efficient than their fossil fuel counterparts. For example, today's electric cars use on average 70% less energy to travel one kilometre than a conventional car. In turn, by reducing upward pressure on electricity demand, efficiency measures on appliances and equipment make it easier for cleaner sources of power to gain market share. Clean electrification and efficiency bring down fossil fuel demand and production. This helps to reduce associated methane emissions, although it is not a substitute for concerted policy efforts to reduce emissions as quickly as possible from fossil fuel operations. Innovation has the potential to support more rapid electrification, for example through the development of advanced batteries that are able to bring electricity into heavy-duty segments of the transport sector, and also to bring low emissions electricity indirectly into other sectors via low-carbon hydrogen.

Clean electrification

Cleaning up the electricity mix and extending the electrification of end-uses is a central pillar of transition strategies. It plays a key role in the structural transformation of the energy sector in all our scenarios, and it supports energy-related sustainable development goals, notably access to electricity.

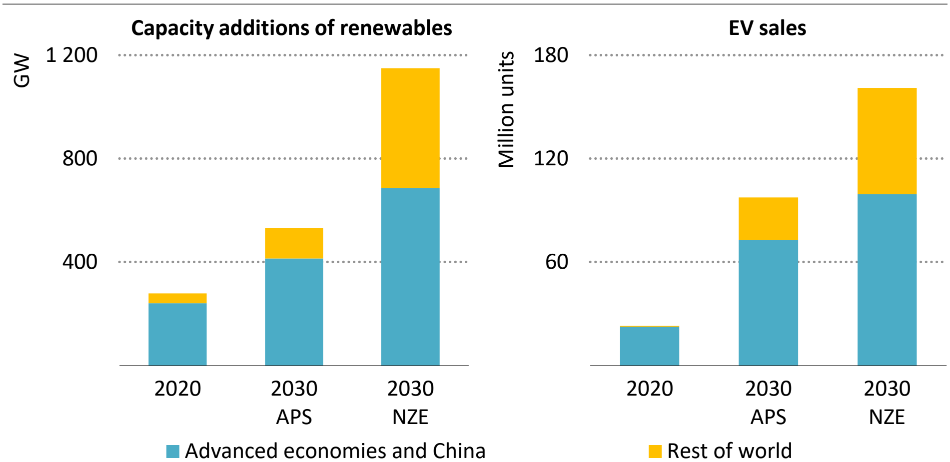
The electricity sector emitted 12.3 Gt CO_2 in 2020 (36% of all energy-related emissions), which is more than any other sector. Coal remains the largest single source of electricity worldwide, and by far the largest source of electricity sector emissions: it contributes just over one-third of electricity supply but is responsible for nearly three-quarters of electricity sector CO_2 emissions. The power sector is already moving away from coal, and it continues to do so in all our scenarios. Accelerating the decarbonisation of the electricity mix is the single most important way to close the 2030 gap between the APS and NZE. In the NZE, faster decarbonisation of electricity cuts emissions by 5 Gt, compared with the APS, and this accounts for 40% of the CO_2 emissions gap between the two scenarios in 2030. We calculate that nearly 60% of this total (about 2.9 Gt) could be cut at no cost to electricity consumers.

Rapid decarbonisation of the electricity sector requires a massive surge in the deployment of low emissions generation. The share of renewables increases from almost 30% of electricity generation globally in 2020 to about 45% in 2030 in the APS, but this is still fifteen percentage points short of the level reached in the NZE. Nuclear power and dispatchable low emissions capacity, such as hydropower, biomass and geothermal are important elements of the picture, but capacity additions are dominated by solar PV and wind. The largest increases in deployment to close the emissions gap take place in emerging market and developing economies.

Decarbonising the global power sector is not only a question of expanding low emissions generation, but also of tackling emissions from existing sources. This requires an end to investment in new unabated coal-fired power plants, as well as strategies to retrofit, repurpose or retire existing ones (see section 1.7). Scaling up grids and all sources of flexibility, including energy storage systems, is also pivotal: investment in electricity infrastructure in the NZE accelerates more quickly than investment in generation. Alongside a rapid expansion and modernisation of grids, utility-scale battery storage capacity increases 18-times from 2020 to 2030 in the APS, and more than 30-times in the NZE.

The transformation of electricity supply goes hand-in-hand with a major increase in electricity use as demand in existing end-uses grows and as new end-uses such as transport and heating are electrified (Figure 1.8). Rapid electrification of passenger mobility in advanced economies and China is already built into the APS, and expanding this to emerging market and developing economies is essential if the gap between the APS and the NZE is to be closed. The challenge is significant: in the NZE, the share of EV cars in total car sales is over 60% in 2030. Faster electrification of transport, together with some deployment of hydrogen-based fuels, would close about 1 Gt of the ambition gap with the NZE.

Figure 1.8 ▹ Selected indicators of clean electrification in the Announced Pledges and Net Zero Emissions by 2050 scenarios



To close the gap between announced pledges and a net zero pathway, all countries need to do more, with the largest increases in emerging market and developing economies

Notes: EV includes battery electric vehicles, plug-in hybrid electric vehicles and fuel cell electric vehicles. This figure shows EV sales of all vehicle types including passenger vehicles, trucks, buses and two/three-wheelers.

Heat pumps are the largest electrification opportunity in the buildings sector, displacing heating from fossil fuel boilers. Although electric heat pumps are an increasingly attractive option, gas-fired boilers remain the dominant form of space heating in the STEPS and in many countries in the APS. Ensuring that new buildings meet zero-carbon-ready standards[6], and providing incentives for householders to install heat pumps when existing heating options breakdown or need to be replaced, both help to close the gap between the APS and the NZE. Electrification is also increasingly used in the NZE to provide low-temperature heat in industry.

Energy efficiency

Improvements in energy efficiency curb demand for electricity and fuels of all kinds. In the STEPS, overall global energy demand continues to climb; in the APS it plateaus after 2030; in the NZE, it is 15% lower than in the APS by 2030. As a result, the energy intensity of the global economy decreases by 4% per year between 2020 and 2030 in the NZE, more than double the average rate of the previous decade. Without this improvement in energy efficiency, total final consumption in the NZE would be about a third higher in 2030, significantly increasing the cost and difficulty of decarbonising energy supply.

Much stronger policies on end-use energy efficiency in the NZE reduce emissions by about 1.3 Gt CO_2 in 2030, compared with the APS, and are of particular importance in the transport and buildings sectors. We estimate that almost 80% of these additional energy efficiency gains in the NZE could be achieved cost-effectively over the next decade. Avoided demand through measures such as digitalisation and materials efficiency reduce emissions in the NZE by a further 1.3 Gt by 2030: much of the potential here is in the industry sector, where opportunities for materials efficiency are substantial and low emissions technologies are less mature than in most other sectors. Behavioural changes contribute around another 1 Gt by 2030 to the additional emissions reductions in the NZE, notably in the transport sector.

Stronger standards for appliances and fuel economy are instrumental in achieving these efficiency gains in the NZE, as is a stronger policy emphasis on materials efficiency in industry. In the buildings sector, the number of building retrofits would need to increase two-and-half-times compared with announced pledges to close the gap; this is particularly important in advanced economies. Energy efficiency measures such as retrofits and appliance standards also save about 0.5 Gt of indirect CO_2 emissions outside the buildings sector, largely by reducing electricity demand.

Methane

Methane has contributed around 30% of the global rise in temperature today and the IPCC 6th Assessment Report highlights that rapid and sustained reductions in methane emissions are key to limit near-term warming and improve air quality. The energy sector is one of the largest sources of methane emissions today: we estimate that fossil fuel operations emitted

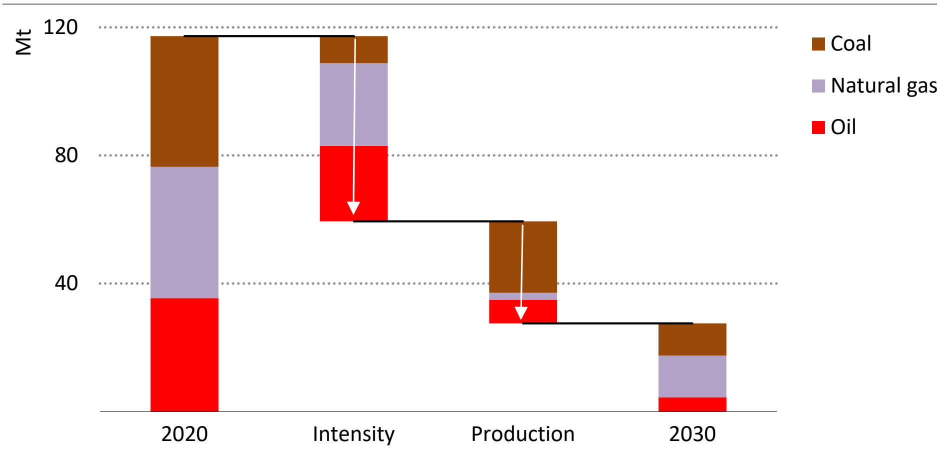
[6] A zero-carbon-ready building is highly energy efficient and uses either renewable energy directly or from an energy supply that will be fully decarbonised by 2050 in the NZE (such as electricity or district heat).

around 120 Mt of methane globally in 2020, equivalent to around 3.5 gigatonnes of carbon-dioxide equivalent (Gt CO_2-eq).

We estimate that almost 45% of current oil and gas methane emissions could be avoided at no net cost (based on average natural gas prices from 2017-21) given that the cost of deploying the abatement measures is less than the value of the gas that would be captured. There are a number of well-known technologies and measures that can be deployed to address methane emissions from oil and gas operations. If countries were to implement a set of well-established policy tools – namely leak detection and repair requirements, staple technology standards and a ban on non-emergency flaring and venting – emissions from oil and gas operations could be halved within a short timeframe (IEA, 2021b). Further reductions could be pursued through measures such as performance standards or emission taxes supported by more robust measurement and verification systems. Technology developments, in particular in the field of satellite observation, could help with the development of such systems. Applying a USD 15/t CO_2-eq price to methane from oil and gas operations would be enough to deploy nearly all abatement measures.

There are also opportunities to reduce methane emissions from coal production using existing technologies. However abatement opportunities in the coal sector are often less cost-effective than in the oil and gas sector. This is because methane sources in coal mines tend to be more widely dispersed and to have lower methane concentrations. Plus, often there is inadequate infrastructure to facilitate the use of captured methane. In the NZE, most of the decline in coal-related methane emissions comes from the rapid decline in coal production.

Figure 1.9 ▷ Methane emissions from fossil fuel operations and reductions to 2030 in the Net Zero Emissions by 2050 Scenario



Concerted efforts to reduce leaks drive over 80% of methane emissions reductions in oil and gas; the most effective way to reduce emissions from coal is to produce less

Total methane emissions from all fossil fuel operations fall by around 75% between 2020 and 2030 in the NZE (Figure 1.9). Around one-third of this decline is the result of an overall reduction in fossil fuel consumption. The larger share comes from a rapid deployment of emissions reduction measures and technologies, which leads to the elimination of all technically avoidable methane emissions by 2030.

Innovation

Clean electrification, efficiency and methane emissions reductions do the heavy lifting over the next ten years, but they cannot carry the world all the way to a net zero future. Almost half of the emissions reductions achieved in the NZE in 2050 come from technologies that are at the demonstration or prototype stage today, and that are needed in particular to decarbonise heavy industrial sectors and long-distance transport because these sectors are in general not susceptible to electrification. For this reason, another important "gap" that needs to be closed in the 2020s relates to innovation. Governments need to step up support in key technology areas, such as advanced batteries, low-carbon fuels, hydrogen electrolysers and direct air capture. They also need to collaborate internationally to reduce costs and ease the path of new technologies to market. In the NZE, around USD 90 billion of public money is mobilised to complete a portfolio of demonstration projects before 2030. Currently, only about USD 25 billion is budgeted for that period.

Announced pledges lag on key NZE milestones related to hydrogen-based and other low-carbon fuels, as well as CCUS. For example, by 2030 the APS achieves less than 40% of the level of deployment of clean shipping fuels seen in the NZE, and it is even further behind the NZE on the deployment of hydrogen in industry. Options like industrial CCUS or electric trucks make substantial inroads into emissions in the NZE only after 2030, but early deployment before 2030 is essential to drive down costs and establish enabling infrastructure. Because of long infrastructure lifetimes and relatively slow rates of change in these areas, catching up after 2030 will be particularly challenging if these milestones are missed. It is therefore critical that policy support in the near term is directed towards early deployment of key innovative technologies and the development of supporting infrastructure.

In the NZE, new technologies that have an important future role make vital early progress. Hydrogen-based fuels and fossil fuels with CCUS make up just under 1.5% of total final consumption by 2030, up from almost nothing today. These relatively small inroads into the market prepare the ground for these technologies to ramp up after 2030 and make a bigger contribution towards net zero energy emissions by 2050.

1.4 Energy consumers of tomorrow

Any assessment of the outlook for global energy and emissions has to assign a central place to emerging market and developing economies. There are billions of people on the planet who do not yet have the housing stock and appliances that are taken for granted across most advanced economies, and hundreds of millions of people who lack even the most basic access to modern energy. Emerging market and developing economies excluding China[7] account for two-thirds of the global population today, and they will be home to the vast majority of the two billion people that look set to be added to the world's population by 2050. The population of sub-Saharan Africa is projected to grow especially fast, and is on course to double by 2050.

As China has amply demonstrated over the last two decades, and many advanced economies before it, the process of constructing the infrastructure needed in a modern and rapidly developing economy up till now has been very energy- and emissions-intensive. With many emerging market and developing countries now considering how best to meet their future energy and development needs, the falling costs of key clean energy technologies offer a major opportunity to chart a new, lower emissions path to growth that is centred on clean electrification and efficiency (see section 1.3). However, no country has yet shown a cost-effective way to leapfrog to low-carbon technologies in all areas of energy use, such as steel, cement and freight that are instrumental to the construction and operation of modern economies.

The starting point for this journey is not a propitious one. Most emerging market and developing economies face an ongoing public health crisis with the Covid-19 pandemic, without the means or the opportunity to start mass vaccination campaigns in earnest. The pandemic has been a setback for efforts to improve access to modern energy and has further strained the finances of the utilities that are key investors in grids and off-takers for renewable projects (Box 1.2). Increased borrowing to cope with the effects of the pandemic has left little room for many governments to kick-start investment in sustainable recoveries; the annual boost to clean energy coming from public recovery spending amounts to less than USD 10 billion by 2023. Overall, if China is excluded, emerging market and developing economies account for one-fifth of the amounts being invested worldwide on clean energy.

Across all fuels and technologies, emerging market and developing economies are instrumental in shaping global trends in the coming decades. In the STEPS, oil demand in these economies is 12 million barrels per day (mb/d) higher in 2030 than in 2020 (an increase of nearly 30%), gas demand by 520 bcm (a near-25% increase), and coal demand by 160 million tonnes of coal equivalent (Mtce) (a 4% rise). Demand for fossil fuels in advanced economies falls in the APS, but announced pledges do not bend projected demand trends across much of the developing world.

Nevertheless, there are some indications of structural change. The energy intensity of GDP improves by 2.8% annually in the STEPS in this decade; it is accompanied by a similarly positive outlook for carbon intensity. Progress with energy efficiency and clean electrification helps to underpin these trends. More stringent energy performance standards for air conditioners in India are a case in point, helping to improve the efficient use of energy in a fast-growing segment that could otherwise push up peak demand and exacerbate strains on the power sector.

[7] China is included in the aggregate numbers for the category *emerging market and developing economies* in this *Outlook*. However, the scale of the country's industrialisation and infrastructure development over the past two decades means that it dominates this aggregate, so China is often considered in a category of its own.

Box 1.2 ▷ Momentum has been lost on access: It needs to be regained fast

Today, 770 million people worldwide still live without access to electricity, mostly in Africa and developing countries in Asia. After decreasing 9% annually on average between 2015 and 2019, preliminary data show that progress stalled between 2019 and 2021 globally, and that the number of people without electricity access actually increased in sub-Saharan Africa. The impact of the pandemic on household incomes has weakened the ability to pay for electricity: in 2020 up to 90 million people with electricity connections in Africa and developing countries in Asia lost the ability to afford an extended bundle of services.[8] Households may be opting for cheaper and smaller systems that provide fewer energy services than would have been the case before the pandemic.

Progress with access to clean cooking has suffered a similar reversal. We estimate that cooking with traditional use of biomass, coal or kerosene causes 2.5 million premature deaths annually, slowing development and entrenching gender inequality. Between 2015 and 2019, the global population without clean cooking access decreased on average by 2% a year, led by efforts in developing countries in Asia. Between 2019 and 2021, however, it increased by 30 million (slightly over 1%). The pandemic diminished the ability of many to pay for modern fuels and to travel to liquefied petroleum gas (LPG) refilling stations during lockdowns, and more time spent at home increased exposure to air pollution and the associated health risks.

Governments and development agencies have provided emergency financial relief to reduce these impacts. Poverty or lifeline electricity tariffs were expanded in some cases, although this element of support is often limited to grid electricity, despite the fact that an increasing number of people are gaining access through off-grid solutions. To maintain access to clean cooking fuels, some governments, notably in India, provided support for free refills of LPG cylinders. Many of these support schemes will need to be extended to offset the continuing impact of Covid-19, and to provide renewed momentum towards access to modern energy for all as economic recoveries accelerate.

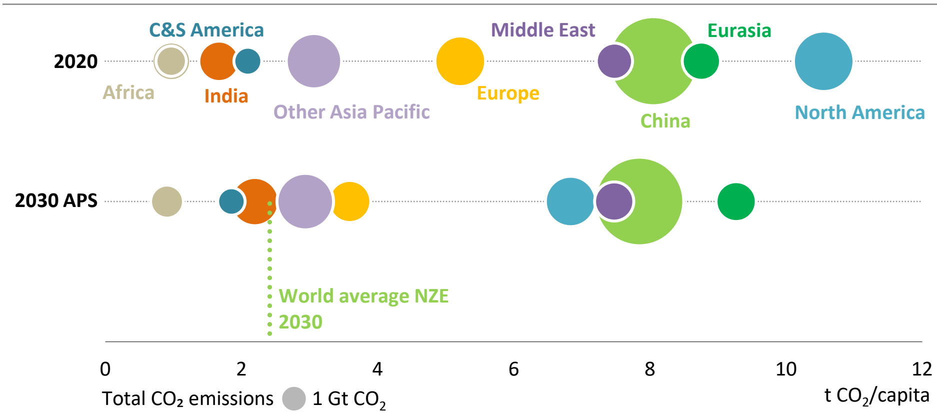
China is currently a global leader in renewable energy installations, and this continues in our scenarios, but an increasing number of emerging market and developing economies are following suit. The pace of capacity additions picks up in many countries in the STEPS: these include well-established markets like India and Brazil, where transport biofuels also flourish, as well as more recent ones in the Middle East and Africa. Renewables account for almost two-thirds of all new power capacity additions in emerging market and developing economies (excluding China) in the STEPS by 2030, up from about half today. Increased investment in robust grids and other sources of flexibility is vital to the reliable operation of solar PV and wind-rich systems; it is particularly important in India as it closes in on its target to increase renewable capacity to 450 GW by 2030, from around 150 GW today.

[8] An extended bundle of services includes four lightbulbs operating for four hours per day, a fan for six hours per day, a radio or television for four hours per day and a refrigerator.

Electricity demand grows rapidly in emerging market and developing economies in the STEPS. This reflects increased uptake of industrial electric motors and rising levels of appliance ownership rather than large-scale electrification of new end-uses such as transport. While electric two/three-wheelers gain ground quickly in many countries, passenger EVs face a number of non-economic barriers that are not completely overcome in the STEPS (or in the APS). These include insufficient recharging infrastructure, weak or unreliable grids, and reliance in some countries, especially in Africa, on the second-hand vehicle market where EVs will only become available with a time lag. Despite these barriers, there are some economies within this grouping (for example Singapore and Costa Rica) that already have phase-out policies in place for different categories of conventional vehicles.

Clean electrification cannot answer all the needs of economies undergoing rapid urbanisation and industrialisation. Transitions in fuels and energy-intensive sectors such as construction materials, chemicals and long-distance transport are particularly important. Here the signals in the STEPS are less encouraging, despite continued improvements in efficiency and fuel switching from more polluting fuels to electricity and natural gas. Some new projects are developed for low-carbon liquids and gases, notably for hydrogen in countries either with a large renewable energy resource base or with large natural gas resources (the Middle East is well placed on both counts), but in the STEPS they do not reach the scale that would make hydrogen a mainstream element of industrial strategies and operations.

Figure 1.10 ▷ CO_2 emissions per capita by region in 2020 and the Announced Pledges Scenario in 2030



CO_2 emissions per capita in emerging market and developing economies remain below the average of advanced economies in 2030, except in Eurasia, China and the Middle East

Notes: C&S America = Central and South America. Bubble size is proportional to total emissions from each region. The world average excludes CO_2 emissions from international aviation and shipping.

Taken together, this means that emerging market and developing economies are set to account for the bulk of CO_2 emissions growth in the coming decades unless much stronger action is taken to transform their energy systems. Emissions from emerging market and developing economies (excluding China) are projected to rise by 5.5 Gt to 2050 in the STEPS, with the largest increase from industry and transport (rather than power). In contrast, emissions are projected to decline by 3.7 Gt in advanced economies and by 3 Gt in China. The divergence in trends is even more significant in the APS.

Only a fraction of emissions from emerging market and developing economies are covered by net zero pledges. Greater ambition is warranted and necessary. However, while tackling climate change is a common cause, responsibilities and capabilities for climate action differ.[9] An international catalyst is essential in the form of stronger financial support, recognising that the average cost of emissions reductions in these economies is much lower than in advanced economies. Moreover, despite limited country-wide emissions reduction pledges, per capita CO_2 emissions in emerging market and developing economies (excluding China) are less than half of the advanced economy average in 2030 in the APS (Figure 1.10). Producer economies across the Middle East and Eurasia are the exception: they are among the highest emitting regions on a per capita basis.

1.5 Mobilising investment and finance

Getting the world on track for net zero emissions by 2050 requires clean energy transition-related investment to accelerate from current levels to around USD 4 trillion annually by 2030. The APS sees progress on this front, but the level of investment required in the NZE is three-quarters higher. This expansion is driven by a USD 1.1 trillion increase, relative to the APS, in annual investment in clean power generation and electricity infrastructure (two-thirds for generation and one-third for networks), a USD 0.5 trillion increase in investment in energy efficiency and end-use decarbonisation in the buildings, industry and transport sectors, as well as a rapid scaling up from a low base of low emissions fuels based on hydrogen or bioenergy. All regions see a surge in clean energy spend, but the required increase is particularly large in emerging market and developing economies.

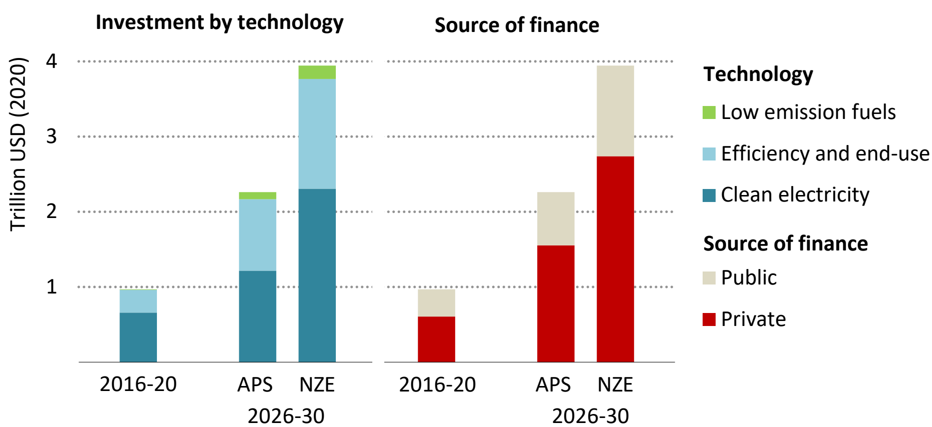
The large increase in capital investment in the NZE is partly compensated for by the lower operating expenditure that follow the shift away from upstream fuel supply and fossil fuel generation projects towards capital-intensive clean technologies. Keeping upfront financing costs low nevertheless is critical to the speed and affordability of this transformation. In recent years, economy-wide financing costs have tended to come down around the world. However, capital remains up to seven-times more expensive in emerging market and

[9] As an illustration, of the eight countries whose targets and actions have been assessed by the Climate Action Tracker as either "compatible" or "almost sufficient" with a 1.5 °C trajectory, seven are emerging market and developing economies. The methodology used for this assessment considers what is the country's fair level of contribution to the global effort (https://climateactiontracker.org/).

developing economies than in advanced economies, while fiscal expansions and inflationary pressures around the world increase the risk of growing debt burdens and higher borrowing costs in the future.

Achieving rapid clean energy transitions depends on enhancing access to low cost finance for clean energy projects. This means channelling retained earnings from the balance sheets of large energy companies, as well as opening funding from a range of companies and external sources – notably banks and the enormous pools of capital in financial markets. We estimate that around 70% of clean energy investment will need to be carried out by private developers, consumers and financiers responding to market signals and policies set by governments (Figure 1.11). But an expansion of public sources of finance is also required. Public actors, including state-owned enterprises (SOEs), often have a key part to play in funding network infrastructure and clean energy transitions in emissions-intensive sectors. Public finance institutions will need to catalyse private capital, and their role is especially important in the NZE, where their investment more than doubles compared with the APS.

Figure 1.11 ▷ Average annual clean energy investment and financing in the Announced Pledges and Net Zero Emissions by 2050 scenarios



Annual clean energy investment in the NZE is 75% higher than in the APS and is mostly met by private actors, although public finance plays a critical role in mobilising capital

Note: Public finance includes state-owned enterprises and public finance institutions.

Mobilising clean energy investment will depend on obtaining finance from both local and international sources. International capital providers may find it easiest to invest in large, bankable assets, such as renewable power with long-term contracts, but action is also needed to better connect financial markets with projects for end-use decarbonisation and to build capacity for local currency fundraising, particularly in emerging market and developing economies. While clean energy transitions rely on much higher levels of both equity and debt, capital structures are likely to hinge on the mobilisation of more debt, including through expanded use of project finance and third-party arrangements, and it is used to finance over half of all investment by 2030.

While many actions are needed to mobilise the necessary capital for clean energy transitions, two cross-cutting themes in particular need urgent consideration by public and private decision makers.

Redoubling international support

An international catalyst is needed to boost clean energy investment. Fulfilling the commitment by advanced economies to mobilise USD 100 billion per year in climate finance is necessary, but not sufficient. Development finance institutions (DFIs) have a central part to play, and will need to focus on financing emissions reductions across a broad range of sectors and activities, as well as stepping up delivery efforts. In 2020, climate finance commitments reported by the multilateral development banks (MDBs) topped USD 65 billion, more than double the amount five years ago, and comprised nearly 30% of their total financing. Some MDBs aim to boost climate investments from 30% to over 50% of their portfolio by 2025. Meeting net zero goals will depend on ensuring the delivery and reinforcement of such commitments over time.

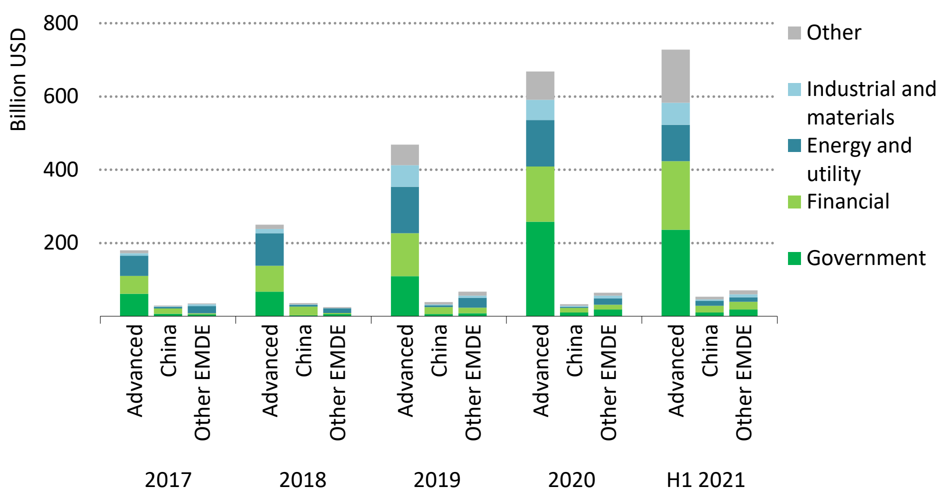
Mobilising additional private capital on the back of these commitments will rely in particular on the enhanced deployment of blended finance to catalyse project development. This will need to include the packaging of a range of instruments and approaches ranging from guarantees to concessional loans to first-loss equity. Such packages are critical to improving the risk profiles of some market-ready investments (e.g. renewables-based power in many sub-Saharan Africa countries) and to support development of small-scale projects that lack a track record with banks (e.g. building retrofits or EV charging infrastructure). It will also be important to deploy risk capital in sectors at early stages of readiness to support, for example, industrial decarbonisation, which currently accounts for a small share of DFIs climate finance commitments, and to help in cases where risks are hard to mitigate, such as energy access projects for vulnerable communities or in remote areas.

All of these actions require DFIs to find ways to manage the tensions that can emerge between the objectives of providing risk capital to those areas most in need, promoting private sector development, fulfilling their role as banks with robust systems of financial management and accountability, and maintaining strong environmental and social safeguards. Maximising the effectiveness of scarce public capital may be best done by pairing funding with technical assistance and capacity building for local actors, especially in emerging market and developing economies, and by collaborations with domestic intermediaries. A multipronged effort will also be needed to manage the financial and human consequences of phasing out emissions-intensive assets such as coal plants (see section 1.7).

Mobilising wider pools of private capital

If clean energy transitions are to be successful, then private developers and financiers need to increase the amount of capital they allocate to energy transitions and to emerging market and developing economies. The growing emphasis on sustainable finance should encourage both shifts. There is no shortage of institutional investor appetite, as the continued surge of sustainable debt issuance shows: over USD 850 billion was issued over the first-half of 2021, which is more than the total for the whole of 2020 (Figure 1.12).

Figure 1.12 ▷ Historical levels of sustainable debt issuance



The availability of sustainable finance has surged but efforts are needed to improve metrics and to step up engagement with emerging economies and emissions-intensive companies

Notes: Advanced = advanced economies; Other EMDE = emerging market and developing economies excluding China; H1 2021 = first-half of 2021. Sustainable debt includes green bond and loans, sustainability-linked bonds and loans, sustainability bonds and social bonds.

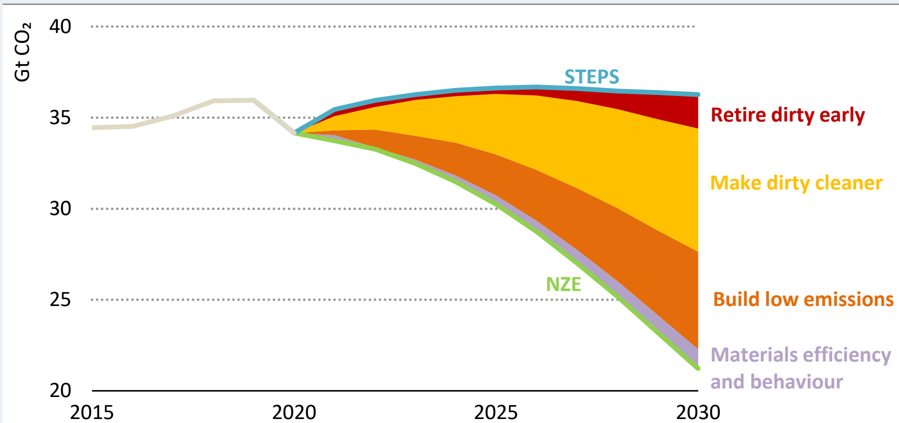
However, a major challenge stems from the fragmented and complex state of reporting and assessment within sustainability frameworks. In order to better incentivise capital markets to fund sustainability in a reliable way, improvements are needed in the quality, quantity and comparability of metrics, corporate disclosures and risk assessments based on clear benchmarks.

As things stand, the alignment of investment portfolios with NZE goals risks excluding countries with high carbon footprints or sectors with more challenging pathways. Sustainable finance approaches are needed that encourage engagement – by both equity and debt investors – with emissions-intensive companies and economies on the development of credible transition plans (Box 1.3). Initiatives by the financial community should also focus on working with regulators and issuers to create sustainability fundraising opportunities in markets that currently lack them.

Box 1.3 ▹ The complex middle ground of transition investment

Measuring the performance and targeting of capital flows against the investment needs of long-term net zero emissions goals is a complex task. Some investments will unequivocally help to reduce emissions; others are sure to increase them. But the idea that all energy sector investments divide neatly into "clean" and "dirty" does not survive contact with the realities of energy transitions. Our scenarios reveal a large number of gradations: a large portion of investments go towards sectors, technologies and infrastructure that do not immediately deliver zero emissions energy or energy services, but do enable such investments or provide incremental emissions reductions; some of these investments can also help to deliver zero emissions energy over time, but are contingent on actions elsewhere in the system, notably those concerned with decarbonising the power sector. In practice, this middle ground of actions that "make dirty cleaner" is crucial in determining the speed and scope of energy transitions, and delivers the largest share of emissions reductions in getting from the STEPS trajectory to a net zero one (Figure 1.13).

Figure 1.13 ▹ Emissions reductions in the Net Zero Emissions by 2050 Scenario relative to the Stated Policies Scenario



Delivering net zero requires more than retiring dirty and building low emissions projects; there is a large middle ground that defines the speed and scope of change

To illustrate, we have divided the total energy investment requirement in our scenarios into four categories:

- **Low emissions:** Investments that provide zero emissions (or very low emissions) energy or energy services, regardless of how the energy system evolves. Examples include renewables, low emissions fuels, CCUS and direct air capture.

- **Contingent:** Investments that could provide or enable zero emissions energy or energy services but only with changes elsewhere in the energy system. Examples include electricity networks, electrification of end-use equipment or improvements in the efficiency of electrical appliances, and EVs, that rely on the eventual decarbonisation of power generation.
- **Transition:** Investments that provide emissions reductions but do not themselves deliver zero emissions energy or energy services. Examples include efficiency or flexibility measures that reduce fossil fuel use, investments that support fuel switching away from coal or oil to less polluting alternatives (e.g. new gas boilers that replace coal-fired ones, refurbishments of power plants to support co-firing with low emissions fuels), and gas-fired plants that enable higher penetration of variable renewables.
- **Unabated fossil fuels that do not enable emissions reductions:** Investments in coal, oil and natural gas that do not provide any emissions reductions from today.[10] Examples include investment in coal mines and in unabated coal-fired power plants.

The allocation of investment in certain assets or technologies varies across countries/regions and over time: for example, a new gas-fired power plant may help to reduce emissions in one area, but not in another; investment in a coal-fired power plant may shift from one category to another if it is repurposed or retrofitted with CCUS or to co-fire with low-carbon fuels; and investments in electricity grids, appliance efficiency and EVs shift from being contingent to low emissions as power systems move towards near full decarbonisation. The results show that in the NZE around half of investment over the next decade falls in the complex middle ground of spending (Figure 1.14).

The results highlight challenges for environmental, social and governance (ESG) regulation and sustainable finance taxonomies, as well as for companies in their corporate planning and decision making. The key challenge is how to ensure that adequate financial channels remain open to support these “contingent” and “transition” investments without this becoming a loophole for investments that are not aligned with the Paris Agreement, or that allow for greenwashing.

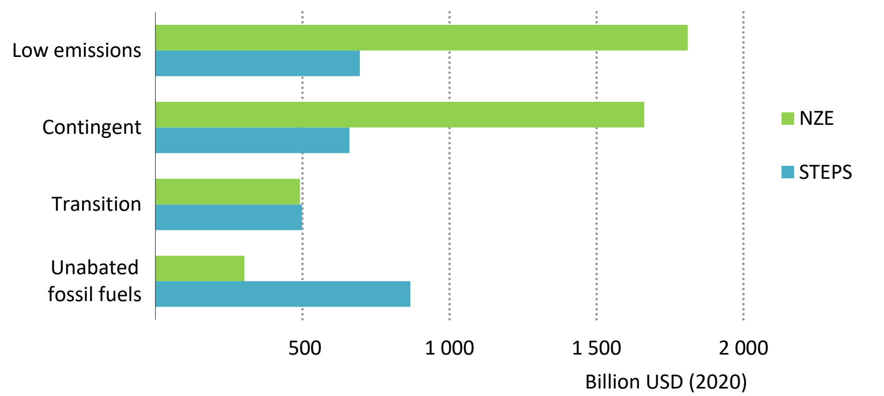
One of the most important ways for companies to send appropriate signals about investment in these categories is by setting credible (science-based) targets that include measures to reduce emissions, and to complement this by improving the quality and quantity of metrics, governance and key performance indicators that allow the financial community to assess their progress towards these targets. A number of companies around the world have set ambitious targets, but their potential impact remains uneven.

[10] Upstream fossil fuel investments are allocated according to how much of the energy produced is used within each category. For example, investment in a natural gas field is apportioned based on how much of the gas produced is used with CCUS (assigned to low emissions), used for coal-to-gas switching (assigned to transition), and used without providing any emissions reductions (assigned to unabated fossil fuels). In considering investment in fossil fuels, we assume that emissions from the production and processing of fossil fuels is minimised (as is the case in the NZE).

The Scope 1 and Scope 2 emissions reduction targets for the largest oil and gas, and industrial end-use companies account for less than 5% of the required emissions reductions in those sectors in the NZE by 2030.

It will also be important for the financial community to engage with emissions-intensive companies and countries to develop credible transition pathways and properly account for these contingent and transition investments in sustainable finance taxonomies. This should be accompanied by work to develop better and more consistent reporting and assessment standards and improved ways to translate climate performance data into investment.

Figure 1.14 ⊳ Average annual energy investment by emissions reduction potential, 2022-30



A large share of investment in sectors and assets that do not immediately deliver zero emissions energy nevertheless are critical for net zero emissions goals

1.6 People-centred transitions

The purpose of the transformation of the energy sector is to improve lives and livelihoods. Alongside the benefits of avoiding the worst of climate change, this means enabling citizens to seize the opportunities and navigate the disruptions caused by the shift to clean energy technologies. It means eradicating energy poverty: no system is sustainable if it continues to exclude large parts of the global population from access to modern energy.[11] And it means putting considerations of employment, equity, inclusion, affordability, access and sustainable economic development at the centre of the process.

[11] This section draws on *WEO* modelling and analysis to illustrate themes that are also central to the work of the IEA's Global Commission on People-Centred Clean Energy Transitions: https://www.iea.org/programmes/our-inclusive-energy-future.

Employment in clean energy areas is set to become a very dynamic part of labour markets, with growth more than offsetting a decline in traditional fossil fuel supply sectors. As well as creating jobs in renewables and energy network industries, transitions increase employment in related sectors such as construction (retrofits and energy-efficient buildings) and manufacturing (efficient appliances and EVs). In total, we estimate that an additional 13 million workers are employed in clean energy and related sectors by 2030 in the APS, and this figure doubles in the NZE (Figure 1.15).

The transition also comes with dislocation: new jobs are not necessarily created in the same places where jobs are lost. Skill sets are not automatically transferable, and new skills are needed. This is true both within specific countries and internationally. Governments need to manage the impacts in a co-ordinated way, seeking transition pathways that maximise opportunities for decent, high quality work and for workers to make use of existing skills, and mobilising long-term support for workers and communities where jobs are lost.

Figure 1.15 ▷ Employment growth in clean energy and related areas to 2030

Clean energy job gains outpace losses in fossil fuels jobs in the APS and job growth in clean energy and related segments doubles in the NZE

Notes: Efficiency considers buildings and industry efficiency measures. Cars reflect job losses in manufacturing ICE-specific components, and job gains from producing electric and hybrid cars, as well as jobs created from increased car sales globally. Critical mineral job estimates assume highly mechanised mining practices, which modestly estimate job growth when compared to labour productivity in some developing regions today. Innovative technologies include batteries, hydrogen and CCUS.

Quantifying the employment effects of various transition pathways facilitates proper planning of support measures, including training and education programmes. Many countries have designed programmes that seek to use existing strengths in the oil and gas sector in emerging areas such as offshore wind, CCUS, geothermal and hydrogen: the United

Kingdom's North Sea Transition Deal is a case in point. Other countries, including South Africa, have instituted broad social dialogues on people-centred transitions, encompassing companies, trade unions, regional and local governments, civil society and the financial sector.

As transitions gain pace, there will be increased competition for clean energy supply chains and related jobs. Most clean energy jobs are created close to the location of a project, whether it is a wind farm or construction of energy-efficient housing. However, we estimate that a quarter of energy employment is tied to supply chains that may be located in other countries, particularly in the case of solar PV, wind, batteries, grid components and vehicle components. Some governments are looking to onshore these elements, or using economic recovery funding to make strategic investments in emerging segments such as CCUS, advanced battery technologies and low-carbon fuels. These industries, although nascent today, grow to employ nearly 1 million workers worldwide by 2030 in the APS. Favouring domestic manufacturing capacity could lead to more secure supply chains in some instances, as well as additional jobs. But, it could also drive up clean energy technology costs if it erects barriers to trade and reduces economies of scale.

Changes in the energy sector must support **social and economic development** and improve quality of life. A starting point is to bring modern energy to those that lack access. We estimate that providing universal access to electricity and clean cooking by 2030 would require investments of USD 43 billion per year, closing an important gap in the global energy system at a fraction of the overall cost of transitions. The affordability and security of energy supply are also vital considerations when it comes to quality of life.

The co-benefits of well-managed transitions include health and productivity gains. Over 90% of the world's population breathe polluted air on a daily basis, which we estimate leads to over 5 million premature deaths a year. Air pollution also leads to multiple serious diseases, placing an extra burden on healthcare systems currently struggling to deal with the Covid-19 pandemic. While the STEPS and the APS see a rising number of premature deaths during the next decade, the NZE leads to dramatic reductions: by 2030 there are 1.9 million fewer premature deaths from household air pollution per year than in 2020, with over 95% of the reduction occurring in emerging market and developing economies.

The average person spends the vast majority of their time indoors, which means that the way transition policies affect buildings is an important element of well-being. In the NZE, immediate action is taken to ensure that, by the end of this decade, all new buildings meet zero-carbon-ready standards and around one-in-five existing buildings are retrofitted to those standards. Shifting to zero-carbon-ready buildings improves thermal comfort through major upgrades to building envelopes, e.g. improved insulation, glazing, weatherproofing and optimised ventilation. Remaining heating and cooling needs are met by the most efficient equipment such as heat pumps, often facilitated by automated controls. Managed well, these improvements can foster good physical and mental health by creating indoor living environments with healthy air temperatures, humidity levels, noise levels and improved air quality (IEA, 2017). Energy efficiency retrofit programmes for low-income housing deliver the greatest benefits, while highly energy-efficient workplaces and schools have also demonstrated positive impacts on productivity.

Good policy design takes into account issues of **equity and inclusion** as well. There are many ways to address these issues. For example, action can take the form of recycling revenues from carbon pricing schemes to relieve distributional impacts; introducing initiatives to bring young generations into the energy and climate policy debate as they have an essential stake in the consequences of the course that is set; and finding better ways to assess the gender impacts of policy choices and to advance the participation of women in the energy sector.

Far-reaching energy transitions require **support and engagement across society.** A number of changes depend on broad social acceptance. In the NZE, at least half of emissions reductions over the next decade require some kind of consumer buy-in, e.g. a decision to switch to an EV or a heat pump. Around 4% of emissions reductions require behavioural changes, e.g. cycling rather than driving to work.

Box 1.4 ▷ Incorporating gender in energy transition policies

Despite compelling evidence of the social and economic benefits of equal opportunities and diversity in the labour force, many sectors of the global economy perform poorly in terms of gender balance; the energy sector is one of the worst. Women represent a small portion of the labour force and few are in senior positions. At a global level, women occupy only one-in-five jobs in the oil and gas sector and one-in-three jobs in the renewable energy sector (IRENA, 2019). In addition, according to data from almost 2 500 publicly listed energy firms, women make up just under 14% of senior managers (representation is strongest in utilities), compared with 16% in 30 000 non-energy firms (IEA, 2021c).

Transitions present an opportunity to mainstream policies and measures to address issues of gender equality in energy and related sectors. This will require tailored policy support, with solutions designed to take into account the specific dynamics of the various sectors and sub-sectors, and the channels through which gender equality can be improved as energy transitions progress.

The transport sector provides a good example of the opportunities. At present, there are large differences between the ways in which men and women use transport services. Research shows that mobility patterns of women are much more for care work and housekeeping than is the case for men. The average distances travelled also differ as do the number of trips and the time of day. In many countries, women have less access to private cars than men, and so represent a majority of public transport users (ITF, 2019). The exposure of women to different forms of gender-based violence, such as harassment on public transport, adds an additional layer of risk. Women sometimes have to take longer trips to ensure safety, especially at night, adding monthly costs that can amount to USD 25-50 (Kaufman et al., 2018). Plans to get more women engaged in the transport sector need to be designed with these differences in mind.

Positive examples include the City of Guadalajara in Mexico, which employed the results from a comprehensive survey on the transport patterns of women and girls over a large corridor and incorporated its findings into their policy planning (contrary to the traditional approach based on gender-blind origin-destination surveys). Many governments have also incorporated gender-related approaches in their government programmes or public procurement processes. These include demanding a minimum share of women in manufacturing or installation processes, or incorporating a gender assessment when evaluating bids. Effective policies across the energy sector require a much greater push to support the collection of disaggregated gender data, which is still relatively rare.

Societal support is about more than consumer buy-in and behavioural change, important though they are, and gaining broad public support for change involves some difficult trade-offs. For example, creating economic incentives for a shift towards heat pumps could make natural gas more expensive (and push up household heating bills in the interim). Similarly, introducing carbon prices to generate changes in energy consumption patterns could provoke a backlash from lower income and/or rural households, in the absence of effective ways to manage the distributional consequences. Acceptance of a changing energy sector is also critical for the siting and permitting of new infrastructure. Energy transitions do not mean an end to large infrastructure projects, successful transitions need them. Such projects do not only include technologies such as CCUS or nuclear, but also wind, solar and grid investments, all which can face opposition from local communities. Ways need to be found to engage those concerned and assuage their concerns. A clear and engaged social debate on the case for change is vital.

1.7 Phasing out coal

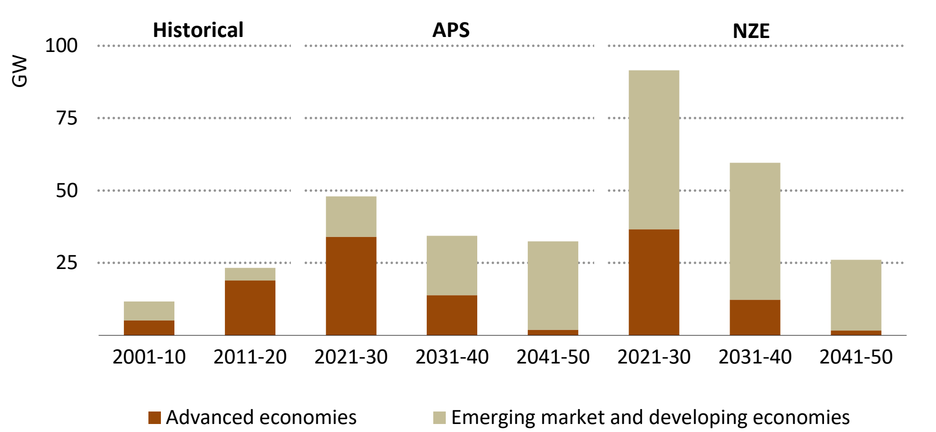
All scenarios that meet climate goals feature a rapid decline in coal use. It is the most carbon-intensive fuel, predominantly used in a sector – electricity generation – where renewable energy options are the most cost-effective new sources in most markets. Global unabated coal use in the energy system falls by around 5% to 2030 in the STEPS, by 10% in the APS, and by 55% in the NZE. However, managing the move away from coal is not simple, especially when it proceeds at the speed required in the NZE where all unabated coal power generation stops by 2040.

There are two aspects to the phase-out of coal in the power sector: halting the construction of new plants and managing the decline in emissions from existing assets. The first is the easier to achieve. There are no new investment decisions for the construction of coal-fired power in the NZE, but as much as 200 GW receive the go-ahead and are completed by 2030 in the APS, mainly in China, India and Southeast Asia, and over 215 GW are approved and built by 2030 in the STEPS, and more go ahead after 2030 in both scenarios. There is a powerful economic and environmental case for countries to proceed instead with low emissions sources of electricity, as well as pressure to do so from financial markets and major international players: all G7 countries have committed to ending new support for unabated coal-fired power and China has pledged to end support for building new coal plants abroad. China's announcement is potentially very significant: it could lead to the cancellation of up to 190 GW of coal projects that are built in the APS to 2050, saving about 20 Gt in cumulative emissions if they are replaced with low-emissions generation.

We estimate that an even larger amount of 350 GW of coal-fired capacity would not be needed in 2030 if policy makers establish the enabling conditions and all of the cost-effective deployment of low emissions sources of electricity is realised (see Chapter 3). This would effectively halt all new investment decisions in the APS and facilitate the retirement of an extra 150 GW of coal-fired capacity by 2030.

Delivering emissions reductions from the existing fleet of coal-fired plants is an even more crucial component of climate action, but a much trickier challenge for public policy. Given the dependence of a number of countries and regions on coal, the closure or repurposing of coal mines and power plants could have significant economic and social consequences. Coal-dependent regions are often highly specialised "mono-industry" areas, where the economy and the local identity are closely tied to the coal value chain. Managing closures appropriately and successfully depends on planning for the impacts on affected workers and communities, and on the repurposing and reclamation of affected land. This is likely to entail long-term engagement by many different parts of government, as well as local businesses.

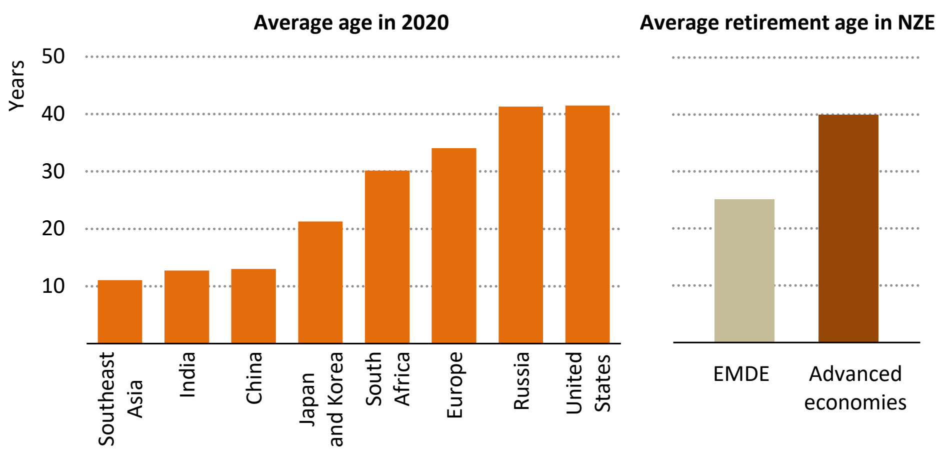
Figure 1.16 ▷ Annual average coal power plant retirements in the Announced Pledges and Net Zero Emissions by 2050 scenarios



Coal power plant retirements increase fourfold over the next decade in the net zero pathway, notably in emerging market and developing economies

The NZE employs a three-pronged approach to tackle emissions cost-effectively while maintaining reliable electricity supply. In total, 2030 emissions from existing coal-fired power plants are three-quarters below the level in 2020, a reduction of over 7 Gt. Existing plants are either retrofitted with CCUS or co-fired with low emissions fuels such as biomass or ammonia; repurposed to focus on system adequacy or flexibility; or retired. The retrofit and repurpose options limit the impact on workers and local communities, but there is nonetheless a steep increase in plant retirements. Since 2010, coal power plant retirements have averaged around 25 GW each year, largely reflecting the closure of ageing plants in Europe and the United States (Figure 1.16). In the APS, annual closures more than double by 2030. Meeting the goals of the NZE requires annual retirements averaging over 90 GW over the next decade, removing around 40% of the existing coal power fleet by 2030.[12]

Figure 1.17 ▷ Average age of existing coal power plants in 2020 in selected regions and average age at retirement in the Net Zero Scenario



Existing coal-fired power plants in emerging market and developing economies are relatively young, and in the NZE they retire when they are less than 25 years old

Note: EMDE = emerging market and developing economies.

While the priority is to phase out the oldest and least efficient plants, more than USD 1 trillion of capital has yet to be recovered in younger plants in the existing coal fleet (mostly in Asia, which accounts for two-thirds of global capacity). A rapid phase out risks creating stranded assets. Existing coal-fired power plants in emerging market and developing economies are relatively young: for example, plants in Asia are on average 13 years old (Figure 1.17). In the APS, coal-fired plants in these countries are retired on average when

[12] In addition to the 480 GW of coal-fired capacity retired in the APS to 2030, we estimate that another 100 GW could be permanently closed without raising electricity bills for consumers.

they are 35 years old, and in the NZE they are retired when they are around 25 years old. In advanced economies, the average age of coal power plant fleet is already almost 35 years, and they are retired on average in eight years in the APS and in five years in the NZE.

Approaches to phase out coal around the world

Phasing out coal at the scale and speed needed in the NZE will require a comprehensive and sustained commitment by national and local governments and the international community to manage transitions for people, communities, assets, land and local environmental quality. Governments have an opportunity to initiate phase outs as part of a broad, coherent and ambitious climate strategy, but other factors – such as changing market fundamentals for coal and local air quality concerns – also provide strong impetus for change. As such, any use of public funds to compensate owners and secure early retirements on climate grounds needs to be carefully assessed so as to ensure that funding is focused on assets that are unlikely to be retired on their own.

In all cases, early planning and social dialogue with affected stakeholders is critical. The multiplicity of government actors involved in local economic development, energy and environmental management makes planning challenging, especially in emerging market and developing economies, and the establishment of special purpose entities might be necessary to pool various funding sources and manage disbursements on the ground. There is an important role for blended finance, along with carbon pricing, in accelerating the closure of coal power plants and increasing investment in clean energy. The early involvement of banks and other investors is critical to deal with potential external financial exposures. Managing social and environmental impacts calls for dedicated and long-term local focus and financing, especially in the most challenging instances where whole towns and communities have been heavily reliant on the coal industry for employment and income.

There is no single blueprint for managing the phase-out of coal-fired generation because a great deal inevitably depends on local circumstances and priorities. Transitions require a range of financial mechanisms that are tailored to coal plants of different types and age, as well as to the varied market structures within which they operate.

The 21 markets that have committed to phase out coal-fired power – nearly all are advanced economies in Europe – represent less than 5% of the global coal generation fleet, and only seven have domestic mining industries that supply coal for power generation. They tend to have well-developed financial systems and market structures characterised by high degrees of private participation. Advanced economies also tend to have slow electricity demand growth, which enables even modest increases in low emissions sources to displace coal. Their focus has been on system planning, tailored support, regulatory incentives and capital markets.

As part of its Just Transition Mechanism, the European Union has capitalised a fund with over USD 20 billion to support economic diversification and assist affected areas and workers. Germany designed a similar regional support programme offering compensation for losses faced by workers and companies, and also has a mechanism that provides tenders that compensate plant owners in exchange for retiring coal capacity.[13] In the United States, regulators have allowed accelerated depreciation schedules, backed by ratepayers, to support faster cost recovery for some assets; some utilities are now looking to refinance coal plants through asset-backed bond issuance and reinvest the proceeds in renewables. The development of sustainability-linked and transition finance instruments could open additional ways to fund emissions reductions through capital markets, leveraging the appetite of private investors for sustainability.

In emerging market and developing economies, where the bulk of existing coal assets are located, circumstances are often quite different. Rapid growth in low-carbon generation is required just to keep up with rising electricity demand, and this limits the scope to displace existing coal-fired power. Investment frameworks are often characterised by lower levels of financial development and higher levels of state ownership. Coal plants are often shielded from competition via long-term off-take agreements. In some markets there are concerns over the potential exposure of the banking system to stranded assets, which adds another layer of complexity.

There are fewer examples of targeted financial innovation in these economies. In China, 20 GW of coal power was retired over the past decade through administrative orders as authorities sought to improve local air quality and curb inefficient plants, but recent closures have been modest in scale. While China's reliance on state-owned generators complicates the political economy of transition, the lower cost of capital of these companies also creates an opportunity to manage the economic burden of closures. In India, where the presence of over 50 GW of financially stressed coal assets has created strains in the banking system, the government is exploring strategies to manage a transition to clean electricity which include the introduction of market-based economic dispatch and the accelerated closure of the least efficient plants.

Efforts to manage transitions from coal in other emerging market and developing economies are largely being facilitated by DFIs, which are designing targeted packages. For example, Chile has a phase-out strategy that is supported by blended finance. Chile established a phase-out schedule and introduced a carbon tax together with a carbon price floor, supported by a concessional loan from the Inter-American Development Bank; this was instrumental in bringing about the early retirement of two coal-fired units.

International efforts are focusing on ways to separate out coal assets into new financing and ownership structures, while creating economic opportunities for workers and communities. The Asian Development Bank is carrying out a feasibility study with potential host countries in Southeast Asia (initially Indonesia, Philippines and Viet Nam) on the Energy Transition

[13] Over the course of three auctions, regulators awarded around USD 700 million for the closure of more than 8 GW of hard coal and small lignite capacity in Germany by 2022 (based on publicly available data for the first and third auctions, and on an IEA estimate for the second). The tender mechanism targets hard coal and small lignite power plants. Another mechanism to provide direct compensation for the early closure of lignite-fired power plants currently is subject to a state aid review by the European Commission.

Mechanism, a platform to accelerate the retirement of coal power using blended finance and to support investment in renewables, all in an equitable, scalable and market-based manner. The World Bank is supporting long-term transitions for coal regions through institutional governance reforms, assistance to communities and repurposing of land and assets. The Climate Investment Fund's Accelerating Coal Transition programme aims to support the closure and repurposing of coal plants through blended finance of USD 2.5 billion for each target country, including USD 300 million for regional economic development and retraining.

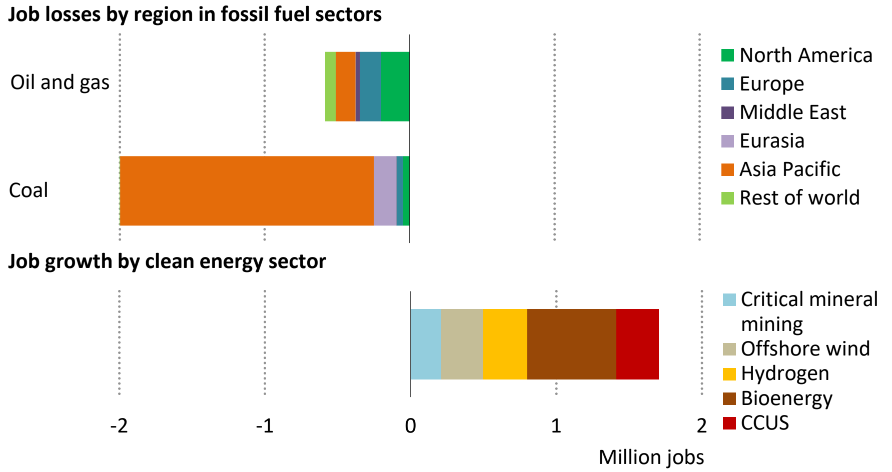
Efforts of this kind will play a particularly vital role in supporting transitions in markets where a strong relationship exists between the energy sector and the government or in those with challenging political economies. In South Africa, for example, domestic and international stakeholders are considering a multi-faceted strategic and financial approach to help Eskom, the state-owned utility, to shift to renewables, reduce its debt load and ensure a just transition for coal miners and plant workers. In Indonesia, PLN, the state-owned utility, has announced it that it aims to retire all (50 GW) coal plants by 2055.

Box 1.5 ⊳ Pledges signal a further decline in global coal employment

The APS does not mark the end of coal-fired power generation, but it has clear implications for coal-related employment. Direct coal-related jobs are set to continue the declines seen over the past decade, driven by environmental and demand pressure, especially in advanced economies, as well as by increased productivity, particularly in Asia. By 2030, 30% fewer people work in coal than in 2019, one-third of those declines are associated with productivity gains in coal mining. The drop is most notable in China, although this is mainly the result of continued restructuring in the industry rather than lower demand (Figure 1.18). Coal employment in India, which has the second-largest number of coal workers worldwide, could be bolstered by the policy ambition to increase domestic output, but there are major uncertainties over domestic demand, especially if policies tighten.

Although in aggregate energy transitions create substantial job growth, there is little scope to replace jobs lost in traditional sectors on a one-to-one basis with opportunities in clean energy. Rising demand for critical minerals offers some transfer of employment in the mining sector, but these opportunities are not always located in the same area as coal supply. Miners working at fully modernised mines have skills that could be readily transferred, but over 90% of coal workers are in emerging market and developing economies, and are often unskilled. Most of the scope to re-deploy existing workers to new clean energy projects in practice is in the oil and gas sector. Coal employment is only a small portion of total employment in most countries (less than 0.5% in China and less than 0.1% in India), but it accounts for a high percentage of total earnings and tax revenues in many communities. There is a particular need to help workers and communities where coal plant closures are likely to have cascading effects on communities and supporting businesses.

Figure 1.18 ▷ Changes in fossil fuel employment and energy areas with overlapping skills in the Announced Pledges Scenario to 2030



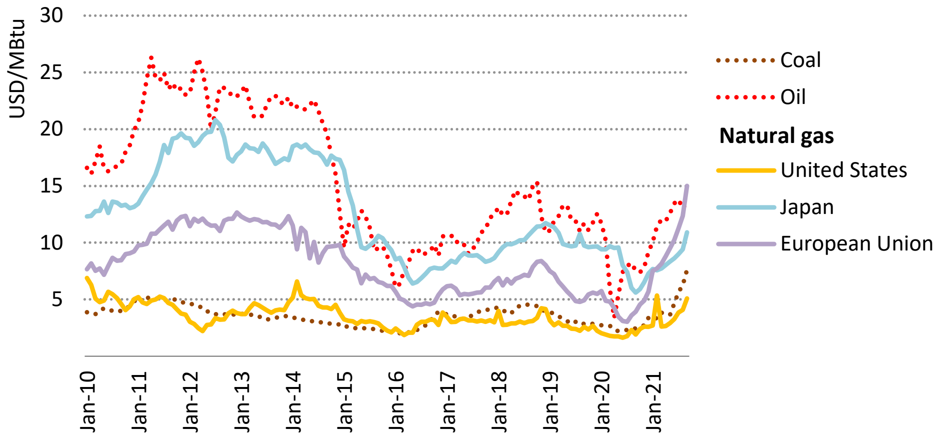
Skilled fossil fuel workers have opportunities to transition to clean energy jobs, though the options are not a direct match for most coal sector jobs lost in Asia

1.8 Prices and affordability

The economic recovery in 2021 has tightened commodity markets and put upward pressure on prices across the board. Crude oil prices whipsawed from USD 20/barrel in the immediate aftermath of the pandemic in mid-2020 to around USD 70/barrel in mid-2021. Spot natural gas prices have been on a relentless upward march around the world, and they reached their highest ever levels in Europe during the second-half of 2021 (more than ten-times the record lows reached in June 2020). Coal prices in 2021 have also seen strong growth on the back of a rebound in demand, especially in Asia (Figure 1.19). High natural gas and coal prices have fed through to higher power prices in many markets, particularly where output from renewables has been relatively low.

Prices for key critical materials, such as lithium and copper, have rebounded strongly and are near or above the highest levels observed in the past decade. This rise in prices may reflect not just the economic recovery but also the commodity market's rising expectation of the widespread use of these critical minerals in clean energy transitions. All else being equal, we estimate that, if current spot prices for key critical minerals were maintained, they would increase clean energy investment costs in the STEPS by over USD 400 billion, and by USD 700 billion in the NZE, by 2030.

Figure 1.19 ▷ Oil, natural gas and coal prices by region, 2010-2021



Gas and coal prices dipped significantly during the pandemic, but have recently risen sharply

Notes: USD/MBtu = US dollar per million British thermal units. Gas prices for the European Union and Japan are weighted average import costs. The United States gas price reflects the wholesale price on the domestic market. Coal prices are an average of steam coal import prices in the European Union and Japan and domestic sales and imports in coastal China.

High prices are a signal that supply is struggling to meet demand. In recent years, investment in oil and gas supply has often appeared to be geared towards a world of stagnant or even falling demand, while purchases of internal combustion engine (ICE) vehicles and expansion of natural gas infrastructure point the other way: towards ever increasing oil and gas consumption. The Covid-19 pandemic, which led to a near-record low in new oil and gas investment in 2020, intensified this trend.

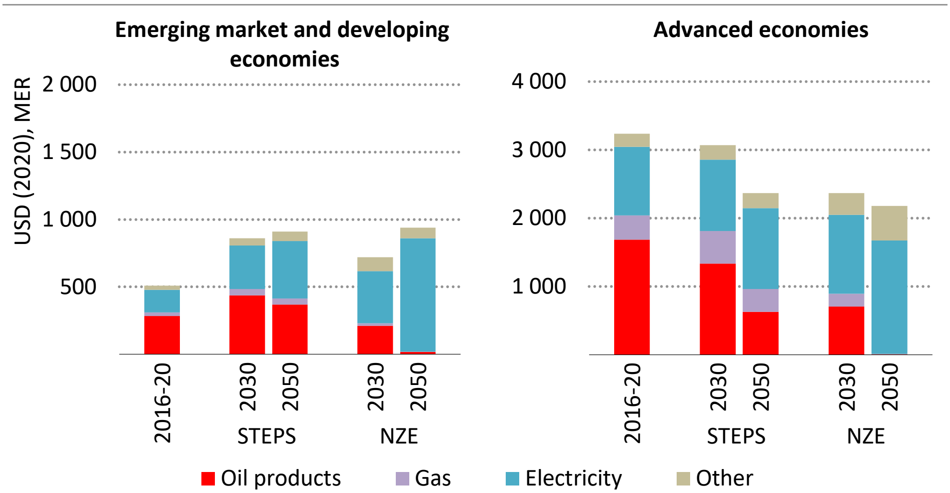
Uncertainty about future levels of demand is reflected in our scenarios. In the STEPS, rising oil and gas demand leads to price levels that incentivise investment in new supply. In the NZE, on the other hand, a rapid drop in oil and gas consumption means that there are no new investments in supply projects beyond those already announced or under construction: prices are set by the operating costs of the marginal project required to meet demand, and this results in significantly lower fossil fuel prices than in recent years. Navigating the uncertainty between these two outlooks will not be easy, and volatility and price shocks cannot be discounted during the transition (see section 1.9).

The effect of high fossil fuel prices on clean energy transitions is not clear cut. High prices narrow the competitiveness gap with lower carbon fuels and technologies such as renewables or bioenergy. They ought to incentivise producers to take action such as reducing methane leaks or gas flaring, and consumers to improve energy efficiency or moderate consumption. But they also send strong signals to invest in new supplies, which would lock in new sources of emissions if companies and investors act on them. Higher cost sources of oil and gas often have a higher level of emissions, and this could exacerbate additional lock in. Rising energy bills for households or industries might also put pressure on governments to raise fossil fuel subsidies, reduce clean energy levies or dilute planned support packages for low-carbon technologies. Equally, it might make them more determined to push ahead as rapidly as possible with efforts move away from fossil fuels. Relative changes in the price of coal, gas and oil could also lead to fuel substitution effects, for example if high natural gas prices were to encourage a switch to coal or fuel oil, or the other way around.

Affordability

The extent to which commodity prices feed through to household and other energy bills is determined by policy and market design, as well as by whatever taxes, subsidies, capital costs and environmental surcharges are reflected in the final bill. In an ideal world, energy bills would be based on cost-reflective energy prices and would encourage efficient and sustainable choices, but without harming low income households or choking off economic activity.

Figure 1.20 ▷ Average household energy bills by fuel in the Stated Policies and Net Zero Emissions by 2050 scenarios



Targeted support, efficiency improvements and lower use of oil can help ensure energy affordability during transitions, which is especially important for the developing world

Notes: MER = market exchange rate. Spending related to additional upfront investment is not included in energy bills.

In the STEPS, average household energy bills in advanced economies decline from an average of around USD 3 200 over the last five years to USD 2 400 per household in 2050 (Figure 1.20). In emerging market and developing economies they rise by 80% over this period – more than the growth in average disposable income – as a result of the rapid growth in appliance and vehicle ownership which occurs in parallel with rising electricity, gas and oil prices. Energy efficiency improvements, electrification and switching to low-carbon sources could all help to make energy more affordable. However, they often require upfront investment and, even though such costs are offset over time by energy bill savings, access to finance remains an important hurdle to overcome, especially for low income households. Targeted subsidies for low-carbon energy, particularly electricity, may be necessary to lessen the burden of price increases on low income families as energy systems move towards net zero emissions.

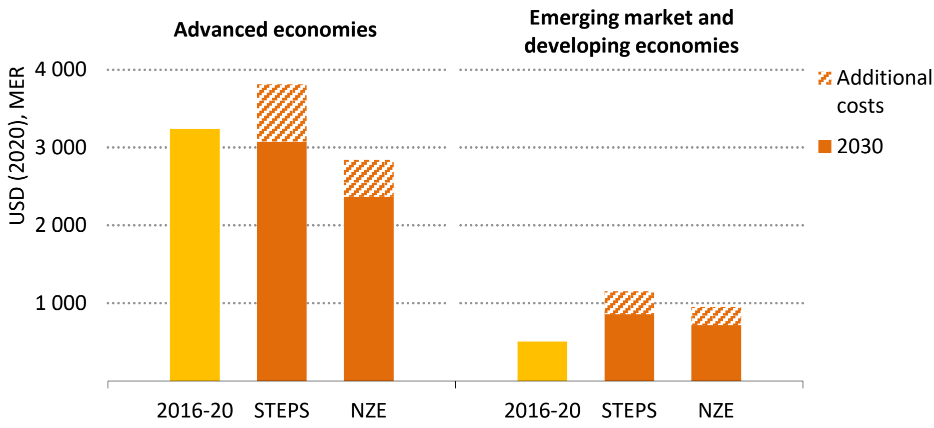
The share of electricity in household energy bills rises in all scenarios. In the NZE, electricity accounts for 90% of household bills in emerging market and developing economies and close to 80% in advanced economies by 2050, compared to a global average of around 30% in 2020.

In advanced economies, household electricity bills in 2050 are higher in the NZE than in the STEPS, however overall energy bills are on average nearly 10% lower because of efficiency gains and because households no longer need to pay for natural gas for heating and oil for cars. In emerging market and developing economies, higher electricity bills are offset for the same reasons, and so the total household energy bill is lower in the NZE than in the STEPS in 2030, and ends up broadly the same in the two scenarios by 2050. This outcome depends strongly on efficiency improvements; without additional improvements relative to the STEPS, average household energy bills globally in the NZE in 2050 would be a third higher.

As events in 2021 show, consumers are vulnerable when prices rise sharply. We have tested this by modelling the impact of a fossil fuel price shock in 2030 on household energy bills in the STEPS and NZE, taking the highest oil, natural gas and coal prices reached in each region over the period from 2010 to 2020 (Figure 1.21). We find that:

- In the STEPS, households in advanced economies would pay 25% extra for their energy, or an additional USD 750, in this sensitivity case. In emerging market and developing economies, households would pay 35% more, primarily because gas, coal and oil make up a larger share of total household energy use in 2030 than in advanced economies. On average across all countries, the price shock raises household electricity bills by 10% in 2030, while the cost of gas-based heating doubles and that of oil-based transport rises by 45%.
- In the NZE, the additional cost to households in advanced economies is USD 470, nearly 40% less than in the STEPS, and in emerging market and developing economies it is 20% less than in the STEPS. The impact of higher commodity prices is dampened by more rapid efficiency gains, by reduced direct use of oil and gas, and by electricity having a higher share in total household energy expenditure (electricity is less affected by the price shock than oil and gas because of the rising role of renewables). In advanced economies, the price shock still leaves total costs to consumers in the NZE below the level of costs in the STEPS without a price shock.

Figure 1.21 ▷ Impact of a commodity price shock on average household energy bills in 2030 by scenario



Applying the highest oil, gas and coal prices of the last decade in 2030 raises household energy bills more in the STEPS than in the NZE, and from a higher price base

Notes: MER = market exchange rate. Spending related to additional upfront investment is not included in energy bills.

The reduced exposure to commodity price changes in the NZE is also due to a more capital-intensive energy system, in which the fixed charges for recovering investment in infrastructure become more important drivers of energy bills in the long run. This is especially true for the power sector, which in the NZE becomes dominated by renewables with zero marginal cost, but nonetheless requires a ramp up in grid and battery investments to almost USD 1 trillion by 2050, a more than threefold increase on current levels. The cost of developing critical minerals also becomes more important in setting energy prices in such a capital-intensive world, but these have a less immediate effect on end-user bills than oil, gas or coal prices. Since much of the additional investment in the NZE occurs in end-use sectors themselves, the cost of capital to consumers also forms a crucial part of the energy affordability equation.

Volatile electricity prices cannot be discounted during the transition, however. Fuel costs can still play an outsized role in price formation even though their contribution to overall electricity supply shrink, as in many markets where marginal cost pricing determines wholesale prices based on a merit order where natural gas or coal plants are dispatched according to their short-run costs of generation. Moreover, the weather-dependent nature of electricity supply (from wind and solar) and demand (from air conditioning or heat pumps) can cause significant price volatility, which can contribute to lower or higher consumer bills. Wholesale price volatility is reduced in the NZE by a broad suite of short- and long-duration sources of flexibility (via batteries, hydropower, low emissions thermal generation sources, interconnected grids and demand-side response). Their uptake relies on updated market frameworks to reflect the value of all grid services provided.

In all countries, governments, as far as possible, will want to anticipate and counteract the potential drivers of significant price increases. It will be particularly important to ensure that energy services remain accessible and affordable for all households. Possible actions in support of this include facilitating improvements in energy efficiency and incentivising fuel switching to renewables or electricity, especially for the least well-off households.

1.9 Energy security and the risk of disorderly change

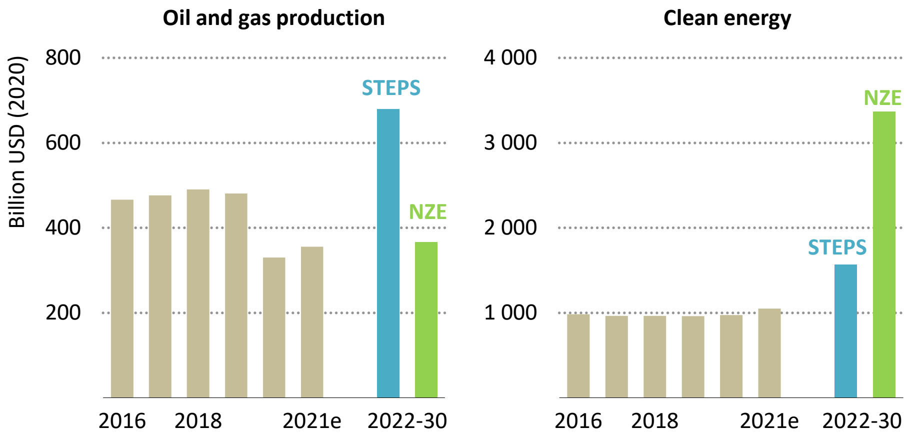
By design, the scenarios in this *Outlook* describe smooth, orderly processes of change. In practice, however, energy transitions can be volatile and disjointed affairs, characterised by competing interests and stop-go policies. As the world makes its much-needed way towards net zero emissions, there is an ever-present risk of mismatches between energy supply and demand as a result of a lack of appropriate investment signals, insufficient technological progress, poorly designed policies or bottlenecks arising from a lack of infrastructure. In the APS, countries undertake clean energy transitions at different speeds, raising the risk of tensions in global trade and constraints on technology transfer. In the NZE, potential new hazards could arise alongside the rise of clean energy.

Investment mismatches

Energy transitions bring about a major shift in the primary energy mix away from carbon-intensive fuels towards low-carbon energy sources. Although the share of fossil fuels in the mix has remained at around 80% over several decades, it declines to around 50% by 2050 in the APS and collapses to just over 20% in the NZE. Lower demand for fossil fuels, and in particular for oil and natural gas, ultimately reduces some traditional energy security hazards, but it cannot be taken for granted that the journey will be a smooth one. Our projections highlight the huge uncertainty over the trajectory for future demand. If there are no further changes in today's policy settings, as in the STEPS, oil demand in 2050 remains above 100 mb/d. By contrast, if the world single-mindedly pursues a 1.5 °C stabilisation objective, then oil demand falls to 24 mb/d in the same year. The comparable range for natural gas is between 5 100 bcm in the STEPS and 1 750 bcm in the NZE.

These variations come with dramatically different implications for investment (Figure 1.22). The declines in oil and gas demand in the NZE are sufficiently steep that no new field developments are required: continued spending to maintain production from existing assets, and reduce the associated emissions, amounts to an annual average of USD 210 billion between 2020 and 2050 in the NZE. In the STEPS, on the other hand, the annual amount required for investment is around USD 680 billion, well above current levels. If companies and investors misread demand trends amid uncertainty about the future, there is a risk of either market tightening or of over investment leading to underutilised and stranded assets.

Figure 1.22 ▷ Investment in oil and gas production and clean energy in the Stated Policies and Net Zero Emissions by 2050 scenarios



Currently, investment in oil and gas production is closer to the NZE than the STEPS, even while today's spending on clean energy is well below levels reached in both scenarios

Notes: 2021e = estimated values for 2021. See Annex C for definition of clean energy.

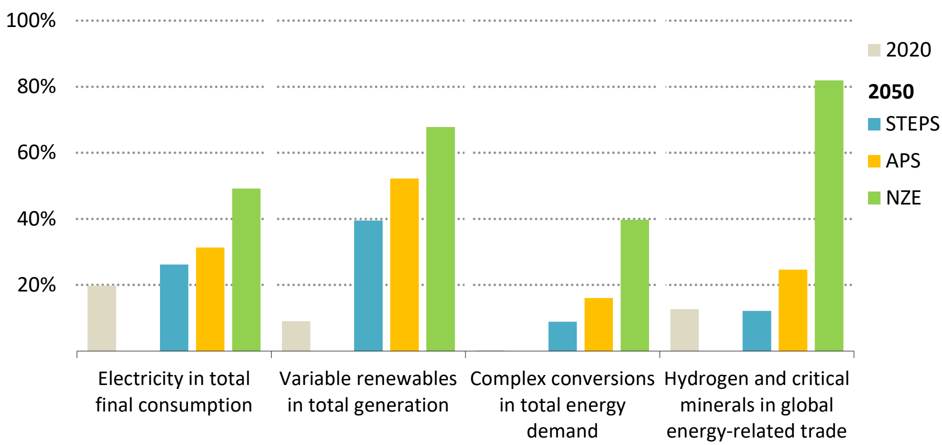
The fact that no new oil and natural gas fields are required in the NZE does not mean that limiting investment in new fields will lead to the energy transition outcomes in this scenario. If demand remains at higher levels, this would result in tight supply in the years ahead, raising the risks of higher and more volatile prices. It is not clear that higher prices would trigger supply responses to the same extent as in the past. A strong policy push to reduce oil and gas demand in line with the trajectory envisaged in the NZE therefore is key to achieving deep reductions in emissions and minimising the risk of market tightening.

Market design and infrastructure in increasingly integrated systems

Many of the new energy security challenges in a decarbonising world arise in the power sector as societies come to depend more on electricity for their energy needs. Across all scenarios the share of variable renewables in electricity generation rises to reach 40-70% by 2050 (and even more in some regions), far above the global average of just under 10% today (Figure 1.23). Wind and solar PV generation varies with the weather as well as with the time of day and year, and this can cause sudden changes to generation patterns on a daily or weekly basis. A large share of seasonal energy demand is also transferred onto the power system through the increasing use of electric heating and cooling equipment. Electricity storage, demand-side response and dispatchable low emissions sources of power are essential to meet flexibility requirements in clean energy transitions.

Managing imbalances between supply and demand, especially over longer timeframes, without resorting to emissions-intensive fuels requires a fundamental transformation of how energy systems operate. Today's energy sector is in essence a series of interlinked but largely independent delivery channels for fuels, heat and electricity to consumers. The energy system of the future consists of a much more complex web of interactions between solid, liquid and gaseous fuels, and electricity. In the NZE by 2050, around 40% of primary energy is converted at least twice before reaching end-users. Energy travels through batteries and electrolysers, undergoes conversions from electricity to heat or fuels, and back again. Such conversion processes are essential to provide the system flexibility needed to match the supply of variable renewables and demand for electricity at least cost. The need for such flexibility in the NZE is considerable: utility-scale battery storage increases from less than 20 GW in 2020 to over 3 000 GW by 2050, and there are millions of behind-the-meter enablers of flexibility, in the form of smart meters, EVs and charging infrastructure.

Figure 1.23 ▷ Key indicators of energy system change by scenario



New energy security challenges arise in systems increasingly reliant on electricity, low-carbon technologies, higher levels of supply variability and more complex conversions

Note: Complex conversions are a primary energy source that has undergone two or more conversions before being delivered to end-users. It includes roundtrip battery storage.

A more complex energy system, with electrification at its core, raises important questions about the future of natural gas infrastructure, which in many parts of the world plays an important role in meeting seasonal demand for heating as well as short-term peaks in power generation. Current underground gas storage facilities have a capacity of 420 bcm per year – equivalent to more than half of the world's residential space heating demand. This buffer for households relying on gas for heating is not easily replicated by the electricity system. Gas power plants are also a mainstay of today's electricity security because of their ability to flexibly ramp up and down in response to changes in variable renewable output or peaks in demand. In the APS, even though generation on an annual basis declines in the United States and the European Union, the peak of generation from gas-fired power plants in those regions is 10-15% higher in 2030 than in 2020. This underscores the need for market designs that recognise the flexibility value of existing infrastructure even as the focus turns to developing innovative options that can replicate the services that natural gas provides (including low-carbon hydrogen).

Ultimately, secure transitions require careful sequencing to ensure that change in one area is complemented by change elsewhere. A reduction in oil and gas investment requires a surge in capital spending on low emissions fuels and technologies. Bans or limitations on the use of gas boilers or ICE vehicles only work if there are low-carbon alternatives that can deliver the same energy services, ideally at a similar or lower cost to consumers. Minimising the contribution of unabated coal and gas power plants to electricity supply requires lower carbon sources of flexibility in their place. These changes bring opportunities to make use of parts of today's fuel supply system in new ways: for example, there is scope for the supply, transport and storage of hydrogen to piggyback on existing gas pipelines and storage. The key point is that policy makers need to understand not just the value of energy, but also the value of the system's overall capacity to provide it when needed.

The world's energy infrastructure faces increasing physical risks from a changing climate. We estimate that around a quarter of the world's electricity networks face a high risk of destructive cyclone winds, while over 10% of dispatchable generation fleets and coastal refineries are prone to severe coastal flooding and a third of freshwater-cooled thermal power plants are located in high water stress areas. These risks are set to increase over time, highlighting the urgent need to enhance the resilience of energy systems to climate change.

Shifting geopolitics of energy security

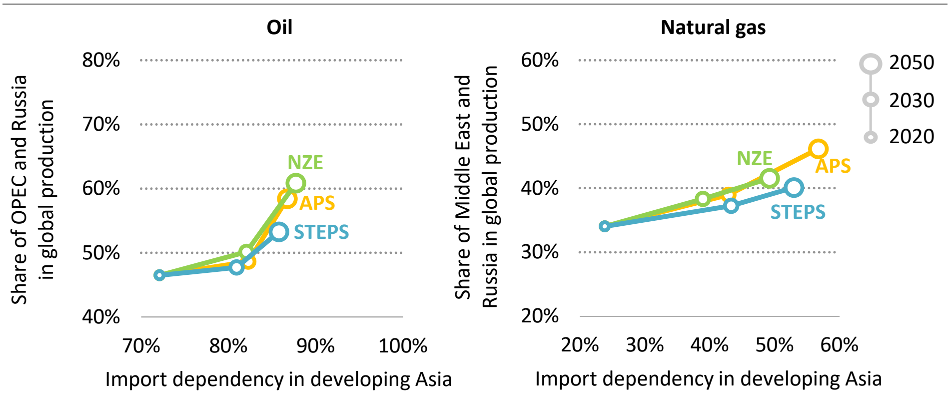
Clean energy transitions are set to bring about a major change in the energy trade patterns that have long been dominated by fossil fuels. The rising importance of critical minerals and low-carbon hydrogen means that their combined share in global energy-related trade doubles to 25% by 2050 in the APS. In the NZE, the share rises further to 80% by 2050 as the value of fossil fuels trade plunges, completely overturning the current dynamics of international energy-related trade.

Energy geopolitics are typically associated with oil and gas. However, clean energy technologies are not immune from geopolitical hazards. The production and trade of critical minerals provide a case in point. Overall mineral requirements for clean energy technologies almost triple between today and 2050 in the STEPS, and up to sixfold in the NZE. However, today's supply and investment plans point to a risk of supply lagging behind projected demand in the NZE. Higher or more volatile prices for critical minerals could make global progress towards a clean energy future slower or more costly. Recent price rallies for critical minerals illustrate the point: all other things being equal, they could make solar panels, wind turbines, EV batteries and grid lines 5-15% more expensive, with ripple effects on the costs of transitions.

The challenges are compounded by a lack of geographical diversity in critical mineral extraction and processing operations. In many cases, the supply of critical minerals is concentrated in a smaller number of countries than is the case for oil and natural gas. This is inevitably a source of concern because it means that supply chains for solar panels, wind turbines and batteries using imported materials could quickly be affected by regulatory changes, trade restrictions or even political instability in a small number of countries. Early attention from policy makers is required to develop a comprehensive approach to mineral security that encompasses measures to scale up investment and promote technology innovation together with a strong focus on recycling, supply chain resilience and sustainability.

The NZE also sees the emergence of inter-regional hydrogen trade (including trade in hydrogen-based fuels such as ammonia), with regions that possess abundant low cost production potential exporting to those with more limited production options. Hydrogen trade grows to around USD 100 billion by 2050 in the APS, higher than the value of current international coal trade, and to USD 300 billion in the NZE. However, there is a question mark over how infrastructure and market norms will develop as demand increases. Hazards could arise from a lack of co-ordination between potential exporters and importers or bottlenecks in infrastructure and equipment manufacturing capacity. Careful co-ordination and dialogue will be essential to bring forward new supply chains in a timely way.

Figure 1.24 ▷ Import dependency in developing economies in Asia and the level of supply concentration for oil and natural gas by scenario



Hydrocarbon import dependency in developing economies in Asia rises in all scenarios, while production concentrates in a small number of countries

While new dimensions of energy geopolitics arise, the traditional significance of trade in hydrocarbons does not vanish. Oil and gas supplies in the APS and NZE become increasingly concentrated in a small number of low cost producers. The share of Organization of the Petroleum Exporting Countries (OPEC) members and the Russian Federation (hereafter Russia) in global oil production rises considerably from 47% today to 61% in 2050 in the NZE. Many of the producer economies poised to take a larger share in future supply nevertheless face the prospect of significantly falling hydrocarbon income as overall demand falls. For the moment, these producers remain poorly prepared for transitions, with limited progress on economic and energy diversification, raising the possibility of a bumpy and volatile ride. Meanwhile, import dependency on fossil fuels in developing economies in Asia remains high in all scenarios (Figure 1.24), leading to further concentration of trade flows between the Middle East and Asia. This suggests that Asian importers will continue to be exposed to risks arising from physical or geopolitical events in the Middle East or accidents near trade chokepoints, underscoring the need for vigilance on the security of supply even in a world with contracting fossil fuel demand.

1.10 Fuels: old and new

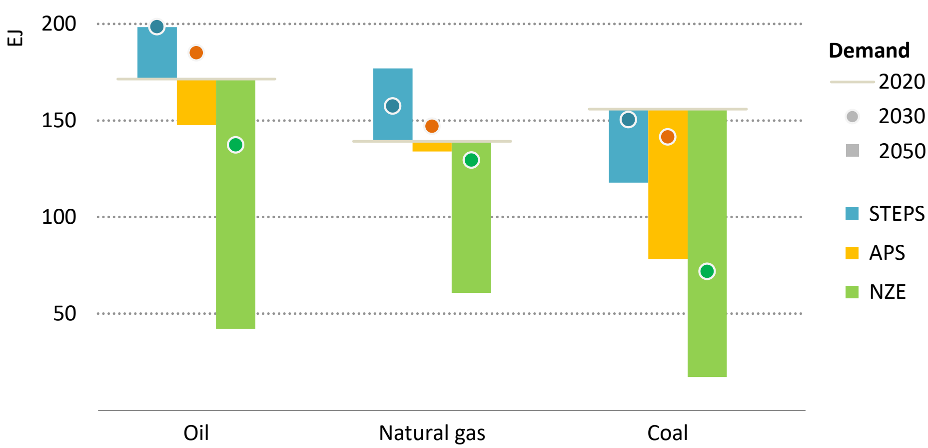
Clean electrification is a central element in all scenarios in this *Outlook*, but it is not possible to electrify everything. Even in the NZE, electricity comprises less than 50% of total final energy consumption in 2050: in the APS and the STEPS the comparable figures are 31% and 26%. Liquid, gaseous and solid fuels of various types will continue to make a major contribution to the global energy mix through to 2050.

Oil demand, for the first time, shows an eventual decline in all scenarios in this *Outlook*, although the timing and sharpness of the drop vary widely. In the STEPS, demand levels off at 104 mb/d in the mid-2030s and then declines very slightly to 2050. Oil use in road transport increases by around 6 mb/d through to 2030, with a particularly sharp rise in 2021, and it increases by close to 8 mb/d in aviation, shipping and petrochemicals. In the APS, global oil demand peaks soon after 2025 at 97 mb/d and declines to 77 mb/d in 2050. Oil use falls by around 4 mb/d in countries with net zero pledges between 2020 and 2030, but that is offset by an 8 mb/d increase in the rest of the world. In the NZE, oil demand falls to 72 mb/d in 2030 and to 24 mb/d by 2050. By 2030, 60% of all passenger cars sold globally are electric, and no new ICE passenger cars are sold anywhere after 2035. Oil use as a petrochemical feedstock is the only area to see an increase in demand; in 2050, 55% of all oil consumed globally is for petrochemicals.

Natural gas demand increases in all scenarios over the next five years, with sharp divergences afterwards. Many factors affect to what extent, and for how long, natural gas can retain a place in the energy mix when clean energy transitions accelerate, and the outlook is far from uniform across different countries and regions. In the STEPS, natural gas demand grows to around 4 500 bcm in 2030 (15% higher than in 2020) and to 5 100 bcm in 2050. Use in industry and in the power sector increases to 2050, and natural gas remains the default option for space heating. In the APS, demand reaches its maximum level soon after 2025 and then declines to 3 850 bcm in 2050: countries with net zero pledges move away from the use of gas in buildings, and see a near 25% decrease in consumption in the power sector to 2030. In the NZE, demand drops sharply from 2025 onwards and falls to 1 750 bcm in 2050. By 2050, more than 50% of natural gas consumed is used to produce low-carbon hydrogen, and 70% of gas use is in facilities equipped with CCUS.

Coal faces structural decline in all scenarios (Figure 1.25). In the STEPS, global coal demand rises slightly to 2025 and then starts a slow decline to 2050 when it is around 25% lower than in 2020. Between 2025 and 2030, total coal demand in China starts to fall and there are large reductions in coal use in advanced economies, mainly as a result of lower demand in the power sector. In the APS, global coal demand in 2030 is only 6% lower than in the STEPS because more than 80% of coal demand today comes from countries that do not have net zero pledges or aim only to reduce emissions after 2030. But it declines rapidly after 2030, notably in China, and global demand in 2050 is only half what it was in 2020. In the NZE, global coal demand drops by 55% to 2030 and by 90% to 2050; in 2050, 80% of the small remaining amount of coal still being used is equipped with CCUS.

Figure 1.25 ⊳ Fossil fuel use by scenario



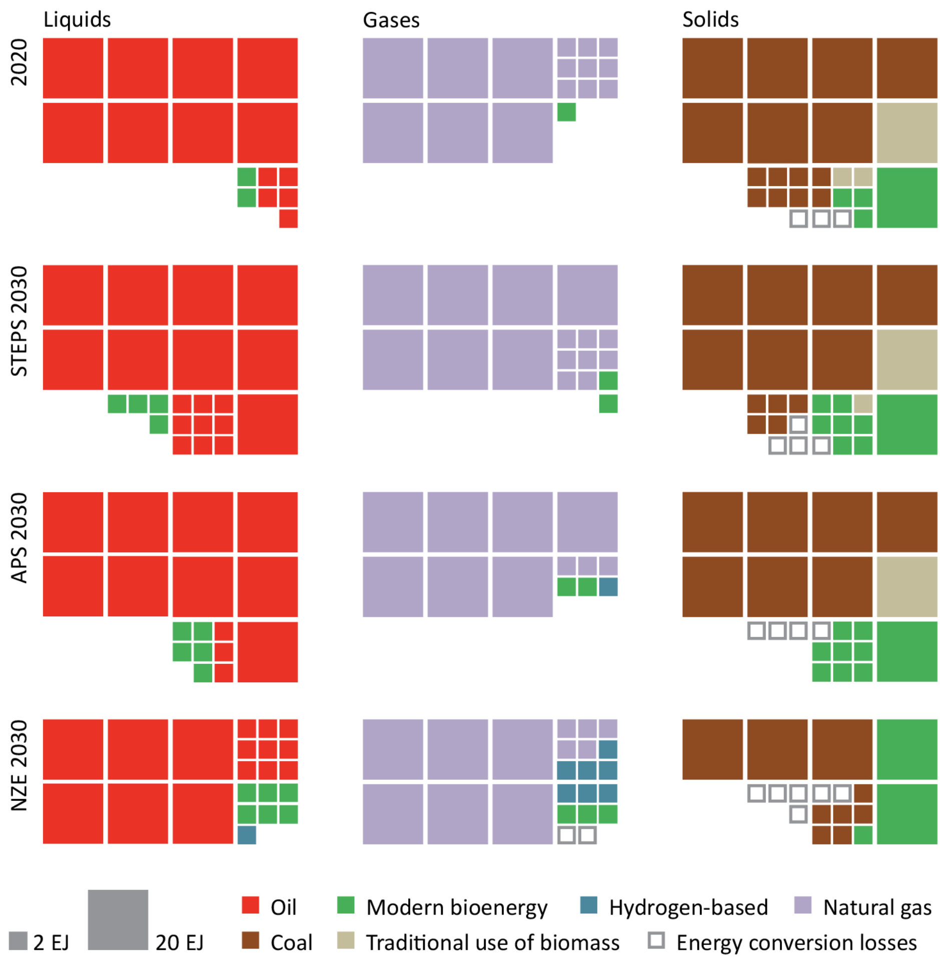
Oil demand peaks in each scenario, but the level and timing vary; natural gas increases to 2025 with sharp divergences thereafter; coal falls in all scenarios

Note: 1 EJ is around 0.5 mb/d of oil, 29 bcm of natural gas or 34 Mtce of coal.

In the STEPS, the increase in oil demand means oil prices rise to around USD 77 per barrel in 2030. Tight oil operators in the United States choose to prioritise returns over production growth, and tight oil satisfies much less of the increase in global oil demand than in the past. OPEC production increases by around 6 mb/d to 2030, and Russian production is maintained: OPEC and Russia together provide 48% of total oil supply in 2030, an increase from 2020 but well below their share during much of the last decade. Internationally traded volumes of natural gas expand by over 240 bcm between 2020 and 2030. Australia remains the largest exporter of coal although exports fall by around 5% to 2030.

In the APS, producer countries with net zero pledges pursue efforts to minimise emissions from oil and gas operations. This increases their production costs relative to other producers as well as their financing costs, but some remain competitive and are able to increase exports of oil and gas when domestic demand declines faster than supply: for example, in 2030 the United States exports 3.5 mb/d of oil and 200 bcm of natural gas in the APS (compared with 2.5 mb/d of oil and 220 bcm of natural gas in the STEPS). This puts downward pressure on prices, and limits export opportunities for a number of new and emerging producers. OPEC and Russia together provide 48% of total oil supply in 2030. Internationally traded natural gas volumes grow by 160 bcm between 2020 and 2030, while the drop in coal demand in countries with net zero pledges mean that coal exports fall from all producers.

Figure 1.26 ▷ The rising share of low emissions fuels in the energy mix



All low emissions fuels make progress to 2030, but announced pledges are not enough to close the gap with the NZE or to provide the springboard needed for their post-2030 growth

Note: Energy conversion losses = fuel consumed in the transformation process to produce other liquid, gaseous or solid fuels for final consumption.

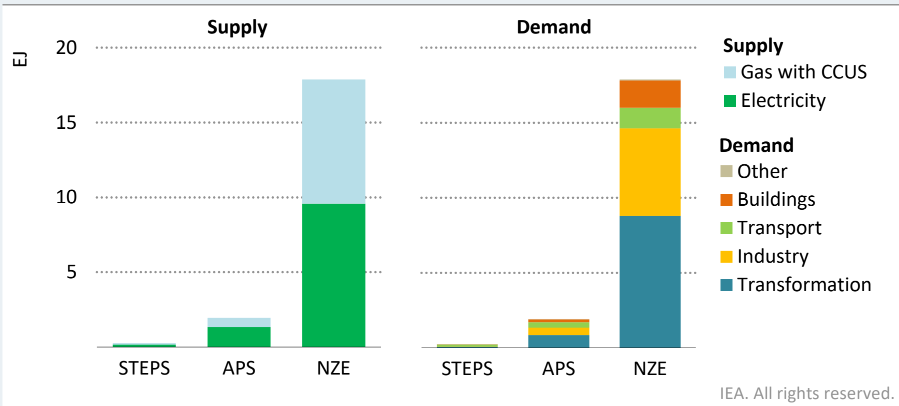
Minimising methane leaks and flaring should be a top priority in the quest to reduce emissions from fossil fuel operations. On average, we estimate that 8% of natural gas and natural gas liquids entering flares are not combusted and leak into the atmosphere. This is more than double previous estimates, and suggests that flaring resulted in more than 500 Mt CO_2-eq GHG emissions in 2020, which is more than the annual CO_2 emissions from all cars in the European Union.

There is a growing role for alternative, low emissions fuels such as modern bioenergy and hydrogen-based fuels in all scenarios (Figure 1.26). These play a key role in the achievement of net zero targets, especially in sectors where direct electrification is most challenging. Policy support for these low emissions fuels varies significantly among countries, with most recent attention paid to low-carbon carbon hydrogen (Box 1.6), but the use of modern bioenergy also grows substantially. Just under 2 mb/d of biofuels were used in 2020, but volumes double to 2030 in the STEPS, increase by two-and-half times in the APS and triple in the NZE. The use of modern forms of solid bioenergy increases by 30-70% across the scenarios to 2030. In the NZE, biogas provides clean cooking access for 400 million people in 2030, and total biogases demand rises to 5.5 EJ.

Box 1.6 ▷ Is there a pot of hydrogen at the end of the rainbow?

Today, 17 governments have published low-carbon hydrogen strategies and more than 20 countries are developing them. These strategies mainly focus on targets for hydrogen supply, although attention is increasingly being paid to the policies needed to stimulate demand both for low-carbon hydrogen and hydrogen-based liquids, including ammonia, methanol and other synthetic liquid hydrocarbons with a very low emissions intensity.

Figure 1.27 ▷ Low-carbon hydrogen and hydrogen-based fuel demand and supply by scenario in 2030

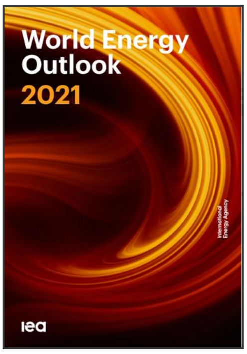


Hydrogen demand increases across the board and is produced by both electrolysis and natural gas with CCUS

Note: Transformation includes electricity and heat, production of hydrogen-based fuels and refineries.

The STEPS sees small increases in the use of low-carbon hydrogen and hydrogen-based fuels to 2030 (Figure 1.27). In the APS and the NZE, demand picks up more rapidly as low-carbon hydrogen and hydrogen-based fuels are used to provide flexibility in the power sector, hydrogen currently used in industry is replaced by low-carbon hydrogen, and new end-uses emerge (including in transport and for heating in buildings in some circumstances). In the NZE, around half of low-carbon hydrogen production in 2030 is from electrolysis and half is from coal and natural gas equipped with CCUS (although this ratio varies considerably among countries).

Progress in the decade to 2030 will be critical to the later success of low-carbon hydrogen and hydrogen-based fuels. Success will depend on major investments in innovation to lower the costs of production and in transport to ensure that new end-user equipment and vehicles quickly become available on the market. There are likely to be large regional variations in production costs for hydrogen and hydrogen-based fuels, and imports could be more economically attractive than domestic production for some countries.



From:
World Energy Outlook 2021

Access the complete publication at:
https://doi.org/10.1787/14fcb638-en

Please cite this chapter as:

International Energy Agency (2021), “Overview”, in *World Energy Outlook 2021*, OECD Publishing, Paris.

DOI: https://doi.org/10.1787/4700b315-en

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