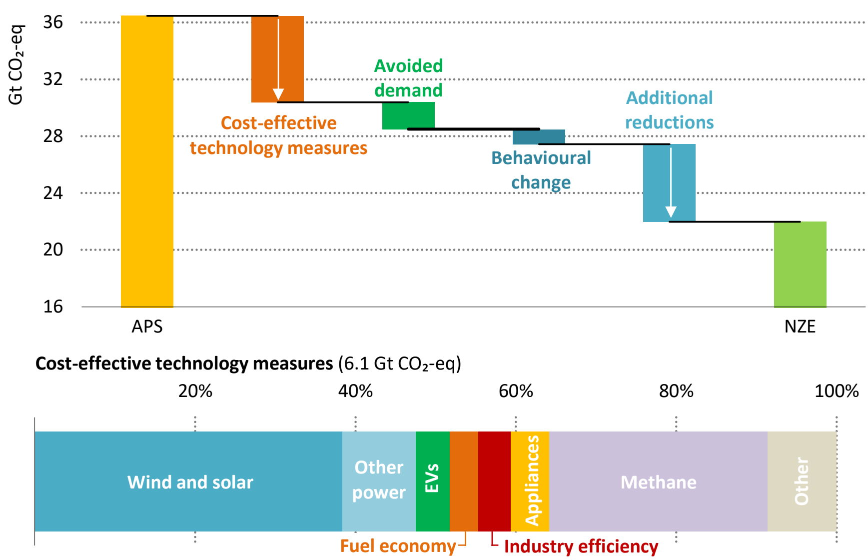
The ambition gap to 1.5 °C

An energy guidebook for COP26

SUMMARY

- Announced net zero pledges and updated Nationally Determined Contributions have been fully incorporated into the IEA's new Announced Pledges Scenario (APS). The APS closes less than 20% of the gap in 2030 between the Stated Policies Scenario (STEPS) and the Net Zero Emissions by 2050 Scenario (NZE), leaving an "ambition gap" of 12 gigatonnes (Gt) CO_2 that needs to be closed to put the world on the pathway to reach net zero emissions by 2050. Including fossil fuel methane emissions increases the gap to 14 gigatonnes of carbon-dioxide equivalent (Gt CO_2-eq).
- Over 40% of this gap between the APS and the NZE pathway could be bridged with cost-effective technology measures, and an additional 25% could come from measures to temper demand, including materials efficiency and digitalisation.

Figure 3.1 ⊳ Breakdown of measures to close the ambition gap by 2030



Over 40% of the 2030 ambition gap between the APS and NZE can be closed with cost-effective technology measures

- Accelerating the decarbonisation of the electricity sector is the single most important way to close the 2030 ambition gap, and could cut emissions by around 5 Gt. We estimate that up to 60% of the gap in the electricity sector can be closed through cost-effective expansion of wind, solar photovoltaics (PV), hydro and nuclear power, reducing the need for coal by 350 gigawatts (GW) by 2030 compared with the APS.

Stopping all new investment decisions in coal would cancel the construction of 200 GW and avoid 0.8 Gt of CO_2 emissions in 2030. Another 150 GW of coal capacity could be closed at no cost to consumers in addition to the 480 GW retired in the APS to 2030.

- Reducing methane emissions is also a critical lever to close the 2030 ambition gap. Fossil fuel methane emissions are almost 2 Gt CO_2-eq higher in the APS than in the NZE in 2030, largely because about 60% of current methane emissions come from countries without net zero pledges.[1] We estimate that almost 1.7 Gt CO_2-eq of this gap could be closed cost-effectively in the NZE by 2030.
- Energy efficiency in end-use sectors and measures to reduce demand together could contribute to cut about 2.6 Gt of the ambition gap. We estimate that almost 80% of the energy efficiency potential in the NZE could be achieved cost-effectively by 2030. Key measures include stronger standards for fuel economy and appliance efficiency, as well as more robust policy emphasis on materials efficiency in industry.
- Electrification, hydrogen and carbon capture, utilisation and storage (CCUS) account for a bit less than 2 Gt of the emissions reductions gap between the APS and NZE by 2030. Making the most of the increasing cost-effectiveness of electric vehicles (EVs) in all regions could lead to 60 million more electric cars on the road in 2030 than under announced pledges. Innovative technologies for iron and steel production based on hydrogen or CCUS remain expensive by 2030, but pushing their deployment to NZE levels in the short term is an investment that accelerates innovation and enables 660 million tonnes (Mt) of steel to be produced cost-effectively using these technologies in 2050, almost four-times more than in the APS.
- Although electrification, hydrogen-based fuels, CCUS and carbon removal are responsible for only 15% of the ambition gap in 2030, they account for 40% of the gap between the scenarios in 2050. Announced pledges included in the APS lag far behind key NZE milestones related to the deployment of these technologies. The gap can be closed with “breakthrough programmes” in areas like electrification, hydrogen-based fuels, CCUS and carbon removal, extra funding for demonstration projects, and enhanced international co-operation on innovation.
- Bridging the ambition gap from the APS to the NZE by 2030 would require an increase of clean energy investment of about USD 1.7 trillion, relative to the APS. 70% of this would go to emerging market and developing economies. Well over USD 1 trillion of the additional investment would be to support measures that are cost-effective in 2030. Public finance plays a catalytic role in mobilising finance in the NZE: annual clean energy investments by domestic and international public finance institutions in emerging market and developing economies total at least USD 65 billion under announced pledges, but this rises to over USD 200 billion by 2030 in the NZE.

[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).

3.1 Introduction

The 26th Conference of the Parties (COP26) to the United Nations Framework Convention on Climate Change (UNFCCC) takes place in November 2021 in Glasgow, having been postponed from 2020 due to the Covid-19 pandemic. It comes five years after the entry into force of the Paris Agreement, and provides a critical opportunity to strengthen the ambition of the global response to climate change. The COP26 Presidency has set a number of key objectives for the meeting:

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- Gather new 2030 emissions reduction pledges from countries, in line with the goal of net zero emissions by 2050.
- Strengthen national adaptation efforts and enhance international collaboration on enabling adaptation.
- Deliver on developed countries' pledge to mobilise USD 100 billion in annual financial support for developing countries.
- Finalise the detailed rulebook for the Paris Agreement and enhance collaboration between governments, business and civil society to enable climate action in key sectors.

In advance of COP26, the Intergovernmental Panel on Climate Change (IPCC) released the first volume of its Sixth Assessment Report, *Climate Change 2021: The Physical Science Basis* (IPCC, 2021). The report confirms that the global surface temperature has already warmed by 1.1 degrees Celsius (°C) compared to the pre-industrial era. Stabilising the global surface temperature requires achieving net zero CO_2 emissions together with sharp reductions in other greenhouse gas (GHG) emissions. The remaining carbon budget for limiting warming to 1.5 °C (with a 50% probability) will last only around 11 years at the current rate of emissions. The report highlighted the observed increases in extreme weather events such as heat waves, floods, droughts and storms, and the growing robustness of scientific attribution of such events to climate change caused by humans.

A rising number of countries have announced new long-term net zero pledges or submitted updated Nationally Determined Contributions (NDCs) to the UNFCCC in the run up to COP26, or both. This chapter explores to what extent these announced ambitions and targets, including the most recent ones, will deliver the emissions reductions required to achieve net zero emissions by 2050. It examines actions that could help to close the gap between current stated ambitions and the net zero emissions pathway, and suggests cost-effective measures that our analysis identifies as priorities.

The "ambition gap" represents the divergence between current ambitions and the pathway to achieve net zero emissions by 2050. The focus in this chapter is the ambition gap between the Announced Pledges Scenario (APS) and the Net Zero Emissions by 2050 Scenario (NZE). There is also a gap between stated policy targets and current measures, referred to as the "implementation gap", which is analysed as the divergence between the Stated Policies Scenario (STEPS) and the APS and is presented in Chapter 4. Together the ambition and implementation gaps define the actions required to transition from current measures as reflected in the Stated Policies Scenario to the realisation of the Net Zero Emissions by 2050 Scenario.

Chapter 3:

- Provides an overview of the NZE to give context for the discussion of the ambition gap (section 3.2).
- Summarises the analysis of the ambition gap and highlights four key points for policy makers (section 3.3).
- Examines in detail the ambition gap in the electricity sector (section 3.4).
- Examines in detail the ambition gap in end-use sectors (industry, transport and buildings) (section 3.5).
- Discusses the critical issue of reducing fossil fuel methane emissions (section 3.6).
- Considers the role of behavioural change in the NZE pathway (section 3.7).
- Considers the consequences of the ambition gap for the achievement of the UN Sustainable Development Goals related to air pollution (section 3.8).

3.2 Achieving net zero emissions by 2050

The NZE is designed to reach net zero CO_2 emissions from energy and industrial processes by 2050, without offsets from other sectors, while ensuring secure energy supplies, economic growth and development (IEA, 2021a). The NZE stays within the remaining cumulative emissions budget of 500 gigatonnes (Gt) from 2020 onwards, consistent with a 50% chance of limiting warming to below 1.5 °C (IPCC, 2021).[2] The NZE is a path towards net zero emissions by 2050: it is far from being the only possible path. We know that the real-world transition is sure to involve surprises in terms of technologies, policies and behaviours.

In addition to the objective of net zero emissions by 2050, several other principles guided the design of the NZE:

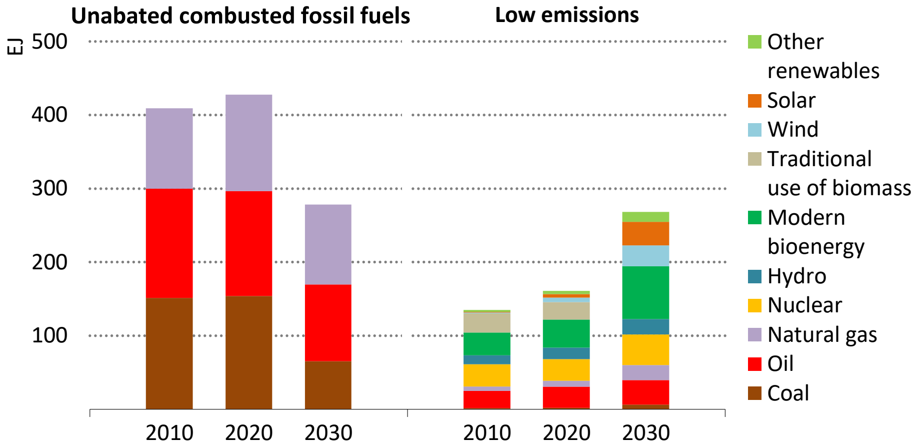
- It draws on all available technologies and emissions reduction options, including those currently at demonstration or prototype stage. It does not entail the adoption of technologies that are not currently known and understood today, but does assume a significant shortening of the time to large-scale deployment for technologies currently under development. The NZE also aims to limit, as far as possible, the deployment of negative emissions technologies.
- It requires substantial international co-operation, with all countries contributing to the net zero goal (Box 3.1). Co-operation accelerates technology innovation and diffusion, and facilitates emissions reductions in emerging market and developing economies.
- It aims to ensure an orderly transition, including by maintaining energy security, minimising energy market volatility and avoiding stranded assets where possible.

[2] This budget is based on Table SPM.2 of the 2021 IPCC report of Working Group 1 (IPCC, 2021). The size of the remaining CO_2 budget for limiting temperature rise to a given level is impacted by the trajectory of non-CO_2 greenhouse gas emissions.

- An equitable transition is central to the NZE. While advanced economies reach net zero emissions before emerging market and developing economies in the NZE, the pathway also achieves full energy access and significant reductions in air pollution as set out in the UN Sustainable Development Goals, and ensures that energy affordability is maintained.

At the heart of the NZE is a massive transition in the way we produce and consume energy (Figure 3.2). Global GDP grows by around 40% between 2020 and 2030, but total energy supply falls by around 7%. Electrification of end-uses, more efficient energy technologies and behavioural change enable a decoupling of economic growth from energy demand. Low emissions sources of energy supply grow by two-thirds between 2020 and 2030. The expansion of solar, wind, and modern bioenergy is particularly significant, while hydropower and nuclear also contribute. Today about one-quarter of total energy supply is from low emissions energy sources and this expands to around one-half by 2030 in the NZE.

Figure 3.2 ▷ Transition in global total energy supply by source to 2030 in the Net Zero Emissions by 2050 Scenario



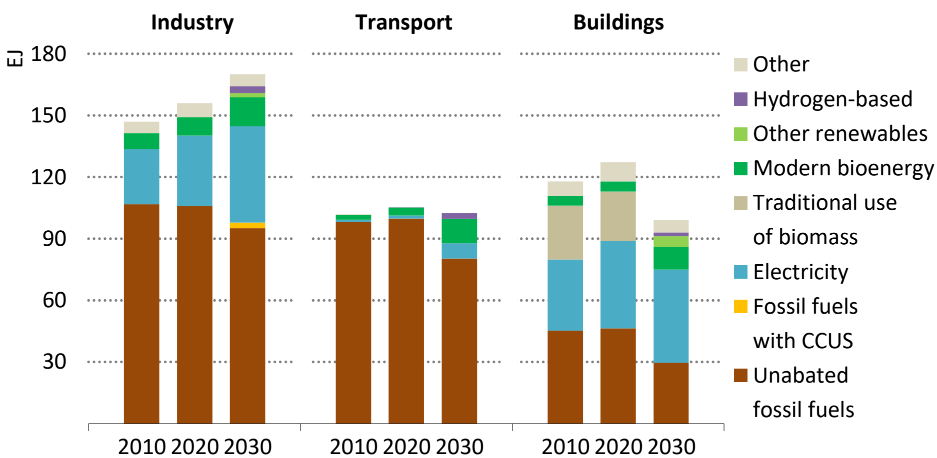
Rapid growth of low emissions energy supply sources significantly displaces unabated fossil fuels by 2030, especially coal

Notes: EJ = exajoules. Other renewables include marine and geothermal energy. Modern bioenergy includes modern solid biomass, liquid biofuels and biogases derived from sustainable sources; it excludes the traditional use of biomass. Low emissions coal, oil and natural gas include fuel combustion equipped with CCUS, as well as fossil fuel used in non-energy purposes. Non-renewable waste use is not reported.

Thanks to this growth in low emissions energy supply, demand for unabated fossil fuels declines by 30% between 2020 and 2030. Coal falls by more than 50% over this period to around 2 500 million tonnes of coal equivalent (Mtce). Oil initially rebounds from the low level seen in 2020, but it soon starts to decline and falls to 72 million barrels per day (mb/d) in 2030. Natural gas follows a slightly different trajectory, with demand increasing for several years in the 2020s before peaking and falling to 3 700 billion cubic metres (bcm) by 2030, which is below its 2020 level. As a result of the declining demand for fossil fuels, no new oil and gas fields are approved for development, and no new coal mines or mine extensions are required.

The transition on the supply side goes hand-in-hand with a rapid transition in the way we consume energy (Figure 3.3). In the NZE, electricity gains ground in all end-use sectors by 2030. In aggregate its share in total final energy consumption rises from 20% to 26% by 2030. Although this may seem like a relatively small change, it implies a rapid turnover rate for the huge global stock of energy-consuming equipment and massive growth in the sales of electric heat pumps, electric vehicles (EVs) and appliances. For example, global sales of EVs increase from 4.6% of total car sales in 2020 to around 60% by 2030.[3]

Figure 3.3 ▷ Final energy consumption by source and sector to 2030 in the Net Zero Emissions by 2050 Scenario



Electrification and the adoption of low emissions fuels accelerate in the 2020s

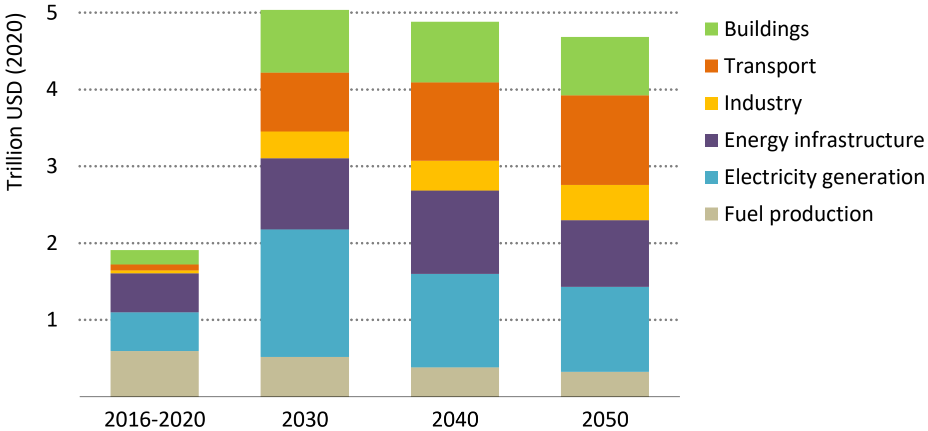
Notes: EJ = exajoules. CCUS from ammonia production is excluded from this figure as it applies to process emissions, not energy consumption.

Some new technologies and low emissions fuels that have an important future role make vital progress in the 2020s. Hydrogen-based fuels and fossil fuels equipped with CCUS account for 3% of total final consumption by 2030, up from almost nothing today. While this may sound insignificant, it is nonetheless important. Without innovation and learning-by-doing to drive down their costs over the next decade, it would be much more difficult for these technologies to ramp up after 2030 to contribute to achieving net zero energy emissions by 2050. The share of modern bioenergy more than doubles by 2030 and its growth is particularly significant in long-distance transport.

[3] EVs include battery electric and plug-in hybrid electric vehicles.

Energy efficiency, avoided demand[4] and behavioural change are essential to reducing energy demand. Between 2020 and 2030, the energy intensity of the global economy decreases by 4.2% per year in the NZE, more than double the average rate of the previous decade. Without this improvement, total final consumption would be about a third higher in 2030, significantly increasing the cost and difficulty of decarbonising energy supply.

Figure 3.4 ▷ Average annual energy investment 2016-2020, and in the Net Zero Emissions by 2050 Scenario



Meeting the accelerated decarbonisation goals of the NZE requires a surge in global energy investment to USD 5 trillion by 2030, with 85% of spending directed to clean energy

Notes: Energy infrastructure includes electricity networks, public EV charging, CO_2 pipelines and storage facilities, direct air capture facilities, hydrogen refuelling stations, import and export terminals for hydrogen, and fossil fuel pipelines and terminals. Buildings, transport and industry categories include investment in energy efficiency, electrification and end-use applications for low emissions fuels (see section 3.5).

The deployment of low emissions technologies requires a surge in energy investment (Figure 3.4). In the NZE, total energy sector capital spending increases from around 2.5% of GDP per year in recent years to around 4.5% of GDP in 2030, before easing to 2.5% in 2050. By 2030, the vast majority of investment goes towards clean energy technologies, of which the largest share is for power generation with total annual investment increasing from around USD 0.5 trillion over the past five years to nearly USD 1.7 trillion in 2030. By then, more is being invested in power generation from renewables in a single year (USD 1.3 trillion) than the largest amount ever invested in fossil fuel production in a year. The record for investment in fossil fuel supply was USD 1.2 trillion in 2014. Investment in energy infrastructure increases from around USD 0.4 trillion to over USD 0.9 trillion in 2030.

[4] Avoided demand is energy service demand changes enabled by technology developments, such as digitalisation.

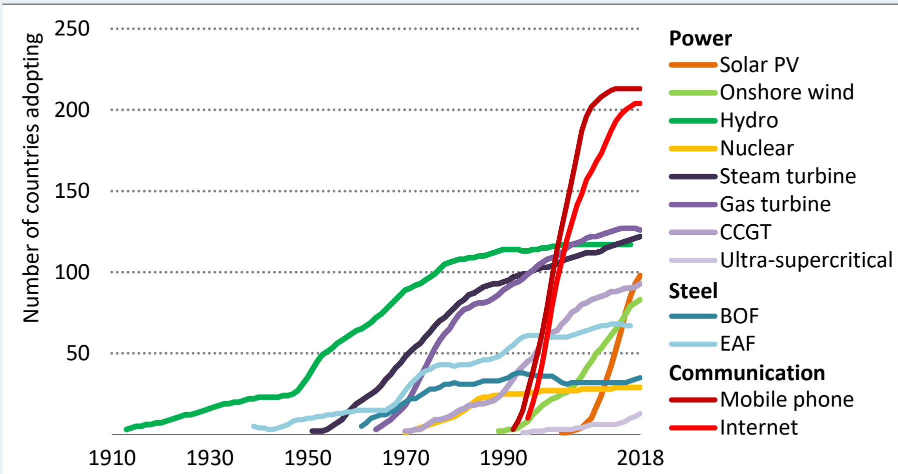
Electricity grids account for the lion's share of this, although investment in CO_2 transportation and storage, EV charging and hydrogen infrastructure also increases substantially, albeit from a low base.

Total investment in end-uses includes all investment in efficiency, electrification and the use of low emissions fuels based on hydrogen, as well as renewables and CCUS. In the NZE, these investments accelerate to USD 1.9 trillion in 2030, and continue to rise afterwards. The increase is particularly significant in transport, where the purchase of EVs drives up spending, and in buildings, where investment is driven by retrofit programmes and electrification.

Box 3.1 ▷ International technology diffusion

The NZE requires very rapid diffusion of clean energy technologies across the world. Historically, many energy technologies have diffused slowly, with substantial lags between early and late adopters (Figure 3.5). Widespread diffusion has often taken decades, with late adopters typically located in emerging market and developing economies.

Figure 3.5 ▷ Number of countries that have adopted selected energy and non-energy technologies, 1910-2018



Compared with historical rates, a substantial acceleration in international diffusion of clean energy technologies is required on the path to net zero emissions

Notes: CCGT = combined-cycle gas turbine; BOF = basic oxygen furnace; EAF = electric arc furnace. Adoption is not defined here as the first observed exploitation of the technology, but rather exploitation at or above a threshold level, defined as 3% of the maximum ever observed per capita technology exploitation of the early adopters.

Sources: IEA calculations based on data from Comin and Hobijn, (2009); Maddison Project Database, (2020); S&P Global (March 2021); WSA, (various years); World Bank, (2021).

Technologies with large unit sizes and complex installation requirements have typically diffused more slowly than technologies with small unit sizes that are relatively easy to take up. Outside the energy sector, mobile phones and the internet are good examples of technologies that have very rapidly been adopted worldwide.

In the energy sector, wind and solar PV power generation technologies have spread globally at a relatively rapid pace. Tackling climate change demands global diffusion of other low-carbon technologies at a similar pace. In the APS, however, there is a risk in that the gap between the early and late adopters of clean technologies could widen. This is particularly the case for complex technologies with large unit sizes such as CCUS, advanced bio-refineries or hydrogen use in industry, where diffusion is likely to be slower than for wind and solar PV unless strong efforts are made to accelerate diffusion. This underscores the need to strengthen co-operation to accelerate the diffusion of new clean energy technologies if the ambition gap between the APS and NZE is to be bridged.

3.3 Moving from announced pledges to achieve net zero emissions by 2050

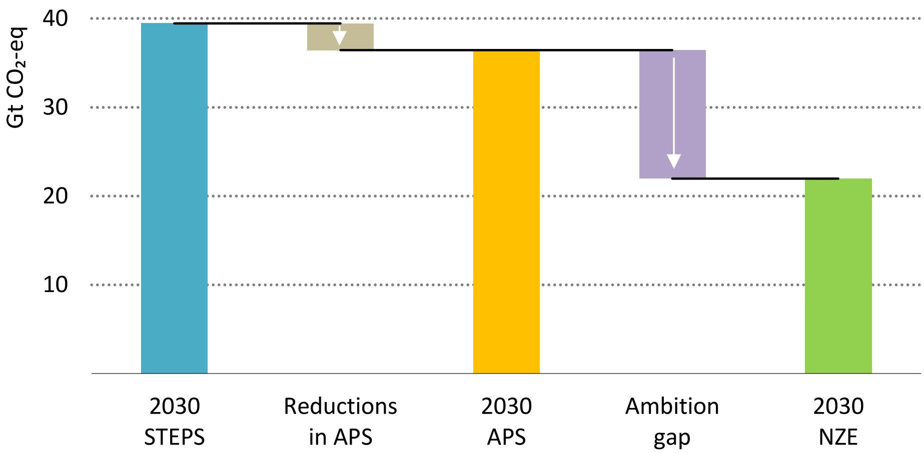
Recent announcements of net zero pledges signal an acceleration of policy ambition on climate change. Countries accounting for between 60-70% of global CO_2 emissions have announced net zero emissions pledges.[5] The APS includes all recent major national announcements of 2030 targets and longer term net zero and other pledges, regardless of whether these have been anchored in implementing legislation or in updated NDCs. It also includes all commitments made in new and updated NDCs, regardless of whether they are underpinned by specific implementation plans. According to national studies, some net zero targets include plans for offsets outside the energy sector, and these have been integrated into the design of the scenario. In the APS, countries fully implement their national targets to 2030 and 2050, and the outlook for exporters of fossil fuels and low emissions fuels like hydrogen is shaped by what full implementation means for global demand for these fuels.

Announced pledges could bridge slightly less than 20% of the gap between the Stated Policies Scenario and the Net Zero Emissions by 2050 Scenario

Total CO_2 and methane emissions reach 39 Gt CO_2-eq in 2030 in the STEPS, up from around 38 Gt in 2020. Full implementation of announced pledges lowers 2030 emissions to 36 Gt in the APS while the NZE reduces them to 22 Gt, leaving an ambition gap of 14 Gt. Full delivery of announced pledges therefore closes slightly less than 20% of the total gap between the STEPS and NZE in 2030 (Figure 3.6). This improves somewhat in the longer term, with the APS closing a little less than 40% of the gap between the STEPS and NZE in 2050.

[5] The range is determined by decisions to include or exclude countries based on the target date of the net zero pledge and the degree of commitment implied in the formulation of the pledge, e.g. draft policy document versus adopted policy document.

Figure 3.6 ▷ **CO_2 and methane emissions from energy and industrial processes in the three scenarios, 2030**



Announced pledges would close less than 20% of the gap between the STEPS and NZE

Note: STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario; NZE = Net Zero Emissions by 2050 Scenario.

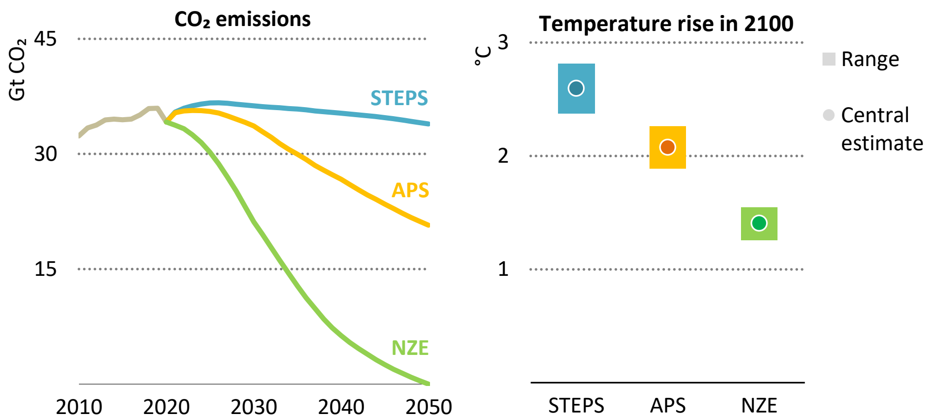
This *World Energy Outlook* (*WEO*) incorporates new analysis of the long-term temperature impacts of our scenarios using the MAGICC climate model, which has been used extensively in IPCC assessment reports (see Chapter 1 for more details). If it were to be accompanied by policies that reduce non-energy GHGs proportionately, and if emissions trends were to continue on a comparable trajectory after 2050, the STEPS would lead to a rise in global average temperatures of about 2.6 °C in 2100.[6] This falls short of the goals of the Paris Agreement to limit warming to well below 2 °C, and to pursue efforts to limit the temperature increase to 1.5 °C. The APS could lower 2100 warming to 2.1 °C, an improvement on the STEPS, but still above the Paris Agreement goals. In the NZE, warming in 2100 is kept below 1.5 °C (Figure 3.7).

All countries bear responsibility for some part of the ambition gap. Under net-zero pledges, the emissions of advanced economies with pledges do not decline in the aggregate as fast as they do in the NZE pathway. The same is true for emerging market and developing economies with pledges, notably from China and particularly over the period to 2030. Updated NDCs do not help much to narrow the gap: it has been estimated that only around 60% of new or updated NDCs submitted to the UNFCCC as of September 2021 actually represent an increase in ambition compared to the previous NDCs (Climate Watch, 2021). Countries without net zero pledges or updated NDCs include a number of large, fast growing and low income emerging market and developing economies. In these countries, transition is much faster in

[6] The temperature rise in this section refers to median warming above the 1850 -1900 average.

the NZE than in the APS, but this assumes that they introduce more stringent policies than those currently in force: it also assumes enhanced international co-operation and financial support. Taken as a group, countries with net zero pledges and countries without net zero pledges are each responsible for about half the ambition gap, indicating that all countries need to increase their level of ambition if the gap is to be closed.

Figure 3.7 ▷ Global energy-related and industrial process CO_2 emissions by scenario and temperature rise above pre-industrial levels in 2100



Announced pledges would not meet the Paris Agreement temperature goals

Notes: Central estimate = median temperature in 2100. Range = 33rd – 67th percentile.

Box 3.2 ▷ The global significance of China's net zero pledge

China is the world's largest energy consumer and carbon emitter. In September 2020, the Chinese president announced China's aim to have CO_2 emissions peak before 2030 and to achieve carbon neutrality before 2060.

A pathway towards this vision is the focus of a recent collaboration between the IEA and leading energy experts in China, reported in *An Energy Sector Roadmap to Carbon Neutrality in China* (IEA, 2021c). This pathway, reflected in the APS, has China's emissions peaking near 2030 in line with its current commitments.

The "China Roadmap" explores opportunities for China to narrow this gap in 2030 by accelerating near-term actions, which could facilitate reaching its NDC aim of making "best efforts to peak early" and provide more flexibility after 2030 as China strives to reach net zero emissions by 2060.

An accelerated trajectory is attainable. If China meets its non-binding target to raise the non-fossil fuel share of total energy supply to 20% by 2025 (from around 16% in 2020), the IEA projects that CO_2 emissions from fuel combustion will be on track to plateau in the mid-2020s and decline modestly to 2030. In both the APS and the accelerated trajectory, energy sector investment climbs significantly in absolute terms, but falls as a share of overall economic activity.

Accelerated action would bring substantial benefits for China. It would further its central role in global clean energy technology value chains and support its emerging position as a world leader in clean energy innovation and the new energy economy. While accelerated action would lead to the loss of 2.3 million jobs in fossil fuel supply and fossil fuel power plants, it would also increase employment in China's clean energy supply by 3.6 million by 2030: the 1.3 million net increase in jobs is three-times that in the APS.

A faster transition would also avoid around 20 Gt of locked in emissions to 2060 from long-lived assets in the power and industry sectors that the APS sees built in the period to 2030. As a result it would reduce by nearly 20% the required average annual pace of emissions reductions after 2030 to reach carbon neutrality by 2060, compared with the APS, leaving more time for markets to adjust, and businesses and consumers to adapt. Beyond the direct impact on emissions, an accelerated transition in China could have a significant impact on innovation, given China's size and industrial strength, and thus facilitate a faster global transition.

Electricity sector decarbonisation is the biggest single lever for closing the 2030 ambition gap

In the APS, total electricity sector CO_2 emissions fall slightly less than 20% from 2020 to 2030, all from countries with net zero pledges, while those without such pledges increase their electricity sector emissions in aggregate. Despite the nearly 20% fall, electricity sector emissions in the APS are around 5 Gt higher in 2030 than in the NZE, which means that the electricity sector accounts for around 35% of the 2030 ambition gap between the APS and NZE scenarios.

Emerging market and developing economies account for the vast majority of this ambition gap in the electricity sector. This reflects the fact that coal tends to dominate the electricity sector in emerging market and developing economies, while most advanced economies have made net zero pledges and start from electricity sectors less reliant on coal. To close the gap, the annual rate of global wind and solar PV capacity additions from 2021 to 2030 would need to be almost twice as high as it is in the APS.

The accelerated electricity sector transition in the net zero pathway requires a large increase in investment in generation and networks in the current decade, compared to the levels seen in the APS. However, low technology costs and the availability of low cost financing in many markets means that policy makers could establish enabling conditions in which up to 60% of the additional generation of solar and wind in the NZE could be achieved at no additional cost to consumers (Figure 3.8). Additional cost-effective measures related to hydropower, nuclear lifetime extensions and some new nuclear projects could displace up to an additional 1 000 terawatt-hours (TWh) of coal- and gas-fired generation in 2030.

We calculate that about 2.3 Gt CO_2 emissions could be cut in 2030 at no cost to electricity consumers by deploying cost-effective wind and solar PV, closing about half of the emissions gap between the APS and NZE in the electricity sector. An additional 0.6 Gt of emissions reductions could be achieved through other cost-effective measures relating to hydropower, nuclear lifetime extensions and new nuclear in some markets.

Section 3.4 examines the electricity sector transition in the APS and NZE in more detail, and explores policy options to accelerate it in line with the NZE pathway.

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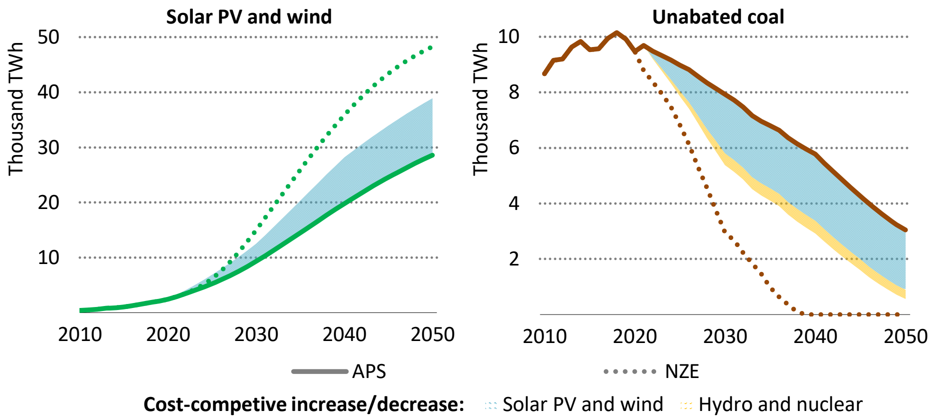
Figure 3.8 ▷ Global solar PV, wind and unabated coal-fired electricity generation in the Announced Pledges and Net Zero Emissions by 2050 scenarios



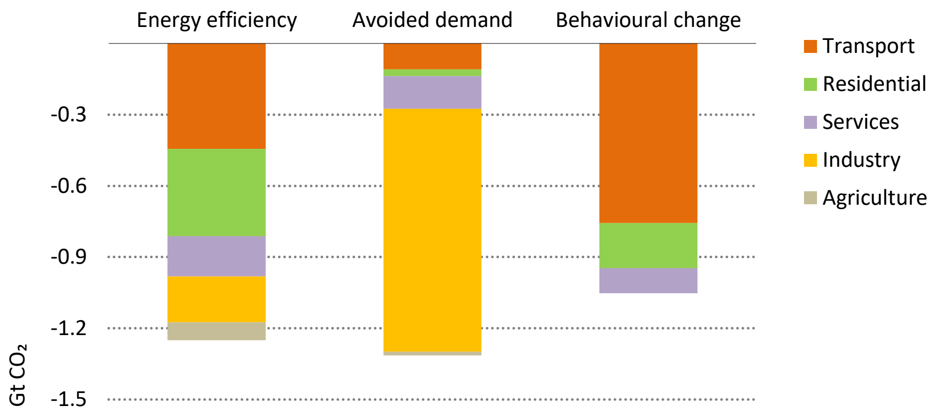
By 2030, 60% of the increase in solar and wind generation seen in the NZE could be achieved at no additional costs to consumers

Note: Cost-effective solar PV and wind are evaluated based on total system costs (Box 3.5).

Energy efficiency and avoided demand are essential to bridge the ambition gap

Much stronger policies for end-use energy efficiency in the NZE reduce emissions by about 1.3 Gt in 2030, compared with the APS, and are of particular importance in the transport and buildings sectors. We estimate that almost 80% of the energy efficiency potential in the NZE could be achieved cost-effectively by 2030. Avoided demand through measures such as digitalisation and materials efficiency helps to reduce emissions by a further 1.3 Gt in 2030. The largest share is in the industry sector, where opportunities for materials efficiency are substantial. In the short term, this helps to compensate for the fact that the industry sector has fewer energy efficiency opportunities, and low emissions technologies are less mature in industry than in most other sectors. Behavioural change contributes a bit more than 1 Gt by 2030 to closing the emissions gap, particularly in the transport sector (Figure 3.9).

Figure 3.9 ▷ Emissions reductions from end-use efficiency, avoided demand and behavioural change in 2030 between the Announced Pledges and Net Zero Emissions scenarios



Energy efficiency improvements and avoided demand would close almost 20% of the ambition gap between the APS and NZE, while behavioural change also plays a role

Note: includes CO_2 emissions reductions in industrial processes due to avoided demand.

More vigorous action in energy efficiency would therefore close about 10% of the ambition gap, and additional measures to avoid demand would close a further 10%. However, the importance of these measures goes beyond emissions reductions. Lower demand reduces the amount of low emissions energy that must be supplied, helps to lower the overall costs of transition and increases the resilience of the energy system.

Box 3.3 ▷ Cost-effectiveness analysis of options to close the ambition gap

The modelling of the Announced Pledges and Net Zero Emissions by 2050 scenarios allow us to identify the levers that reduce emissions at the level of sectors, technologies and policy options. Detailed investment and fuel expenditure data for many of these levers enable a comparison of costs between the APS and NZE. These comparisons assume enabling policies consistent with the level of policy stringency in the NZE. It should be noted that the comparisons of the two scenarios do not take into account the co-benefits of climate action, such as improvements in air pollution or the long-term benefits of mitigating climate change.

For end-use technology options such as EVs, a total cost of ownership or levelised cost of production approach is employed, which takes into account investment and discounted fuel expenditure for the lifetime of the equipment. For energy efficiency options, we compare annuitised investment with fuel expenditure at the sub-sectoral level to identify which measures are cost-effective. All analysis is at the country or regional level, taking into account country or regional investment costs, fuel prices and policies.[7] A total system cost approach is used for the electricity sector, taking account of investment, fuel, balancing and transmission costs (see Box 3.5 for detail).

The assessment of the cost-effectiveness of materials efficiency, digitalisation and other measures which lead to avoided demand is handicapped by the lack of granular data on the investment costs of mitigation options. For example, it was not possible to assess the investments needed to raise the plastic recycling rate, increase steel scrap recycling or promote clinker substitution. For this reason, avoided demand measures are not shown under the heading of cost-effective technology measures in Figure 3.1, although many of these measures would probably cut emissions cost-effectively. The same issue arose for behavioural measures; therefore they are not included in our assessment of cost-effective options.

Some technologies fall far behind in the APS by 2030, risking the 2050 net zero goal

After 2030, end-use sectors decarbonise in the NZE by switching to the use of electricity, hydrogen-based fuels, CCUS in industry, or advanced bioenergy. CCUS is critical to addressing process emissions from cement, natural gas-based hydrogen and biofuel production, for the production of synthetic fuels, and to reach negative emissions from bioenergy with carbon capture and storage and direct air capture with storage. In the electricity sector, most of the heavy lifting is done by renewables in the NZE, but bioenergy, CCUS and hydrogen-based fuels play a critical role in providing low-emissions dispatchable capacity and delivering negative emissions when CCUS is combined with bioenergy.

These emissions reduction options contribute only around 15% to closing the ambition gap between the APS and NZE by 2030. However, their contribution increases after 2030 and accounts for around 40% of the emissions reductions between the two scenarios by 2050. In the NZE, measures to promote the electrification of heavy-duty transport and industry, and the use of hydrogen, ammonia and CCUS, require immediate efforts to bring down costs and build enabling infrastructure. If the deployment of these options is not accelerated in the current decade, the impact on 2030 emissions may be small, but the risk to the feasibility of net zero emissions by 2050 would be substantial.

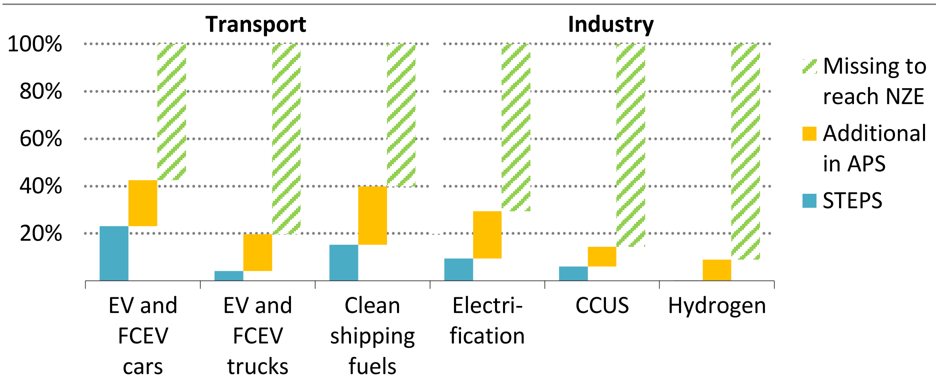
It is therefore a matter of concern that some of the emissions reductions options that are most off-track in the APS by 2030 are those related to electrification, hydrogen-based fuels and CCUS, particularly in the hard-to-abate sectors (Figure 3.10) (Box 3.4 details the milestone comparison method). By 2030, the APS only achieves 40% of the level of deployment of clean shipping fuels seen in the NZE, less than 15% of the level of deployment of CCUS in industry, and less than 10% of the deployment of hydrogen in industry.

Deployment targets and more substantial funding for research and development (R&D) are essential to drive down the costs and bring forward the availability of technologies critical to

[7] The IEA World Energy Model represents the largest countries individually and smaller countries as regional aggregates.

long-term decarbonisation. 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. Robust policy monitoring is also important in order to ensure that technologies are on track and also to enable learning-from-experience in sectors where innovation is still needed.

Figure 3.10 ▷ Tracking progress towards 2030 milestones in transport and industry by scenario



A number of key milestones in the NZE related to clean energy transitions in end-uses significantly lag in the APS

Notes: The 2030 milestones are those set out in the Net Zero Emissions by 2050 Scenario. EV = electric vehicles, FCEV = fuel cell electric vehicles. Clean shipping fuels include biofuels, electricity and hydrogen-based fuels. Low-carbon hydrogen is deployed in the STEPS in industry, but in such small quantities relative to the NZE milestones that it is barely visible when indexed to the NZE.

Box 3.4 ▷ Measuring progress towards 2030 milestones in the *WEO* scenarios

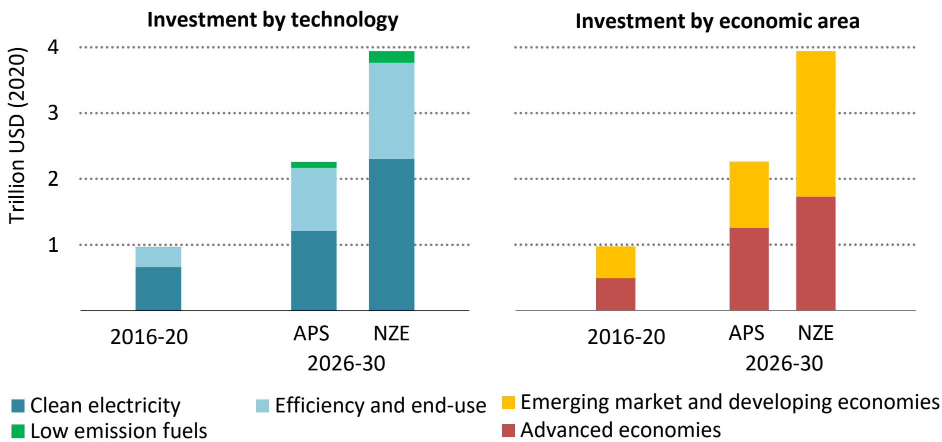
A number of figures in this chapter, e.g. Figure 3.10, present a comparison of key 2030 NZE milestones relative to the STEPS, APS and NZE scenarios. Each milestone is represented as an index in the figures, with the NZE value at 100%. This allows milestones with different units to be shown on the same figure. For each milestone the index is calculated as the change over the period 2020 to 2030, rather than the 2030 value alone. This gives a better indication of the change required to reach the milestones.

For example, the share of electricity in total final consumption in 2030 in the APS is 22% compared with 26% in the NZE. At first glance, this might suggest that there is not much difference between the APS and the NZE on this score. However, the increase from 2020 to 2030 in the share of electricity in total consumption is only two percentage points in the APS (from 20% to 22%) compared with six percentage points in the NZE (from 20% to 26%). The APS thus achieves only about one-third of the increase in electrification from 2020 to 2030 that is achieved in the NZE. Calculating the change in this indicator therefore provides a better indication of the degree to which electrification lags in the APS compared to the NZE.

An additional USD 1.7 trillion of annual clean energy investment is required to achieve the NZE, 70% of which needs to occur in emerging market and developing economies

The APS sees substantial growth in annual clean energy investment, reaching around USD 2.3 trillion by 2030. This is a major step up from the level of recent years. But it still falls well short of the level of clean energy investment seen in the NZE, which rises to around USD 4 trillion annually by 2030 (Figure 3.11). The largest investment gaps in moving from the APS to NZE are in clean power (generation and grids), where annual spending is USD 1.1 trillion higher in the NZE, and in energy efficiency and end-use decarbonisation, where annual spending is over USD 0.5 trillion higher. Investment in low emissions fuels in the NZE is only around USD 0.1 trillion higher than the APS by 2030, but it sees the fastest growth among all areas of clean energy investment.

Figure 3.11 ▷ Average annual investment in clean energy by type and economic area, 2016-2020, and by scenario, 2026-2030



Clean energy investment in the NZE is 75% higher than in the APS, with around 70% of the extra investment needed in emerging market and developing economies

Emerging market and developing economies account for around 70% of the extra investment in clean energy that is required to bridge the gap from the APS to the NZE by 2030. Over 60% of this increment comes from the private sector in the NZE. Mobilising this scale of capital will require significant policy efforts to address project risks and ensure adequate risk-adjusted returns for developers, banks and investors, including through commercial arrangements that support predictable revenues, enhanced creditworthiness of counterparties and enabling infrastructure, among other factors.

Although private finance accounts for most clean energy investment, public sources of capital play a particularly important role in catalysing investment in markets where access to capital is constrained, in sectors lacking bankable projects, and in funding energy infrastructure. Around two-thirds of the additional publicly sourced investment in emerging market and developing economies required in the NZE comes from domestic state-owned enterprises, which play a particularly important role in developing electricity grids. Public finance institutions, including international development banks and domestic green banks, account for the remaining one-third of the additional public investment required. Annual clean energy investments by domestic and international public finance institutions in emerging market and developing economies rise to more than USD 200 billion in 2030 in the NZE, compared with at least USD 65 billion in the APS.[8]

3.4 Electricity sector

Current status and gap to NZE

Global CO_2 emissions from electricity generation increased by just 9% over the last decade even though electricity demand rose by 25%. Renewable energy technologies collectively met almost 65% of electricity demand growth over the decade, led by the rapid expansion of solar PV and wind as their deployment increased fivefold. Innovation and low cost finance have helped drive down the costs of solar PV and wind, and they are now the cheapest new sources of electricity in most markets. Coal-to-gas switching, particularly in the United States, also curbed electricity sector emissions.

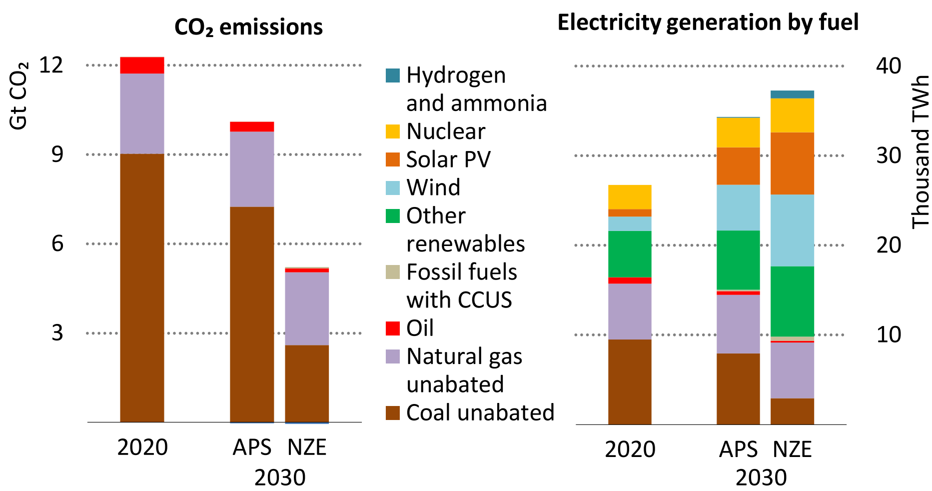
Nevertheless, the electricity sector was responsible for 12.3 Gt CO_2 emissions in 2020, or 36% of all energy-related CO_2 emissions. Coal contributed just over one-third of electricity supply but around three-quarters of electricity sector CO_2 emissions. Natural gas was the second-largest source of both electricity and CO_2 emissions in the sector.

In the APS, electricity demand increases from around 23 300 TWh today to about 30 300 TWh by 2030, an increase of 30%, while global CO_2 emissions from electricity generation fall by around 18% to 10.1 Gt in 2030 (Figure 3.12). The major drivers of demand growth are growth in all end-use sectors and the production of low-carbon hydrogen, which goes from almost nothing today to some 540 TWh by 2030.

In the NZE, total electricity demand rises to about 33 200 TWh in 2030, almost 10% higher than in the APS. Electricity demand for low-carbon hydrogen production increases to 3 850 TWh by 2030 in the NZE, more than seven-times the level in the APS, and electricity demand in the transport and industry sectors is higher in the NZE than in the APS. However, the more significant effort on energy efficiency in the NZE, notably in the buildings sector, helps to offset the effects of increasing electrification and hydrogen production. Electricity sector emissions drop to 5.1 Gt in 2030 in the NZE, making the ambition gap around 5 Gt. Emissions from coal-fired power plants decline by about 70% to 2030 compared with an 18% reduction in the APS.

[8] Public finance institution spend includes primary finance for clean energy projects (debt, equity, grants), but does not include flows to financial intermediaries, guarantees or indirect means of public participation, such as technical assistance. The estimate here differs from official climate finance provided and mobilised by developed countries for developing countries -– which includes bilateral or multilateral development funding specifically targeted at climate change mitigation and adaptation – in both scope and measurement approach.

Figure 3.12 ▷ Global electricity sector CO_2 emissions and generation by source in the Announced Pledges and Net Zero Emissions by 2050 scenarios



Clean electricity transitions accelerate in the APS, though unabated fossil fuels are only cut by 10% to 2030, leaving a 5 Gt emissions gap with the NZE, the largest of any sector

Note: Other renewables include hydropower, bioenergy, marine and geothermal energy.

Beyond 2030, emissions from electricity generation steadily decline to 4.8 Gt by 2050 in the APS, of which unabated coal-fired power plants account for over 2.7 Gt. In the NZE, the electricity sector reaches net zero emissions globally by 2040.

Renewables are set to become the foundation of electricity systems around the world. Over the next decade, announced pledges drive a renewables expansion that is fast enough to keep pace with electricity demand growth and reduce the need for fossil fuels in electricity. The share of renewables increases from almost 30% of global electricity generation in 2020 to about 45% in 2030 in the APS. At that point, the share of renewables in generation exceeds that of fossil fuels, although it is still around fifteen percentage points short of the level reached in the NZE.

Solar PV and wind lead the way, thanks to low costs, widespread availability and policy support in over 130 countries: their capacity more than triples over the next decade, which is nearly enough to meet all electricity demand growth to 2030, and their share of generation rises from under 10% in 2020 to nearly 30% in 2030. Other commercial technologies – hydropower, bioenergy and geothermal – also contribute to the expansion of renewables, while earlier stage technologies such as concentrating solar power and marine power gain a foothold.

Other low emissions sources increase their output by over 800 TWh over the next decade in the APS, complementing the growth of renewables. Nuclear power capacity in operation expands by over 10% by 2030 in the APS, with 25 countries completing new reactors. This more than offsets retirements of ageing reactors, mainly in advanced economies. In the NZE, further efforts to extend the safe operation of existing reactors and accelerate new builds in countries favourable to nuclear power raise its output by another 15% by 2030. Beyond 2030, advanced nuclear power technologies such as small modular reactors expand opportunities for nuclear to produce low emissions electricity, heat and hydrogen.

Fossil fuel power plants equipped with CCUS together with those equipped to use hydrogen and ammonia contribute around 230 TWh of electricity generation by 2030 in the APS. This puts them in a position to make more significant contributions beyond 2030. In the NZE, the unprecedented pace of innovation and uptake sees their contribution by 2030 rise to 1 300 TWh, or 4% of total generation, putting them in a stronger position to make additional long-term contributions to clean energy transitions after 2030.

Global unabated coal-fired electricity generation falls by around 15% from 2020 to 2030 in the APS as low emissions sources of generation are scaled up. In advanced economies, where over 20 countries have announced or are considering to phase out its use, unabated coal-fired generation falls by three-quarters from today's level to 2030, led in particular by the United States and European Union. The shift away from coal is more challenging in fast growing emerging market and developing economies. China remains the largest user of unabated coal in the electricity sector in the APS, accounting for nearly 60% of the global total in 2030. India and Southeast Asia are the next largest users of unabated coal, and are responsible for about 15% and 10% of global use for electricity generation in 2030.

Natural gas is the largest source of electricity in advanced economies today, and the growth of renewables in the APS drives down emissions in part by reducing unabated natural gas-fired generation by 20% from 2020 to 2030. This is, however, well short of the 30% reduction in the NZE. In emerging market and developing economies, unabated natural gas-fired generation increases by about one-third to 2030 in both the APS and NZE. Gas-fired capacity remains an important part of electricity system flexibility in all scenarios to 2050, though the amount of unabated natural gas-fired generation varies widely. It continues to rise in the APS, while falling by 95% on the path to net zero emissions in 2050.

Closing the gap from the APS to the NZE

Bridging the gap between the APS and NZE scenarios in the electricity sector requires policy makers to take action to:

- Scale up the supply of low emissions electricity from wind and solar.
- Accelerate the deployment of dispatchable sources of low emissions electricity such as hydropower and nuclear.
- Stop investment in new unabated coal-fired power plants, while retrofitting, repurposing or retiring existing unabated fossil fuel plants.
- Enhance the flexibility of electricity systems to accommodate high shares of variable renewables.

Accelerating the growth of renewables and other low emissions sources of electricity is the most important step in closing the gap from the APS to the NZE in the electricity sector. Renewables-based generation needs to increase by 12% each year over the next decade in the NZE, compared with 8% per year in the APS. Building on the record level of 248 GW achieved in 2020, solar PV and wind capacity additions reach almost 470 GW in the APS in 2030, but exceed 1 000 GW in the NZE. As a result, global electricity generation from solar PV and wind is 60% higher in the NZE than in the APS.

Given their low technology costs and the availability of low cost financing in many markets, we estimate that up to 60% of the additional solar PV and wind generation between the APS and NZE in 2030 would be cost-effective, and could be enabled by policy levers without raising total system costs or consumer electricity prices (Box 3.5). The related impact on fossil fuels would close 2.3 Gt of the ambition gap. We also estimate that other cost-effective measures related to hydropower, nuclear lifetime extensions and new nuclear power in some markets could close a further 0.6 Gt of the ambition gap.

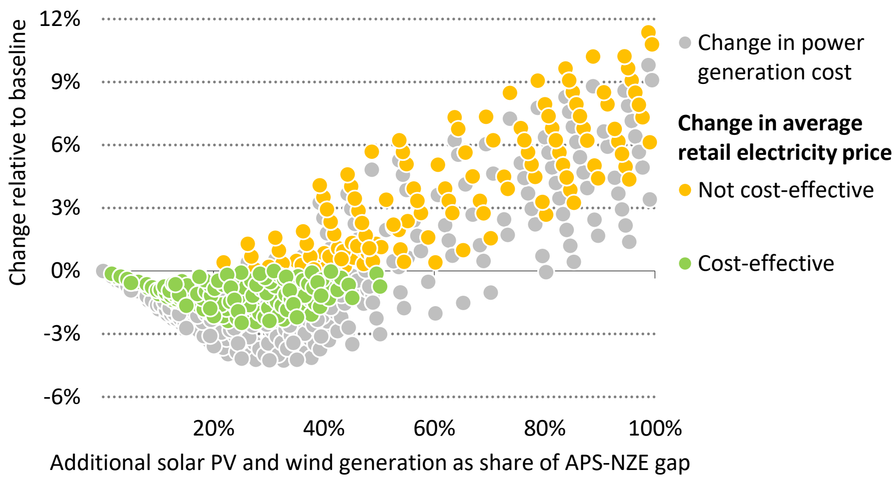
Box 3.5 ▹ Evaluating the cost-effective share of wind and solar expansion

The cost-effective expansion of wind and solar PV was evaluated based on simulated end-user electricity prices in the World Energy Model (WEM), which reflects total power system costs including investment, fuel, operation and maintenance, balancing and grid costs. The exercise considered how much additional wind and solar PV would be cost-effective if the enabling conditions in the NZE were applied, including those related to fuel and CO_2 prices and expanding the availability of low cost financing for wind and solar PV.

Starting from the Announced Pledges Scenario, over 400 additional model runs were performed for each of the 26 WEM regions, steadily increasing the contribution of solar PV and wind up to the amount in the NZE. The additional solar PV and wind generation displaced coal- and gas-fired generation based on their operating costs, simulated operations and presence in each region. Based on their simulated contributions to system adequacy, the additional solar PV and wind capacity also displaced the need for some fossil-fuelled capacity built in the APS.

The evaluation revealed that up to 60% of the worldwide additional wind and solar PV generation in the NZE relative to the APS in 2030 would be cost-effective where policy makers created an environment that enabled this to happen. For example, up to about 50% of the additional wind and solar PV that features in China in 2030 in the NZE could be added without increasing average electricity prices (Figure 3.13). In other words, half of the gap between the APS and NZE in the deployment of wind and solar PV in 2030 in China could be closed without raising costs to consumers. It is particularly important to consider the total system costs when evaluating cost-effectiveness in the electricity sector. If the evaluation had been based on total generation costs that exclude grid-related costs, for example, the amount of cost-effective solar PV and wind would have been exaggerated. Similarly, a focus on technology costs alone would have failed to capture many essential system dynamics and might have provided a misleading assessment.

Figure 3.13 ▷ Change in electricity prices and generation costs for additional solar PV and wind generation in China, 2030



About 50% of the additional wind and solar generation in China in the NZE is cost-effective, provided policy makers establish enabling conditions

Scaling up the market for renewables starts with policy frameworks that provide a clear long-term vision, encourage competition and limit risks for investors throughout the supply chain, from equipment manufacturing to project developers and off-takers. For example, well-planned auction schemes and renewable energy mandates have emerged as effective and efficient approaches in many markets to expand renewable energy. At the same time, action to strengthen the financial health of the sector, including regulations to ensure appropriate cost recovery, is essential to limit off-taker risk for new projects. Electric utilities and distribution companies face financial difficulties in several emerging market and developing economies, notably in India and Africa.

The pace of nuclear power expansion can also be accelerated in the short term, though to a lesser degree, given the length of time it takes to build new nuclear power plants. Annual additions of nuclear power increase from an average of 7 GW from 2016-20 to 23 GW in 2030 in the APS. This is a major achievement, but still short of the 33 GW added in 2030 in the NZE. Retrofitting coal- or gas-fired capacity with CCUS is an important way to help existing fossil fuel power plants contribute to clean energy transitions, and completing the retrofit of 15-25 large projects each year in the second-half of the 2020s would be consistent with the pathway to net zero emissions electricity systems.

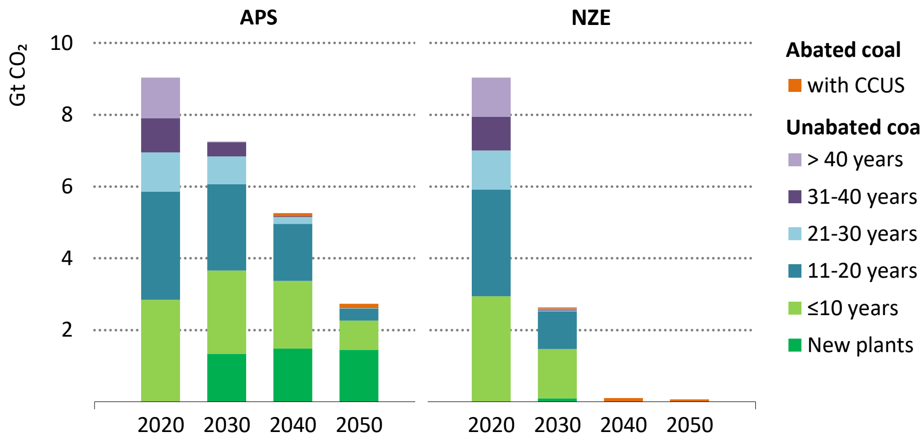
Expanding other low emissions dispatchable capacity and non-emitting sources of flexibility are the next critical steps to close the gap from the APS to the NZE. Hydropower, including pumped storage, has long been a leading source of electricity system flexibility and has the potential to expand its role much further through the modernisation of existing projects, electrification of existing dams and new projects. Bioenergy can offer dispatchable power and low emissions when using sustainable supplies in dedicated power plants, co-fired with coal in solid form or with natural gas as biogas. Geothermal can also be an attractive option where resources are favourable. Ammonia and hydrogen produced from low emissions sources offer a scalable solution that can be co-fired in existing coal- and gas-fired power plants, or used in fully converted or new facilities.

Scaling up energy storage systems will be critical to address the hour-to-hour variability of wind and solar PV, especially as their share of generation increases. Meeting rising flexibility needs while decarbonising electricity is a central challenge for the electricity sector and calls for tapping all sources of flexibility, including power plants, grids, demand-side response and storage (see Chapter 4). Utility-scale battery storage capacity increases 30-fold from 2020 to 2030 in the APS, compared with over 60-fold in the NZE. Ensuring electricity security throughout clean energy transitions also calls for operational and market reforms (see Chapter 6). For example, it is important for markets and regulations to place a proper value on electricity system flexibility and contributions to system adequacy in order to provide signals for investment compatible with net zero pathways.

In the NZE, the expansion of low emissions electricity generation and dispatchable capacity allows a rapid shift away from unabated coal-fired generation. There are over 2 100 GW of coal-fired capacity in operation today, and many are young. However, there are also many ageing plants with rising maintenance costs that face challenging market conditions. The business case for the continued use of any coal-fired power plant depends in many cases on the need for their output and services to the grid, including the contribution they make to capacity adequacy, system stability and flexibility. Where low emissions sources are able to step in and provide all those services, operating existing coal plants or building new ones quickly becomes uneconomic.

If all the cost-effective opportunities for low emissions sources are realised, we estimate that over 350 GW of coal-fired capacity in the APS in 2030 would not be needed, representing about 20% of the global coal plant fleet at that time. Stopping all new investment decisions would cancel the construction of 200 GW of coal-fired power plants in the APS and would save an estimated 0.8 Gt CO_2 emissions in 2030, closing about 15% of the gap in electricity sector emissions between the APS and NZE. This would also allow an extra 150 GW of coal-fired capacity to be permanently closed by 2030, in addition to the 480 GW retired in the APS, without compromising electricity security or raising electricity bills for consumers. In total, the net upfront investment in capacity and grid infrastructure would increase by about USD 300 billion per year on average over the next decade.

Figure 3.14 ▷ CO_2 emissions from coal-fired power plants by age and scenario



The oldest and least efficient coal plants are due to be phased out in the APS, but those built recently will continue operating for decades without strengthened policy

Note: The age of coal plants is as of 2021.

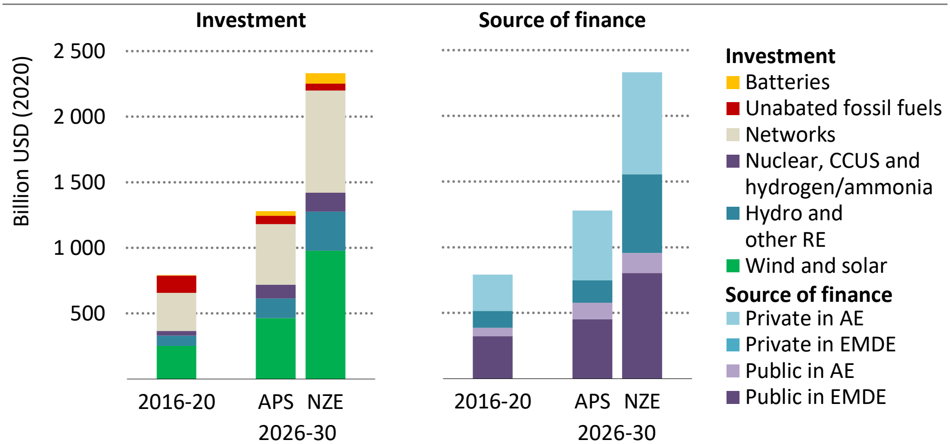
Tackling emissions from coal-fired power plants calls for making the best use of the existing fleet of coal plants until they can be retired. A multi-pronged approach is the most cost-effective way to cut emissions while maintaining electricity security, particularly in emerging market and developing economies. One option is to repurpose facilities to reduce operations and focus on flexibility services, facilitating the integration of renewables and cutting emissions. Another is to retrofit facilities with carbon capture technologies or to co-fire coal with high shares of ammonia or sustainable biomass, enabling continued operations while greatly reducing emissions. Younger and more efficient facilities are the best candidates for retrofitting with carbon capture technologies, and younger plants fitted with such technologies are the only kind of facilities still in operation in the NZE by 2040 (Figure 3.14).

Once coal-fired power plants are no longer needed for their electrical output or system services, financing their retirement becomes critical to ensuring the financial health of the sector (Chapter 1, section 1.7 discusses the financial and social aspects of coal phase-outs around the world). In the APS, the average age of coal-fired capacity at retirement is around 35 years in emerging market and developing economies, and this falls to 25 years in the NZE. In advanced economies, coal plants are already almost 35 years old on average: they are retired after another eight years on average in the APS and five years in the NZE.

Financing the transition of the electricity sector in the NZE

The NZE requires a threefold increase in electricity sector investment by 2030, compared with historical levels, taking it up to an annual average of USD 2.3 trillion by the late 2020s. As a share of GDP, investment in electricity would need to increase from nearly 1.0% over the 2016-2020 period to 2.2% over the second-half of the 2020s. Investment in renewables accounts for 55% of this total. While announced pledges put electricity sector investment on an upward trend, spending falls short of what is needed for the net zero pathway in the NZE by about USD 1.1 trillion in 2030 (Figure 3.15).

Figure 3.15 ▷ Average annual investment by type and source in the electricity sector, 2016-2020, and by scenario, 2026-2030



Investment in renewables and networks increases to fulfil announced pledges, but much more is needed to achieve the net zero emissions pathway, most of it from private capital

Notes: AE = advanced economies; EMDE = emerging market and developing economies; Other RE = other renewables. Investment values represent annual averages for the indicated time periods.

It would be challenging to deliver an increase in investment of this scale, but there are some precedents. For example, annual investment in internet and communication technologies increased by more than 2% of GDP in OECD countries between 1990 and 2000. Although average global annual investment in the power sector doubled over the last two decades from USD 400 billion in 2001-05 to USD 800 billion over the last five years, the NZE requires both faster growth and changes in the sources of finance. In the NZE, the power sector depends increasingly on private sources of capital, international funds and low cost debt financing. Over 60% of capital expenditure on power generation and 40% of spending on grids is financed by private funds in the NZE. Financing from international sources also increases by more than five-times compared with recent levels.

Power companies, generally reliant on international debt financing, would need to continue to play a major role, but other companies with large balance sheets and global experience – including oil and gas firms or other diversified energy actors – could play an important part too. Refinancing could also help recycle capital, bring in institutional investors and improve returns for developers.

Mobilising investment at the speed and scale required would demand substantial changes at the domestic level as well as the international level to improve policy and regulatory frameworks and develop pipelines of projects with the right risk-return balance. International efforts should focus on helping countries, especially emerging market and developing economies, to enhance their investment frameworks for clean power and networks (including by making more effective use of blended finance to catalyse private capital), and to find the right business models to finance the phase-out of coal, while at the same time supporting the displaced coal workers to find new jobs, including in clean energy where possible (see Chapter 1, section 1.7).

3.5 End-use sectors

3.5.1 Industry

Current status and gap to the NZE

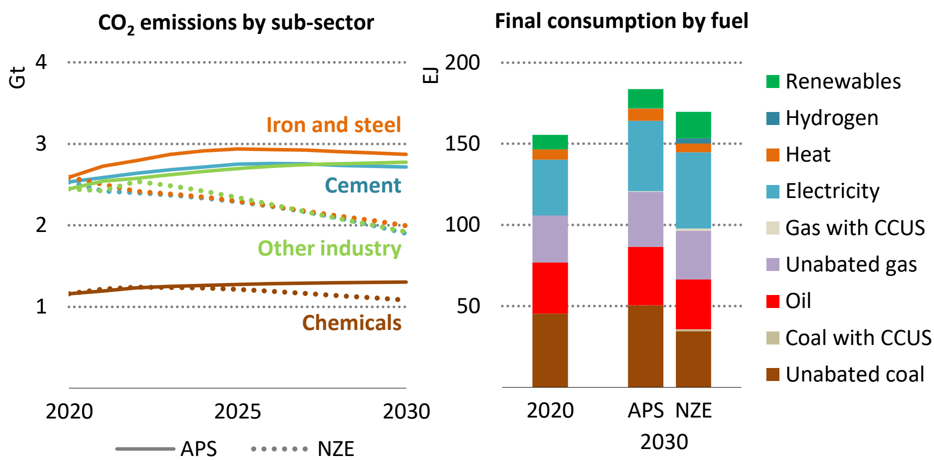
Industry energy consumption represents almost 40% of current global total final consumption and is still dominated by fossil fuels, in particular coal. This high level of reliance on fossil fuels together with the CO_2 emitted in raw material reduction processes (e.g. from limestone in cement production) means that the industry sector emits 8.7 Gt CO_2 today, making it the second-largest emitting sector after power generation.[9]

The challenge ahead for the industry sector is to meet growing industrial product demand while curbing CO_2 emissions. In the APS, the demand for primary industrial products like iron and steel, cement, and primary chemicals rises between today and 2030 by around 10-30%, depending on the sub-sector. Almost all of this growth occurs in emerging market and developing economies as they industrialise and urbanise. The globalisation of supply chains has already led to emerging market and developing economies, and in particular China, accounting for a large share of global industrial production.

In the APS, global industry CO_2 emissions rise above pre-crisis levels in 2021, reach a peak in the late 2020s, and are still higher than today in 2030. A decline in emissions in advanced economies is dwarfed by their continued growth in emerging market and developing economies. Industry emissions are lower in the NZE and reach a peak five years earlier than in the APS. Of the 2.8 Gt CO_2 emissions difference between the APS and the NZE in 2030, cement and steel account for more than half of the gap (Figure 3.16). By source, unabated coal accounts for more than half of the 2.8 Gt gap, process emissions for more than 20% and combustion of oil and gas for around 15% each.

[9] All CO_2 emissions in this section refer to direct CO_2 emissions, i.e. it does not include emissions of the electricity and heat sector, unless otherwise specified.

Figure 3.16 ▷ CO_2 emissions by sub-sector and final energy consumption by fuel in industry in the Announced Pledges and Net Zero Emissions by 2050 scenarios



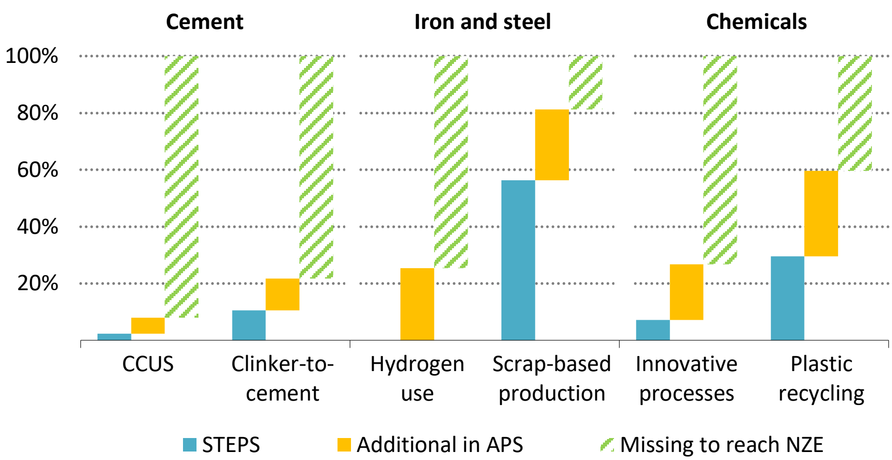
Industry is the largest end-use sector in terms of energy use and CO_2 emissions; its challenge is to meet rising demand for materials while transitioning from unabated fossil fuels

Note: Gas = natural gas.

The **iron and steel** industry is the largest contributor to the ambition gap accounting for 0.9 Gt of the gap between the APS and NZE. Most of the difference is the result of lower steel demand in the NZE, which is brought about by improved design in construction, vehicles and machinery, and by a switch away from coal, especially in emerging market and developing economies. Coal is primarily displaced by electricity, which sees its share in total energy use increase from 15% in the APS to 23% in the NZE, although there is also some switching to natural gas. Electric arc furnaces (EAF) play a key part in the transition from coal together with natural gas-based direct reduced iron (DRI). An increase in the steel recycling rate is also necessary to enable the growth of EAF production routes: in the NZE, the scrap share in metal input reaches 38% by 2030, compared to 31% today. Additional CCUS deployment in the NZE accounts for about 10% of the emissions gap in 2030, although it makes a bigger contribution after 2030 through the deployment of innovative smelters. Low emissions steel production using hydrogen-based DRI and EAF accounts for less than 1% of the gap in 2030, but it too ramps up rapidly in the following decades.

The **cement** sub-sector is the second-largest contributor to the ambition gap between the APS and NZE. Emissions are slightly higher in 2030 in the APS than they are today, while they fall by a quarter in the NZE. Almost half of the emissions reduction in the NZE compared to the APS comes from a 120 Mtce reduction in coal use which is achieved through reducing material demand, improving kiln efficiencies and shifting from coal to bioenergy. A further reduction in emissions comes from additional CCUS deployment to address both combustion and process emissions, with CCUS increasing from 15 Mt CO_2 in the APS to 220 Mt CO_2 in the NZE in 2030 (Figure 3.17). Alternatives to clinker are also deployed to cut process emissions further: in the NZE, the clinker-to-cement ratio[10] declines from a global average of around 0.71 today to 0.65 by 2030 (0.7 in the APS).

Figure 3.17 ▷ Tracking progress towards 2030 milestones by industry sub-sector and scenario



Despite good progress in some areas, technology transformation in the industry sector needs to happen much faster than in the APS to meet climate goals

Notes: The 2030 milestones are those set out in the Net Zero Emissions by 2050 Scenario. The baseline is 2020. Innovative processes refer to electric steam crackers, electrolysis or pyrolysis methanol-to-olefins, low-carbon hydrogen ammonia and methanol production.

Light industries, together with aluminium and pulp and paper production, account for a further 0.7 Gt of the emissions gap. The difference reflects reduced use in the NZE of coal, natural gas and oil in almost equal parts: fossil fuel use decreases strongly in the NZE, reaching 21 EJ by 2030 compared to 28 EJ in the APS.

The **chemicals** industry accounts for just 0.25 Gt of the 2030 emissions gap between the APS and NZE, despite experiencing the highest level of material demand growth of all industrial sectors. Almost half of the difference is due to a reduction in natural gas use in the NZE; a third to reduced oil use, and almost 15% to lower process emissions. Increased materials efficiency and new energy efficient processes making use of biomass-based fuels and CCUS are key to cutting emissions to 2030 and beyond.

[10] Clinker-to-cement ratio is the mass of clinker required to produce one unit of cement. The smaller the ratio the lower the process emissions. Clinker alternatives include calcined clay, volcanic ash or blast furnace slag.

Closing the gap from the APS to the NZE

Decarbonisation is slower to take-off in the industry sector than elsewhere, reflecting the long lifetimes of production facilities and related infrastructure, and the lack of ready access to key alternative technologies, a number of which are still at an early stage of commercialisation. Efforts to close the ambition gap between the APS and the NZE in the industry sector should focus primarily on strengthening policy frameworks for energy and materials efficiency; quickly setting up a comprehensive regulatory framework giving clear direction and incentives for new investment; accelerating electrification of all industrial sub-sectors; and increasing innovation and investment for CCUS technologies and hydrogen-based processes, including by ramping up international co-operation.

- Governments should put in place ambitious policy frameworks to promote material and energy efficiency improvements in the industry sector. Materials efficiency gains are the primary way to avoid energy consumption and CO_2 emissions in the short term. Lifetime extensions of buildings save steel and cement, for example, even though they may require the refurbishment or repurposing of buildings; improved manufacturing techniques could reduce avoidable losses (e.g. in cutting body panels from metal sheets for cars) via improved design, process digitalisation or material substitution; and light-weighting, especially for cars, could reduce material use. Governments should promote energy efficiency for its multiple benefits, notably emissions reduction, cost savings and improved competitiveness: the US Department of Energy Better Plants Program is one example of what might be done.
- Governments should take timely decisions together with industry on large-scale deployment of near zero emissions technologies: by 2024 in advanced economies and 2026 in emerging market and developing economies, governments and companies should have developed strategies for incorporating these technologies into the next series of capacity additions and replacements for industrial plants. This includes decisions on whether to pursue CCUS, hydrogen, or a combination of both. Measures such as emissions mandates and standards, carbon pricing, operational subsidies (such as those in the Netherlands SDE++ scheme) and CCUS-specific market mechanisms could all help to achieve the required level of ambition.
- Governments should enforce policies to increase the competitiveness of electrification over the next decade. Carbon pricing, such as the European Union Emissions Trading System (EU ETS), already provides a framework for action, but additional financial support or incentives may be required to promote the retrofitting of existing assets. Examples of relevant programmes include the National Key Technologies R&D Programme in China, the European Union Horizon programme and ETS Innovation Fund, and the Japan Innovation Fund.
- Governments should set breakthrough cost targets, support demand through mandates or deployment targets, and strengthen R&D in innovative technologies. A large share of future emissions reductions in the industry sector depends on technologies that are not yet available at commercial scale (Box 3.6). The scaling up of CCUS still faces a lot of

technical, economic, infrastructure and societal hurdles, although a number of countries are moving forward: for example, the US Energy Act of 2020 includes an economy-wide portfolio of measures such as support of pilots and demonstration projects, CO_2 storage projects, loans for large-scale projects and carbon removal competition prizes. Despite the growing number of countries that have developed hydrogen strategies, governments also need to be more proactive in supporting hydrogen demand through mandates or incentives. International collaboration is critical to achieving the rate of innovation required through action to co-ordinate R&D, create larger markets for low emissions products, and provide a level playing field.

Beyond these measures, each industrial sub-sector requires specific actions to close the gap. In the cement sub-sector, for example, the development of supply chains for alternatives to clinker has an important part to play. Countries or regions could develop flexible standards and building codes for concrete, of which cement is the key component, that do not prescribe specified amounts of clinker, and this could facilitate the increased uptake of blended cements without compromising safety and performance. In the iron and steel sub-sector, procurement obligations for low emissions steel in public projects would expand the size of its market and help to overcome concerns about industrial competitiveness, while increased recycling and reuse of plastics would reduce energy and related emissions growth in the chemicals industry.

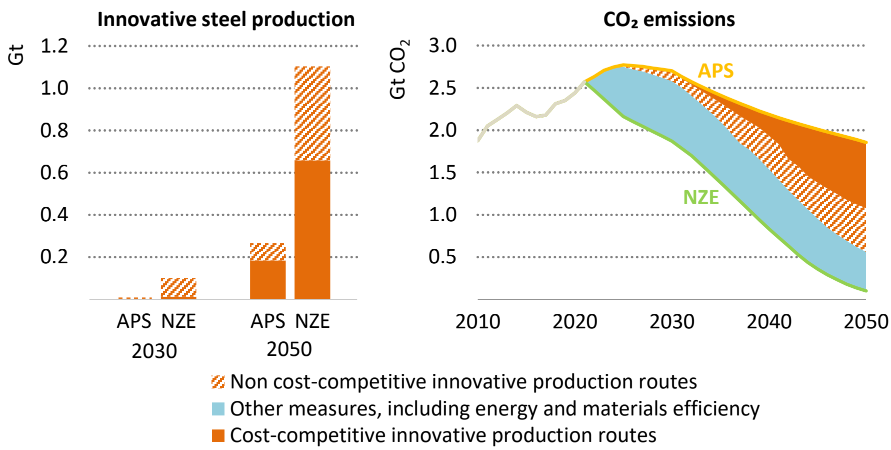
As most energy-intensive industrial products are sold in globalised markets, it is important to find ways to avoid carbon leakage. Governments and international trade associations should push for international standards that can help to increase the market for low-carbon products and prevent unfair competition. Well-designed carbon border adjustment mechanisms may have a role to play here.

Box 3.6 ▷ Can low-carbon steel production compete with conventional processes?

The major challenge for the iron and steel sub-sector in terms of decarbonisation is to find alternative routes for emissions-intensive primary production. Increasing the cost-effectiveness of low emissions production routes is key to mitigating industry emissions without impacting prices.

To try to answer this question, we calculated the levelised cost of production of three low emissions primary production routes: smelting reduction equipped with CCUS, direct reduced iron with CCUS, and hydrogen-based DRI. We compared this with the costs of the main incumbent emissions-intensive technology, which is the blast furnace and basic oxygen furnace method of production (BF-BOF). The assessment was done at the regional level. Capital expenditure for low emissions technologies is assumed to decrease over time and operating expenditure includes energy and CO_2 prices.

Figure 3.18 ▷ Cost-competitive steel production from innovative technologies and related CO_2 emissions in the Announced Pledges and Net Zero Emissions by 2050 scenarios



Innovative steel production technologies become cost-competitive in the long term, if the move from experimental to industrial scale takes place before 2030

Figure 3.18 shows total production from innovative routes in the APS and NZE, and the share which is cost-competitive. It also breaks down steel sub-sector emissions reductions between the APS and the NZE from innovative production routes and other measures such as energy and materials efficiency.

In 2030, the vast majority of reductions come from energy and materials efficiency, which tend to be cost-effective measures. However, the NZE involves a more rapid expansion of innovative production routes by 2030 than the APS does, which drives down costs and accelerates deployment of enabling infrastructure.

This investment pays off in the longer term. Of the 14.7 Gt cumulative CO_2 emissions savings from innovative processes to 2050 in the NZE compared to the APS, 50% are cost-competitive. Technological improvement drives down electrolyser and CCUS investment costs, while a rising CO_2 price also favours low emissions routes. CCUS provides an efficient lever to avoid locked in emissions particularly in relatively young BF-BOF steel plants in Asia (see Chapter 4, Box 4.1).

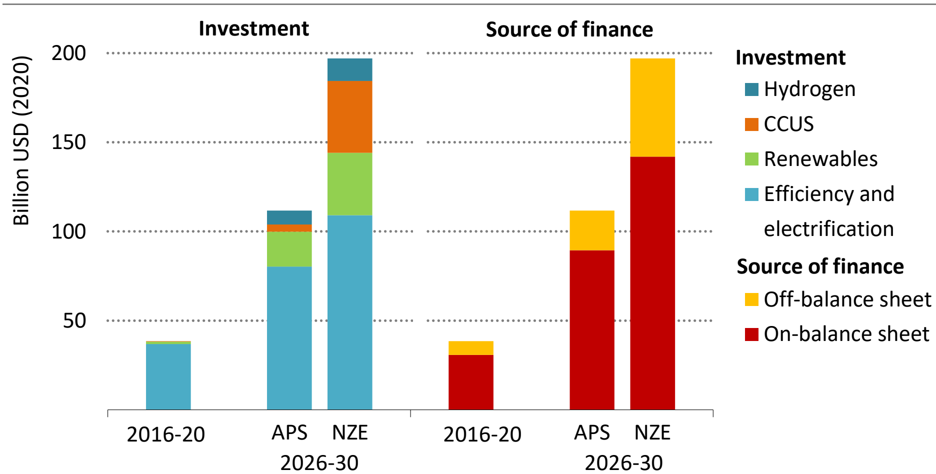
In the iron and steel sub-sector, major stakeholders have already identified the need for low-carbon steel by setting targets or initiating demonstration projects. This includes both steelmaking companies (e.g. ThyssenKrupp, ArcelorMittal, Voestalpine, SSAB and Ovako) and steel consumers ready to pay a premium for low-carbon steel or to invest in innovative steel production through direct partnerships (e.g. BMW and Volvo).

Our calculations suggest that breakthrough programmes targeting cost-effective production from innovative routes by 2030 could achieve worthwhile results and bring about further cost reductions in the longer term. In the shorter term, supporting innovation and demonstration projects could speed up the technological readiness of processes such as CCUS and electrolysers and increase their competitiveness, while setting long-term targets could facilitate the creation of a sizeable market for low-carbon steel.

Financing the industry sector transition to the NZE

Bridging the ambition gap to meet the NZE pathway will require the financing of early projects in new technologies critical for industrial decarbonisation and laying the groundwork for attracting capital at scale. The gap to be bridged is a large one. Global annual investment in industrial decarbonisation expands to over USD 110 billion in the APS by 2030, up from less than USD 40 billion today. However, investments in the NZE climb to almost USD 200 billion (Figure 3.19).

Figure 3.19 ▹ Average annual clean energy investment in industry by type and source, 2016-2020, and by scenario, 2026-2030



Meeting NZE milestones requires investment in industry to increase fivefold by 2030, supported by new financing options in technologies critical for industrial decarbonisation

Note: The source of finance indicates investment financed on the balance sheet of the industrial company, as well as those using off-balance sheet arrangements, such as project or third-party finance.

Many of the industrial technologies needed to meet long-term net zero emissions goals remain at early stages of market readiness and transaction sizes tend to be small, making it challenging to attract project finance from banks and institutional investors. Policies that support effective risk allocation for early commercial-scale projects incorporating low-carbon hydrogen, CCUS and the development of shared infrastructure around industrial clusters will play a vital role in realising economies of scale and attracting new, external sources of capital.

There is a need for stronger international mechanisms to fund early stage technologies as well as public funds to catalyse project development. Direct investments by institutional investors in new industrial technology companies have risen rapidly, but totalled less than USD 10 billion over the past five years. While large companies will be instrumental in anchoring initial projects, there is a good deal of scope for development finance institutions to provide blended finance: industrial decarbonisation currently comprises a very small part of their clean energy commitments. This is particularly critical for emerging market and developing economies, which may not have the resources to fund early stage deployment of low emissions industrial technologies like hydrogen or CCUS. Table 3.1 provides several examples of the financial and commercial arrangements for recent industrial demonstration projections.

Table 3.1 ▷ Examples of commercial-scale project development for industrial clusters, hydrogen and CCUS

Project	Country	Technologies	Source of finance	Commercial arrangement	Status
Puertollano Green Hydrogen Plant	Spain	Solar PV, battery storage, hydrogen electrolysis	Utility balance sheet	Use of hydrogen to produce ammonia and electricity by a fertiliser company.	Construction
Humber Industrial Cluster	United Kingdom	CCUS, hydrogen infrastructure/ electrolysis, wind	Private consortium, government grants	Use by heavy industry, refiners, power plants, mobility and grid injection.	Planned
Western Green Energy Hub	Australia	Solar PV, wind, hydrogen electrolysis	Private consortium, government grants	Off-take by mining companies, ammonia supply for export.	Planned
Porthos Port of Rotterdam	Netherlands	CCUS, hydrogen	Private consortium, government grants	Companies supply CO_2, public-private partnership manages transport/storage, use by refineries.	Planned
Haru Oni Hydrogen Project	Chile	Wind, hydrogen electrolysis, synthetic fuels, direct air carbon capture and storage	Private consortium, government grants	Export-oriented supply of synthetic fuels.	Construction (demo phase)
Varennes Project	Canada	Hydrogen electrolysis, synthetic fuels	Private consortium, government grants	Feedstock from landfills, sale of synthetic fuels.	Planned

Projects that aim to provide low emissions hydrogen in place of hydrogen sourced from fossil fuels are likely to underpin early development because they will be able to draw on existing infrastructure and commercial arrangements. Creating bankable project pipelines at scale will rely on fixed-price contracts with creditworthy off-takers to absorb pricing risks, as well as on infrastructure development which has the potential to support further development of a tradable market. While early use cases focus on existing applications such as refining or ammonia production, scaling up depends on extending contracts to counterparties with growing fuel demand (e.g. heavy industry and transport fleets) and on tradable certificates of origin to improve bankability, as envisaged in the European Union. International hydrogen trade is driving some export-oriented projects (e.g. in Australia, Chile and Oman), but scaling this up depends on the development of international standards, certification and price setting regimes.

The development of industrial clusters around infrastructure for CCUS and hydrogen is also critical to laying the groundwork for financing those technologies at scale. CCUS projects under development in Canada, Netherlands and United Kingdom are creating industrial hubs with shared CO_2 transport and storage infrastructure that help achieve economies of scale and reduce commercial risks for developers.

3.5.2 Transport

Current status and gap to the NZE

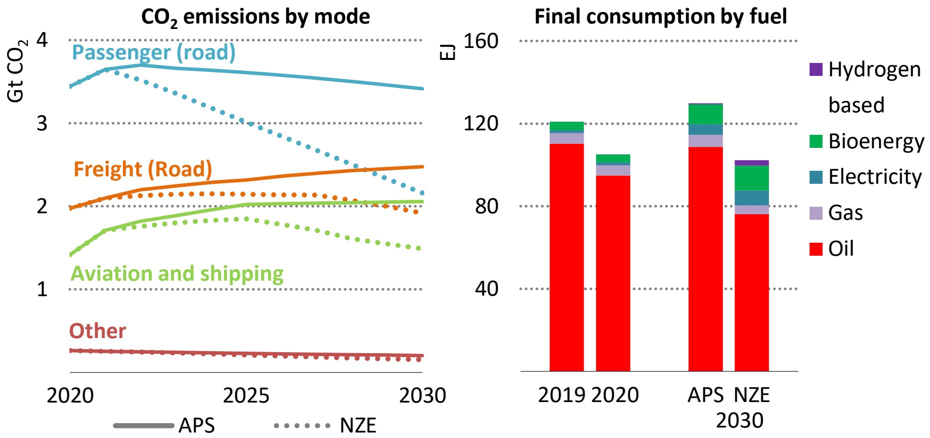
Transport has the highest level of reliance on fossil fuels of any sector and accounts for 37% of CO_2 emissions from end-use sectors (7.1 Gt in 2020).[11] In recent years, transport has seen the fastest growth in CO_2 emissions of any sector as a result of increasing demand and limited uptake of alternative fuels. By 2030, transport emissions are nearly 2.5 Gt higher in the APS than in the NZE, with road transport accounting for around three-quarters of the ambition gap between the two scenarios (Figure 3.20).

One of the major reasons behind the higher emissions in APS is strong demand growth in emerging market and developing economies, many of which do not have net zero pledges. For example, over 40% of global car sales in 2030 take place in emerging market and developing economies without pledges. Weaker energy efficiency and avoided demand policies result in around 1.3 Gt more emissions in the APS in 2030 than in the NZE. In the APS, transport energy demand is 24% higher in 2030 than in 2020, whereas in the NZE it is at roughly the same level as in 2020.

Another major reason for the ambition gap in transport is slower electrification in the APS together with lower deployment of bioenergy and hydrogen-based fuels. This contributes about 1 Gt to the ambition gap. Oil products still account for more than 80% of transport consumption in 2030 in the APS, although electricity reaches close to 5%. In the NZE, however, the share of oil products decreases to around 75% by 2030, and electricity meets close to 10% of demand. The NZE also sees hydrogen-based fuels making inroads, with ammonia starting to be used more in shipping, for example. The difference in the energy mix in transport between the APS and NZE widens dramatically after 2030.

[11] All CO_2 emissions in this section refer to direct CO_2 emissions, i.e. it does not include emissions of the electricity sector or upstream emissions from fuel supply, unless otherwise specified.

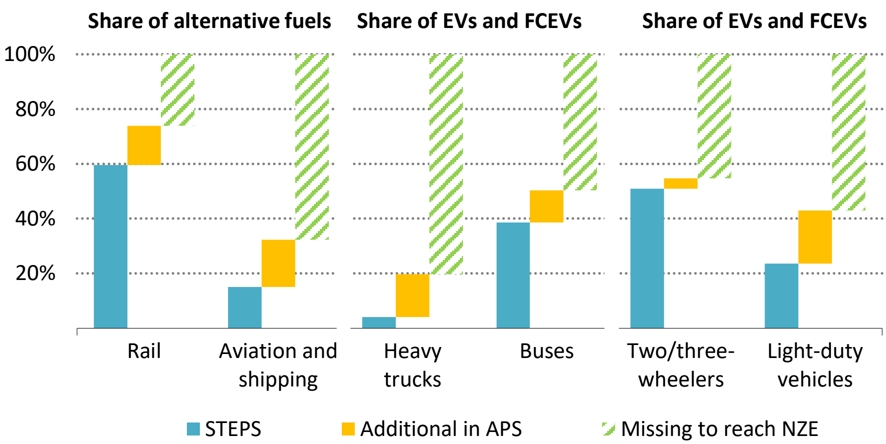
Figure 3.20 ▷ CO_2 emissions and final energy consumption in transport in the Announced Pledges and Net Zero Emissions by 2050 scenarios



By 2030, total CO_2 emissions from transport are more than 40% higher in the APS than in the NZE

Note: Other includes emissions from rail, non-specified transport and pipelines.

Figure 3.21 ▷ Tracking progress towards 2030 milestones in the transport sector by scenario



Decarbonisation of rail and light-duty vehicles is more advanced than in heavy trucks and aviation and shipping, relative to the NZE pathway

Notes: The 2030 milestones are those set out in the Net Zero Emissions by 2050 Scenario. EVs = electric vehicles; FCEVs = fuel cell electric vehicles. Aviation and shipping include both domestic and international activity. Light-duty vehicles include passenger cars and light commercial vehicles. The share of EVs and fuel cell electric vehicles refers to their share in annual sales. Alternative fuels include electricity, bioenergy, hydrogen and hydrogen-based fuels.

In the APS, some regions with net zero ambitions and strengthened NDCs push the transition in the transport sector towards what is required under an NZE pathway. At the global level, however, the transport sector is not on track to reach net zero emissions by 2050, although some modes make better progress than others (Figure 3.21).

Road transport accounts for over 15% of total energy-related CO_2 emissions today. The APS sees road CO_2 emissions increase by around 10% up to 2030, whereas the NZE sees emissions decline by a quarter by 2030 from the current level: the APS reaches this level of road CO_2 emissions only by 2050. Electric two/three-wheelers reach a 60% market share by 2030 in the APS, a significant increase over the current market share of around 30%, but well below the 85% achieved in the NZE. Electric two/three-wheelers have lower additional cost than electric cars and need less power to charge. For this reason, they are widely used in emerging market and developing economies. The market share of EVs in annual car sales reaches around 30% in the APS by 2030, but rises to over 60% in the NZE.[12] The story is similar for electric vehicles in annual truck sales, only starker: EVs account for around 5% of new sales of heavy trucks in the APS by 2030, compared to around 25% in the NZE.

Ambitious new targets have been put forward in several countries that would put them close to reaching the NZE milestones. The United Kingdom has set a target to ban the sale of new internal combustion engine (ICE) cars from 2035 (including hybrids), and Canada recently announced a similar target for 2035. The European Union recently released its Fit for 55 package, which proposes standards effectively banning new ICE car sales from 2035. In recent years, China has been at the centre of the EV transition, and its targets for fuel economy improvements and low emission vehicle shares are a step forward, but a commitment to phase out ICE car sales is essential to achieve carbon neutrality in the long term.

Rail is the most electrified sector among all transport modes, with electricity accounting for over 40% of energy consumption in 2020. In the APS, the share of electricity reaches almost 60% in 2030, compared with nearly 65% in the NZE. Plans for further electrification of railways are in place in several countries (e.g. Germany, India and United Kingdom), as are some projects involving hydrogen trains (e.g. Germany).

Aviation and shipping see early action on innovation, infrastructure development and international co-operation in the NZE to achieve emissions reductions. Oil makes up less than 85% of total aviation fuel demand in 2030 in the NZE, with the rest met by biojet kerosene and synthetic kerosene. For shipping, the oil share reaches around 80% over the same period. In the APS, however, oil still accounts for more than 90% of both aviation and shipping fuel demand in 2030. Policy measures such as blending mandates and excise duties for petroleum products used in these modes would help to support the consumption of alternative fuels.

[12] EVs include battery electric and plug-in hybrid electric vehicles.

Closing the gap from the APS to the NZE

Closing the ambition gap between the APS and NZE requires robust targets across transport modes in all regions, supported by strong policies and incentives. However, the transition faces three particular challenges: driving energy efficiency and behavioural change to reduce energy demand; accelerating the electrification of road and rail modes through supportive policies and the roll-out of infrastructure; and speeding up innovation and infrastructure investment to enable decarbonisation in heavy-duty trucks, aviation and shipping after 2030.

- To close the gap with the NZE, governments need to strengthen fuel economy mandates and implement policies to facilitate modal shift. By 2030, the average fuel economy of both ICE heavy trucks and ICE cars is around 15% better in the NZE than in the APS. Strict fuel efficiency standards, accompanied with policy frameworks for regulating second-hand sales of inefficient models in emerging market and developing economies, are both critical. Fuel efficiency measures also need to be brought in for shipping and aviation. Behavioural change is an important complement to these measures. ICE cars continue to make up around 80% of the cars on roads in 2030 even in the NZE, and measures to limit their use have an immediate and large impact on emissions. In the NZE, the use of ICE cars in large city centres is significantly reduced in most places by 2030, speed limits on motorways are reduced to 100 kilometres per hour, and car drivers moderate their use of air conditioning, helping to reduce fuel consumption. These measures all depend on changes in behaviour and broad social acceptance. To achieve the same level of emissions reductions without such behavioural changes, 100% of new car sales would need to be EVs or FCEVs by 2026, up from about 5% today.
- Governments should seize on the increasing competitiveness of EVs and underpin it with supportive policies and accelerated deployment targets. EVs can already be a cost-effective option for consumers in certain countries and for some modes (Box 3.7). However, there are a number of barriers to their wider deployment, particularly in emerging market and developing economies, and these need to be addressed. One barrier is price: less than 10% of EV models offered globally cost less than USD 15 000. Insufficient public charging infrastructure is another barrier. Emerging market and developing economies today account for only 0.3% of total installed public charging infrastructure. In addition, these economies rely on the global second-hand car market, and therefore tend to lag behind technology developments in advanced economies.[13]
- Governments should set targets and frameworks to establish EV charging infrastructure at scale. This should include the provision of a stable long-term framework for the private sector to invest in markets where demand is well established. The NZE requires a massive roll-out of infrastructure to support the decarbonisation of the transport sector, with 40 million fast chargers and 18 000 hydrogen refuelling stations installed by 2030. The APS sees significant progress, but it is not on the same scale: 15 million fewer fast chargers are installed by 2030, and hydrogen refuelling capacity is around half that of the NZE. Robust government policies on infrastructure roll-out are important in

[13] The numbers in this paragraph apply to emerging market and developing economies excluding China.

electrifying heavy-duty trucking, which sees the biggest gap between the APS and the NZE. It is challenging for emerging market and developing economies to invest in low emissions supply chains for ports and airports, given that they lack quality basic infrastructure in these areas: international co-operation is required to foster the development of the needed infrastructure, with advanced economies playing a key role.

- Governments need to enhance investment in commercialising key technologies for heavy-duty, long-distance transport such as shipping and in aviation, including by improving incentives for such investments. Emissions reductions in these modes are dependent on innovation in key technologies: the share of low-carbon fuels for both aviation and shipping exceeds 15% by 2030 in the NZE, for example, but it reaches only around 6% in the APS. The technologies in question include advanced batteries cells with an energy density of more than 400 watt-hours per kilogramme (Wh/kg), fuel cells, advanced biofuels and synthetic fuels.

Today, more than 360 000 flights have used biofuels, but only six airports have regular biofuel distribution. Less than 5% of all airports handle 90% of international flights. For shipping, the 20 largest ports in the world account for more than half of global cargo. There is a huge opportunity for the international aviation and shipping sectors to focus on the main demand clusters until low-carbon technologies become more cost-competitive.

Box 3.7 ▷ Are EVs cost-competitive in the NZE?

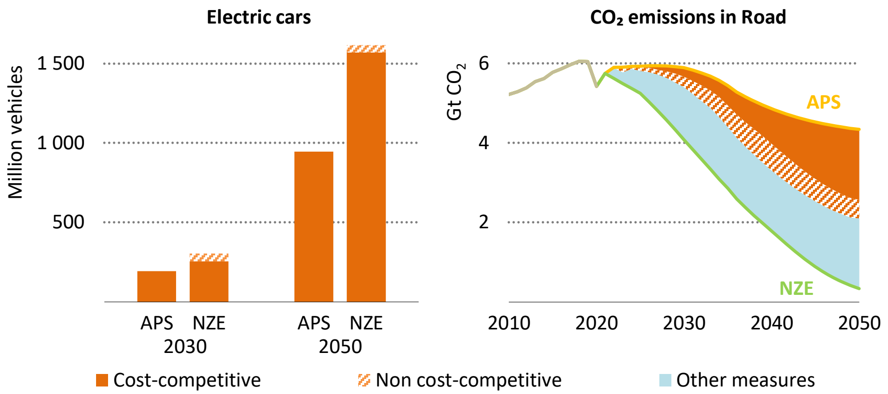
EVs are already competitive with ICE vehicles on a total cost of ownership basis[14] in some regions, especially in places such as the European Union and India where taxes raise the retail price of fuels. But EVs also face non-economic barriers that are not overcome in the STEPS or the APS, especially in emerging market and developing economies. For instance, emerging market and developing economies rely heavily on the second-hand market, which is unlikely to have many EVs until after 2030; rapid adoption of electric light-duty vehicles is particularly dependent on public charging infrastructure within cities; heavy-duty vehicles need an extensive network of fast charging points; and weak or unreliable grids risk delaying electrification in many emerging market and developing economies.

We have assessed the economic potential of EVs in different road vehicle segments at a regional level. Ignoring non-economic barriers, we estimate that the global electric car fleet could cost-effectively reach over 250 million by 2030, around 30% higher than in the APS and only around 15% lower than in the NZE (Figure 3.22).

Progress towards the milestones in the NZE could be made for urban buses, delivery vans and two/three-wheelers by addressing issues such as model availability and lack of infrastructure, while the main need for heavy-duty trucks is further technology development to reduce the high cost and low energy density of batteries so as to make electric heavy-duty trucks cost-competitive across the world.

[14] The total cost of ownership includes both purchase cost and running cost, i.e. fuel and maintenance costs, over the lifetime of the vehicle. The assumed lifetime depends on the particular market.

Figure 3.22 ▷ Cost-competitive stock of electric cars in 2030 and 2050, and CO_2 emissions reduction in road transport to 2050 by scenario



Electric vehicles are critical to closing the transport sector ambition gap and are largely cost-competitive

Note: Other measures includes energy efficiency, avoided demand, as well as the impact of fuel switching to fuels other than electricity, including bioenergy and hydrogen-based fuels.

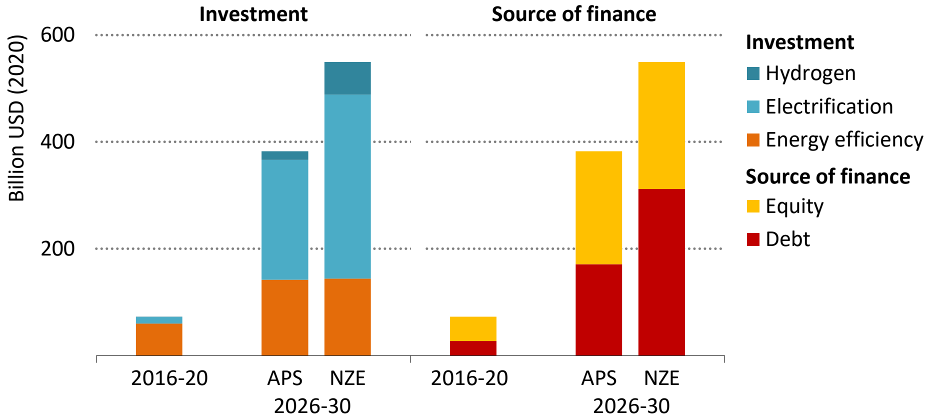
Financing the transport sector transition to the NZE

Global transport-related clean energy investment rises from around USD 75 billion today to over USD 380 billion in the APS and USD 570 billion in NZE by 2030. The scale of this increase requires a rapid growth in low interest debt financing and risk capital equity investment across all types of zero-emission vehicles and charging infrastructure (Figure 3.23).

From a very low base, investment in EVs increases over 15-times in the APS and over 25-times in the NZE by 2030. This requires concerted policy efforts to improve funding and business models for EV charging in emerging market and developing economies, where the weak financial performance of utilities and municipalities in a number of markets constrains the roll-out of publicly funded fast charging infrastructure for heavy trucks and buses.

It is essential for governments to set clear targets for the deployment of EV charging infrastructure and EVs. Governments and state-owned companies can support the development of new business models via calls for proposals for innovative charging solutions. The electrification of transport in emerging market and developing economies in particular depends on support for manufacturing to drive down costs, as well as on new measures to boost demand, for example through government procurement and dedicated credit lines for consumer lending. Development finance institutions and green banks could lend support by expanding concessional loan programmes to consumers and business owners for EV chargers at a below-market rate. Other policy options include supportive tax incentives to enable manufacturers and operators to lower costs of EV charging installation and operation.

Figure 3.23 ▷ Average annual clean energy investment in transport by type and source, 2016-2020, and by scenario, 2026-2030



Transport clean energy investments need to increase almost eightfold in the NZE by 2030, especially for electrification in emerging market and developing economies

Note: Hydrogen = hydrogen and hydrogen-fuel based vehicles and shipping; Electrification = electric vehicles and shipping; Energy efficiency = energy efficiency for road vehicles.

3.5.3 Buildings

Current status and gap to the NZE

Today's buildings sector accounts for almost one-third of total final energy consumption and 15% of end-use sector direct CO_2 emissions, and its share of emissions rises to around 30% if indirect emissions from the electricity and heat used in the buildings are included. Energy use in the buildings sector accounts for almost 3 Gt of direct CO_2 emissions today.[15] Direct emissions from the buildings sector decline by 15% to 2030 in the APS, but by almost 40% in the NZE, resulting in an ambition gap of 0.7 Gt by 2030.

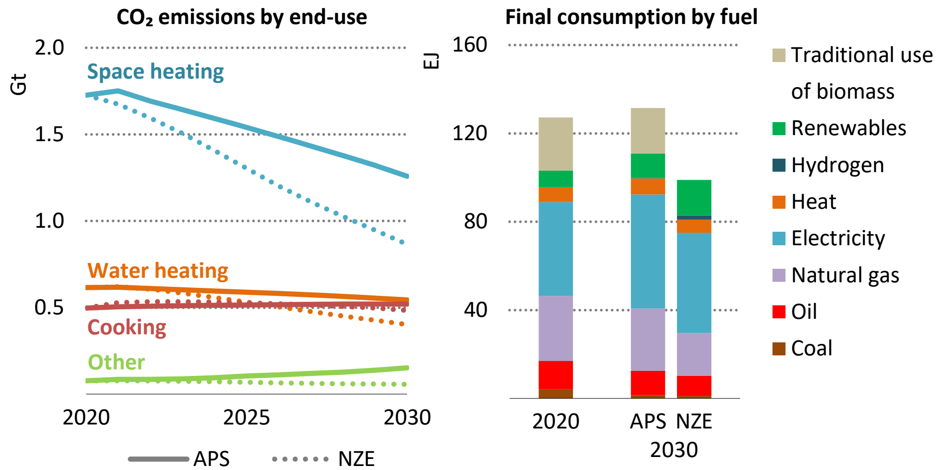
In the APS, energy demand in the buildings sector remains at a level similar to today, despite substantial growth in global GDP and urbanisation. In the NZE, energy efficiency and avoided demand due to behavioural change and passive design measures go much further: demand is 25% below the level in the APS level by 2030, and substantially lower than today, despite growth in global residential floor space of more than 20%.

Emissions reductions in the APS are driven by announced economy-wide emissions reduction targets in many advanced economies which lead to reductions in CO_2 emissions for space and water heating and cooking. Around 80% of the residential floor area growth in the

[15] All CO_2 emissions in this section refer to direct CO_2 emissions, i.e. it does not include emissions of the electricity and heat sector, unless otherwise specified.

buildings sector is in emerging market and developing economies, many of which have not announced net zero pledges. Reflecting this, the APS is far from sufficient to achieve the emissions reductions required in the NZE, resulting in a widening ambition gap (Figure 3.24).

Figure 3.24 ▷ CO_2 emissions by end-use and final energy consumption by fuel in the buildings sector in the Announced Pledges and Net Zero Emissions by 2050 scenarios



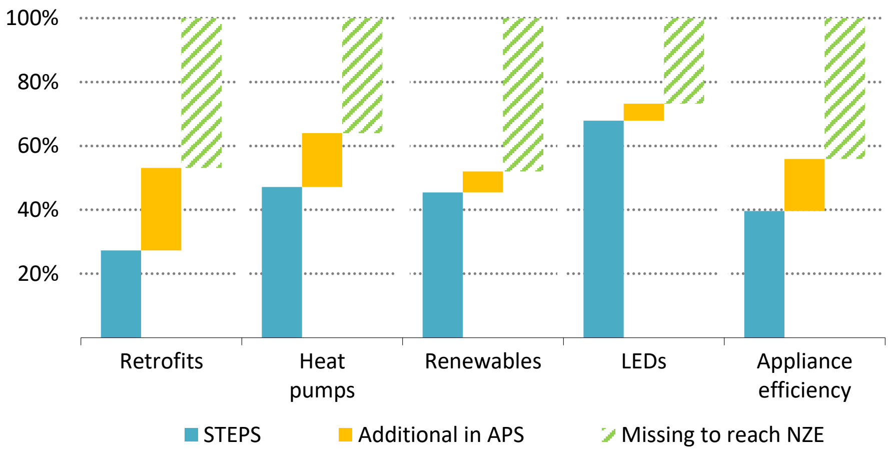
Announced pledges point to a 15% reduction in CO_2 emissions in the buildings sector by 2030, which is insufficient to drive down fossil fuel use in line with the NZE pathway

Note: Other includes emissions from desalination, lighting and fossil fuel-powered appliances.

In the APS, the share of electricity in energy consumption in the buildings sector increases to almost 40% and that of renewables above 8%. The NZE sees a similar shift in the energy mix in the sector, albeit at a more rapid pace and combined with greater energy efficiency improvements: electricity's share of energy consumption increases to 46% and that of renewables to 16% by 2030. Universal access to clean cooking solutions is realised by 2030 in the NZE, eliminating the traditional use of biomass.

Some economies with net zero pledges push the transition in some end-uses towards what is required under an NZE pathway, but at a global level the world remains well short of reaching NZE milestones. Even low cost and rapidly implementable measures such as ensuring that LEDs account for 100% of lighting sales by 2025 are not fully achieved in the APS, and an important share of less efficient lighting remains in use by 2030 in the APS (Figure 3.25). Heat pump deployment accelerates in all scenarios, driven by improving economics and policies. Full achievement of targets in the APS pushes heat pump sales above the level in the STEPS in key markets such as the European Union, but there remains a major heat pump deployment gap between the APS and NZE.

Figure 3.25 ▷ Tracking progress towards 2030 milestones in the buildings sector by scenario



Ambition needs to increase across all end-uses in buildings to put the world on track with the NZE pathway

Notes: The 2030 milestones are those set out in the Net Zero Emissions by 2050 Scenario. Retrofits refer to the residential floor area retrofit to zero carbon-ready building standards. Heat pumps refer to the number of residential heat pumps installed. Renewables refer to the share of renewables in meeting residential heat demand. LEDs refer to the share of light-emitting diodes in the residential lighting stock. Appliance efficiency refers to the average efficiency of the residential appliance stock.

Space heating accounts for 60% of global CO_2 emissions today in the buildings sector. It is responsible for 60% (almost 400 Mt CO_2) of the ambition gap between the APS and NZE in 2030. While technical solutions to decarbonise space heating are available and mature, there remain economic and non-economic barriers. Global emissions from space heating decline by 3% annually to 2030 in the APS. They decline by almost 5% in countries with announced net zero pledges, which account for three-quarters of all CO_2 emissions from space heating, but increase slightly in countries without pledges. By 2050, space heating in countries with net zero pledges is almost completely decarbonised.

The APS assumes full achievement of the announced pledges and targets in the buildings sector. Examples of the suite of targets and policies for the buildings sector in the European Union include the Energy Performance of Buildings Directive and the Renovation Wave for Europe strategy. The EU building sector targets accelerate retrofits and reduce space heating energy demand by almost 20% to 2030 and around 55% to 2050 from current levels, with emissions falling to close to zero by 2050. Canada, Japan and Korea also have announced targets for new buildings to meet stringent efficiency standards by 2030, and by 2025 for buildings over 1 000 m^2 in Korea. Other advanced economies are developing timelines for implementation of zero carbon-ready building codes.[16] For example, the United Kingdom has announced the Future Homes Standard which is set to come into effect in 2025 and end fossil fuel heating in new homes. Many countries have pledged funding for building retrofits in their Covid-19 recovery programmes.

Energy efficiency and avoided demand deliver the largest share of emissions reductions in space heating in the APS, but they fall short of what is required in the NZE. Improving efficiency in existing building is especially important in advanced economies: around 10% of their existing residential building stock is retrofitted by 2030 in the APS, compared to more than 20% in the NZE. Changes to the space heating fuel mix are also critical: fuel switching and electrification provide one-third more emissions reductions to 2030 in the NZE compared with the APS. Heat pumps are key to electrifying space heating: their sales average 3.5 million per month in residential buildings in the APS, boosted to around 5 million units per month in the NZE.

Cooking is the activity most dominated by fossil fuels in buildings today, with liquefied petroleum gas (LPG), natural gas and coal meeting over three-quarters of global cooking energy demand. For those with access to modern cooking technologies, a lack of targets and policies to incentivise switching away from natural gas or LPG based cooking means that fossil fuel use for cooking in the APS increases by 6% by 2030. Adding to the challenge of decarbonising cooking is the need to provide clean cooking access to the 2.5 billion people that currently lack it.

Universal access to clean cooking is achieved by 2030 in the NZE, alongside progress towards the wider decarbonisation of cooking. By 2030 CO_2 emissions from cooking in the NZE are 3% lower than today and 7% lower than in the APS. Emissions decline in the NZE despite the role of LPG in delivering clean cooking access to around 40% of the 2.8 billion people that gain access between today and 2030. While low-carbon cooking plays a dominant role in the NZE, LPG is the only cost-effective solution available today in some places, notably in rural sub-Saharan Africa. The use of LPG for clean cooking results in a slight increase in CO_2 emissions, but a net reduction in overall GHG emissions because it eliminates the methane, nitrous oxides and black carbon emissions caused by the traditional use of biomass (see Chapter 4, section 4.2.2). Beyond 2030, cooking emissions decline by over 15% per year in the NZE, with electricity substituting for some LPG, and with remaining LPG use increasingly decarbonised through the adoption of bio-sourced butane and propane.

Closing the gap from the APS to the NZE

Efforts to close the ambition gap in the buildings sector face five particular challenges: ensuring that the millions of buildings constructed in the next decades are built in a way that is consistent with achieving NZE, especially in emerging market and developing economies where the majority of construction occurs; accelerating retrofits of existing buildings to

[16] A zero carbon-ready building is highly energy efficient and either uses renewable energy directly, or uses an energy supply that will be fully decarbonised by 2050, such as electricity or district heat.

improve their energy efficiency; scaling up the use of electricity and renewables in buildings; achieving universal access to clean cooking and electricity by 2030; and delivering high efficiency appliances and cooling equipment. All the technologies needed to address these challenges are available today: the key requirements are stronger policy action, international co-operation and targeted financial support for households.

- Governments should develop and promulgate mandatory zero carbon-ready building energy codes which take account not just of direct emissions from building operation but also of indirect and embodied emissions (IEA, 2021a). Governments should move quickly to adopt such codes for all new buildings. Ambitious building codes exist today in some regions, as do targets for all new buildings to be zero carbon-ready and for bans on fossil fuel-fired equipment in new constructions. Almost all of these codes and targets are in advanced economies, while 80% of the projected increase in global residential floor area to 2050 will take place in emerging market and developing economies, but there is more for all governments to do.
- Governments should put in place incentives, education campaigns, access to concessional finance, stringent building codes for existing buildings, and facilitate new business models focusing on energy as a service in order to help overcome economic and social barriers to retrofits. Retrofits can reduce building energy demand by well over 60% and enable switching to zero direct emissions heating technologies such as heat pumps. More than 85% of the existing building stock is retrofitted by 2050 in the NZE thanks to action to accelerate retrofits in the 2020s. The challenges are significant, and include the major upfront capital costs of retrofits, disruption to building occupants, split incentives between tenants and building owners, and long payback periods. However, failure to take action during the coming decade to drastically accelerate the rate of retrofit of existing buildings would make later efforts to bridge the ambition gap more difficult and more costly.
- Governments should take measures to speed up fuel switching, which has the single biggest impact on direct emissions from the building sector through to 2030. System-wide emissions reductions linked to electrification increase rapidly as electricity supply is decarbonised in the NZE. Action to accelerate electrification and switching to renewables should build on targets in the APS and include bans on sales of new fossil fuel-fired boilers by 2025 except where fuel supply will be completely decarbonised before 2050. Incentive programmes and blending mandates could help to scale up the deployment of biomethane, making use of existing gas infrastructure. In many emerging market and developing economies, solar thermal is a very cost-effective option for water heating and could be incentivised: uptake in the APS is at only two-thirds of NZE levels. Electrification of heating and cooking could meanwhile be supported by capital subsidies for heat pumps, training programmes for technicians, awareness campaigns and carbon prices.
- Governments should work together to achieve universal access to clean cooking by 2030. The Covid-19 pandemic has led to a reversal of recent progress in many economies. International efforts, including financial commitments, are required to

ensure that the world's poorest and most energy insecure households are not left behind as the world attempts to close the ambition gap.

- Governments should implement minimum energy performance standards (MEPS) which incorporate a doubling of the average energy efficiency of key products by 2030 in line with the Super-Efficient Equipment and Appliance Deployment (SEAD) target (Box 3.8 details the SEAD). Appliances and cooling are the fastest growing uses of energy in buildings today, and their expansion is set to continue as incomes increase, more appliance are purchased, and millions of global households acquire air conditioners and other cooling equipment. Mitigating electricity demand growth from appliances and cooling is critical to electricity sector decarbonisation. This challenge is especially acute in India, Southeast Asia and Africa. MEPS are the most powerful tool available to policy makers. MEPS will need to be upgraded faster than in the past so as to ban sales of the most inefficient appliances and shift almost all sales to the best available technology by 2030. Global co-operation on high efficiency appliances and cooling equipment could reduce costs for consumers by facilitating co-ordination of MEPS and driving innovation.

3

Behavioural change also contributes to reducing emissions from buildings in 2030 in the NZE by around 170 Mt CO_2 more than the APS (see section 3.7). Overall, behavioural change contributes one-quarter of the additional direct emissions reductions in the buildings sector in the NZE relative to the APS by 2030. It also reduces the sector's electricity demand and indirect emissions, accounting for over 3% of the indirect emissions reductions from buildings between the APS and NZE. Changing heating and air conditioner temperature set-points, line drying and reducing washing temperatures all have a part to play. These savings can be achieved without the need for any new technologies or investments, but they do require enhanced consumer awareness and engagement.

Box 3.8 ▷ Efficient and affordable appliances with international co-operation

Worldwide, the average energy efficiency of key equipment sold today needs to double by 2030 to be on track for net zero. MEPS, including bans on sales of the most inefficient appliances, are the primary tool for shifting sales toward the most efficient technologies. More than 120 countries are currently using or planning to use MEPS for lighting, cooling or refrigeration, as detailed in the IEA's forthcoming *Energy Efficiency Market Report 2021*. However, different stringency levels and a lack of international co-operation together result in substantial variation in the efficiency of appliances and equipment within and between countries. The best available air conditioning equipment in a market is typically twice as efficient as that market's average product sold (IEA, 2018). National and international action on the coverage of MEPS needs to expand and increase in stringency in order to drive the shift in sales toward best available technologies required in the NZE. Such actions should be accompanied by complementary labelling programmes.

Consumer affordability concerns are at the forefront of decision making when it comes to increasing the stringency of efficiency standards because of a perception that more efficient technologies cost more. However, the IEA's market research suggests that highly efficient devices can be similar in price to less efficient ones in a given market, and are sometimes actually lower in price (IEA, 2020a). In addition, lower operating costs from higher efficiency create substantial savings over the life of a product, making many efficient products more cost-effective than less efficient models on a total cost of ownership basis.

Today LEDs are more cost-effective than almost all other forms of lighting in all regions. This suggests that a shift to 100% LEDs in lighting sales would benefit consumers. The most efficient air conditioner models are cost-competitive today in around two-thirds of cases, and this increases to three-quarters by 2030 in the NZE as equipment costs for the most efficient models decline and electricity prices rise. Purchasing high efficiency household appliances such as refrigerators and washing machines leaves more money in consumer pockets over the lifetime of the product in the majority of regions, and the benefits increase in the NZE. Overall, two-thirds of the improvements in the efficiency of appliances and air conditioners between the APS and NZE in 2030 are cost-effective, increasing to almost 100% by 2050.

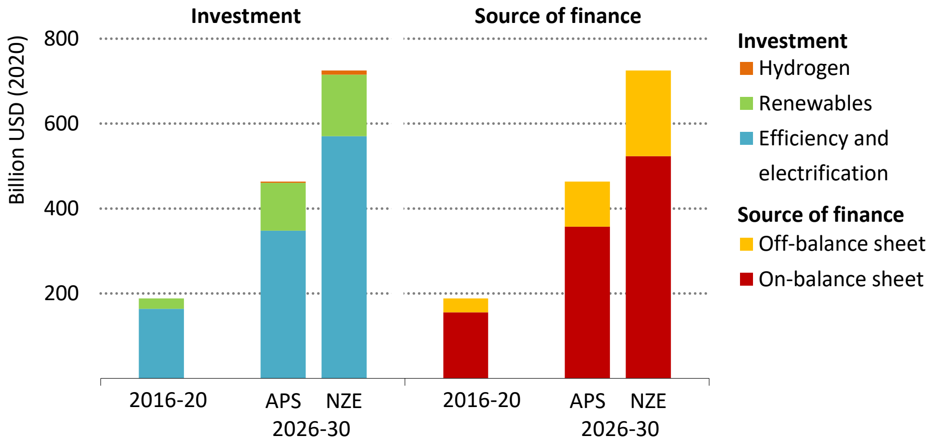
International co-operation to encourage the uptake of more efficient appliances and align MEPS and efficiency labelling has the potential to accelerate action and drive down the costs of efficient appliances. This is the ambition of the Super-Efficient Equipment and Appliance Deployment (SEAD) initiative, a collaboration among more than 20 governments, the IEA and other partners to accelerate and strengthen the design and implementation of energy efficiency policies for appliances and equipment. In 2020, SEAD and the COP26 presidency launched the COP26 Product Efficiency Call to Action, which aims to set countries on a trajectory to double the efficiency of key products sold globally by 2030. G7 leaders endorsed the Call at the 2021 Summit.

Financing the buildings sector transition to the NZE

Being on track for the NZE in the buildings sector requires additional annual clean energy investment of about USD 500 billion in this decade. This is almost four-times what has been spent in recent years and almost 60% higher than the projected level of investment in the APS. The largest gap is in emerging market and developing economies, where investment levels need to increase almost sevenfold by 2030 to stay on track.

Spending on energy saving measures today still relies heavily on the equity of households or companies, especially in emerging market and developing economies, and that remains the case in both the APS and NZE. However, new ways of quantifying energy savings, for instance through smart metering or energy performance contracts, open the door to innovative approaches that use future energy savings as collateral for upfront financing. New financing mechanisms such as leasing arrangements offered by energy services companies (ESCOs) relieve households from the requirement to mobilise initial capital, and offer an opportunity to finance economy-wide energy efficiency measures even in a context of constrained access to affordable finance. These measures are sometimes referred to as non-self-financed or off-balance sheet financing.

Figure 3.26 ▷ Average annual clean energy investment in buildings by type and source, 2016-2020, and by scenario, 2026-2030



Investment in the building sector almost quadruples by 2030 in the NZE, most of which is self-financed, but meeting NZE goals relies on enhancing external financing options

Note: Examples of off-balance sheet financing mechanisms include operating lease arrangements or energy performance shared savings contracts, where a household or a company uses energy efficient equipment provided by a third-party in exchange for rent payment.

In emerging market and developing economies, rapid urbanisation and development calls for huge investment in ensuring that new construction is zero carbon-ready, driven by the adoption of building energy codes. Expanding the use of green certification schemes could attract international refinancing and help to build local capacity ahead of the roll-out of a building energy code. Bulk procurement programmes like those used in India, where the ESCO Energy Efficiency Services Limited organised large-scale sourcing of efficient lighting and air conditioners, could drive down costs and help households in emerging market and developing economies purchase efficient and low-carbon equipment. Funding from development banks will be also essential to catalyse investment in net zero buildings in emerging market and developing economies. A commitment from development finance institutions to finance only zero carbon-ready buildings as part of their portfolios would send a clear signal to governments and investors about the world's commitment to decarbonise buildings and stay on track to reach climate goals.

In advanced economies, an annual retrofit rate of 2.5% of the existing building stock to meet zero carbon-ready building standards and electrification of end-uses such as heating together drive up investment needs in the NZE by 2030. Spending will rely heavily on the availability of dedicated financing options for both homeowners and tenants, for example through green recovery packages. The capitalisation of green banks with a specific mandate to raise and allocate funds for energy efficiency investments could help boost access and support the use of green finance. Green bonds designed to finance low-carbon buildings account for a quarter of the bonds issued under the Climate Bond Initiative since 2015, with this share ultimately expected to reach 40% (CBI, 2021). Green mortgage-backed securities that re-finance and crowd-in private sector investment in green buildings are also being issued in some advanced economies.

3.6 Methane emissions from fossil fuel operations

Current status and gap to the NZE

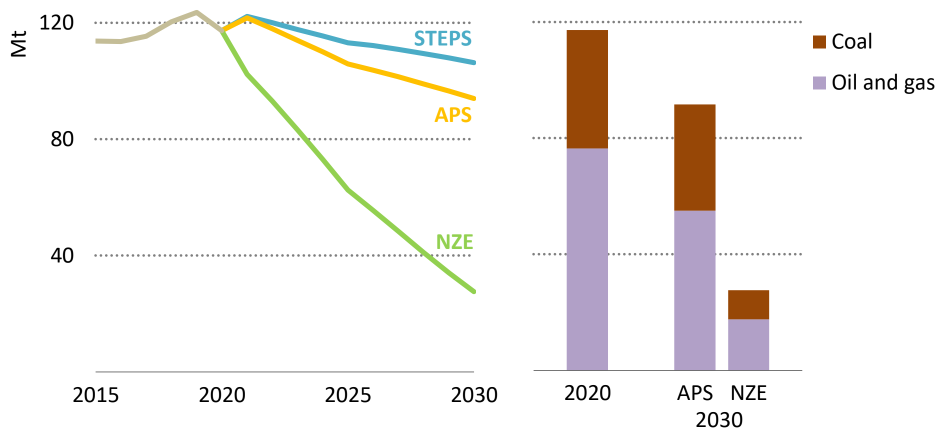
Methane emissions are the second-largest cause of global warming today. The recent IPCC Sixth Assessment Report highlighted that rapid and sustained reductions in these emissions are key to limit near-term warming (IPCC, 2021). The energy sector is one of the largest sources of methane emissions: we estimate that oil and gas operations emitted just over 76 Mt of methane globally in 2020 and that coal operations emitted a further 41 Mt. Total emissions in 2020 represented almost 10% of all energy sector GHG emissions. Methane emissions in 2021 are very far off a net zero by 2050 path.

Today methane emissions from fossil fuel operations are equivalent to around 3.5 Gt CO_2-eq.[17] In the NZE, total methane emissions from fossil fuels fall by around 2.7 Gt CO_2-eq between 2020 and 2030. To put this in perspective, the reduction in energy-related CO_2 emissions between 2020 and 2030 in the NZE is around 12 Gt, so this decline in methane emissions represents an additional 22% reduction in energy-related GHG emissions. Only about 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. Virtually all abatement measures in the oil and gas sector could be deployed cost-effectively over the next ten years in the NZE, and about two-thirds of measures in the coal sector as well.

The gap between methane emissions in the APS and NZE in 2030 is particularly large (almost 65 Mt) (Figure 3.27). This is largely because only about 40% of methane emissions from fossil fuel operations occur in countries with net zero pledges. The two largest emitters are China and Russia, which between them account for well over one-third of related methane sources, and they have not committed to absolute methane reductions before 2030.

[17] 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).

Figure 3.27 ▷ Methane emissions from fossil fuel operations to 2030 by scenario



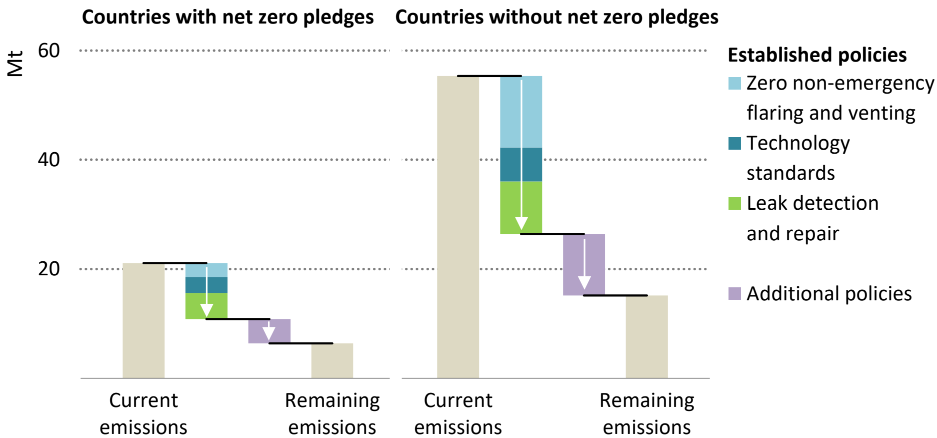
Most methane emissions originate in countries without net zero emissions pledges, resulting in a major gap between the APS and NZE

Closing the gap from the APS to the NZE

Even those countries committed to net zero goals are currently not doing enough to address methane emissions; more ambition is needed to manage both coal-related and oil and gas emissions. Coal methane reductions should be driven by a strong decline in coal production, complemented by policies to increase coal mine methane utilisation and abate emissions from abandoned mines. Oil and gas methane reductions should be driven by the deployment of a wide variety of generally well-known technologies and measures. If countries were to implement a set of well-established policy tools – namely leak detection and repair (LDAR) requirements, staple technology standards and a ban on non-emergency flaring and venting – related emissions could be halved within a very short timeframe (Figure 3.28).

- LDAR programmes are the primary strategy for addressing fugitive emissions from leaking components and malfunctioning equipment. The reduction potential of LDAR programmes depends on their scope, as well as the frequency and method of inspections. Current techniques often involve an on-the-ground inspection with optical gas imaging cameras, but new and emerging technologies, including continuous monitoring sensors, aircraft, drones and satellites, have significant potential to reduce the cost of detecting fugitive sources when used in combination with less frequent on-the-ground surveys. The more often inspections take place, the more quickly leaks are detected and abated; however, cost increases with frequency. For the purposes of this assessment, we assume adoption of a quarterly on-the-ground inspection requirement, a frequency that has been successfully implemented across a number of jurisdictions. Quarterly LDAR has been shown to reduce an estimated two-thirds of fugitive emissions, which would represent a reduction of almost 14.5 Mt methane (CH_4) if applied to all oil and gas operations.

Figure 3.28 ▷ Methane emissions abatement from oil and gas by policy tool



Established policy tools could drive over 70% of technically available methane emissions abatement options, though they need to be complemented with additional policies

- Technology standards are designed to reduce emissions associated with the normal operation of certain equipment, such as compressors or pneumatic devices. There are alternative technologies that can perform the same function as these components, but with lower or zero emissions. Regulations that set limits on emissions from certain types of equipment or that require the replacement with lower or preferably zero emitting alternatives could significantly reduce emissions. For the purposes of this analysis, this category includes measures that mandate the installation of well-known technologies at new facilities or the replacement of higher emitting components with lower emitting alternatives at existing projects. If policy makers adopted these measures, this would lead to a reduction of up to 9 Mt CH_4.
- Policies designed to achieve zero non-emergency flaring and venting could reduce methane emissions from intentional flaring and venting activities by as much as 15.5 Mt CH_4. Many alternatives to flaring are available to companies. While pipelines are one option, others include capture and reinjection, capture for use on site, or capture for compression to take by truck to processing facilities and then to market. Clamping down on flaring alone could create some perverse incentives to vent, which is much worse from an emissions perspective, and this underlines the importance of taking an integrated approach to flaring and venting.

Further reductions could come through policies that provide more flexibility for companies, but that rely on more robust measurement and verification systems, such as performance standards or emission taxes. We estimate that putting a price of USD 450 on each tonne of methane emitted (equivalent to USD 15/tonne CO_2-eq) would be enough to deploy nearly all of the abatement measures. Another possibility is to set company or facility-specific emissions limits which decline over time in line with country level climate goals. Where companies do not have the technical or financial resources to invest in methane abatement, offsetting systems or financing mechanisms may have a role to enable reductions. These instruments are particularly relevant for legacy sources such as abandoned wells and mines.

Countries with climate pledges may also be able to use their buying power to encourage trading partners to tackle methane emissions, given that over 40% of the oil and gas produced in countries without net zero pledges goes to countries with such pledges. Instruments such as preferential rates for lower carbon fuels, carbon border adjustment mechanisms, intensity standards or emissions certificates could underpin these efforts. However, policy support will also be necessary to ensure deep cuts in methane emissions in emerging market and developing economies, and could be provided through preferential financing schemes for abatement efforts, technical assistance and capacity building.

Based on average natural gas prices from 2017-21, almost 45% of current oil and gas methane emissions could be avoided at no net cost by abatement measures which cost less than the market value of the additional gas that is captured. This may lead to some voluntary action to reduce emissions, especially if markets value fuels with lower carbon intensity. However, a lack of information, inadequate infrastructure or misaligned investment incentives limit the extent to which companies will act on their own. Transparency mechanisms such as the planned International Methane Emissions Observatory[18] are likely to play an increasing role in helping the financing sector, policy makers and industry to ensure that deep cuts are made in methane emissions. Governments looking for swift methane reductions should start with their national oil company (NOC), if they have one: NOCs account for over 30% of methane emissions from oil production and almost 40% of emissions from natural gas production.

Annual investment of around USD 13 billion would be required to put into effect all available methane abatement measures in the oil and gas sector. This is less than the total value of the captured gas that could be sold, meaning that methane emissions from oil and gas operations could be reduced by close to 75% while providing overall savings to the global oil and gas industry. Recent technology developments, in particular satellite observation, promise to facilitate targeted action. Nevertheless, some obstacles still have to be overcome, including the lack of policy precedents in certain sectors, e.g. gas distribution, and limited regulatory and technical capacity in several jurisdictions. Outreach efforts and support for methane reduction strategies will be needed to bring all stakeholders together to act decisively on methane.

[18] The International Methane Emissions Observatory (IMEO), established by the UN Environment Programme with support from the European Union and in partnership with the IEA, is an initiative to collect and reconcile data from various sources, including company reporting through the Oil and Gas Methane Partnership 2.0, direct measurements from peer-reviewed studies, satellite observations, and national inventories.

3.7 Behavioural change

Getting to net zero depends to a significant extent on the choices made by people and companies. Although they are influenced by regulation and markets, the choices and values of consumers are not absolutely determined by them, and are of critical importance for clean energy transitions. Raising the level of climate ambition, however, requires more from consumers than a systematic preference to buy clean technologies. They also need to change behaviour to reduce their energy consumption and emissions footprint. In our scenarios, behavioural change refers to ongoing changes (which may be either brought about by regulations or voluntary) in the way that consumers use energy in daily life.[19]

This section discusses the different roles of behavioural change in the APS and NZE, and explores the extent to which such change is a critical factor in some end-uses in closing the gap between the scenarios in 2030.

3.7.1 Role of behavioural change and materials efficiency

The APS incorporates behavioural change in some regions which reduce energy-related activities compared to the Stated Policies Scenario (STEPS), but these changes are limited in both scale and scope.[20] This reflects the lack of announced government policies and commitments to building the public infrastructure that would be needed to bring about more comprehensive behavioural changes. Most of the impacts of these changes occur in industry. Technically straightforward options to boost materials efficiency such as extending the lifetime of buildings, increasing steel recycling rates and stepping up the reuse of chemicals contribute to an overall saving of 100 Mt CO_2 in 2030. There are also small reductions in road transport activity which reflect a move away from private mobility in favour of public transport in some regions, as well as small reductions in demand for passenger aviation, but energy service demand in buildings is the same in the APS as in the STEPS (Figure 3.29).

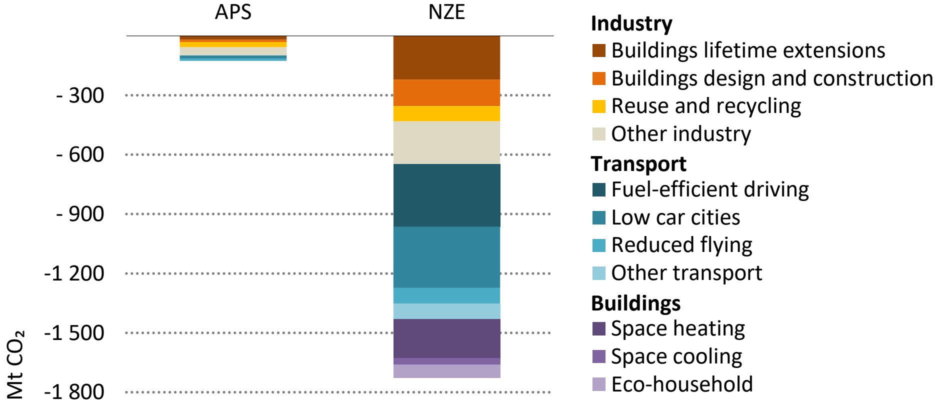
The behavioural changes in the NZE are far more comprehensive than those in the APS, and would require dedicated and sustained policy interventions. Around half of the emissions savings from behavioural changes in the NZE in 2030 are associated with transport. A further one-third of emissions savings come from improvements in materials efficiency in industry, and one-fifth from behavioural changes in buildings.

The behavioural changes in the NZE play a particularly important role in helping to accelerate emissions reductions in the period to 2030, including by reducing emissions from the continued use of existing carbon-intensive assets such as fossil fuel vehicles, or buildings that have not been retrofitted. In some end-uses, behavioural change plays a pivotal role in closing the ambition gap that separates the APS and the NZE in 2030 (Table 3.2). For the most part, behavioural change plays a more important role in closing this gap in advanced economies than in emerging market and developing economies.

[19] In addition to energy-related behavioural changes, pathways assessed by the IPCC which limit warming to 1.5 °C, as well as some national net zero plans, rely substantially on non energy-related behavioural changes, such as a shift towards lower meat diets, to reduce GHG emissions across the whole economy.

[20] Where specific policies have been announced to bring about behavioural changes in national net zero pledges, e.g. the banning of certain domestic aviation routes, these are incorporated in the APS.

Figure 3.29 ▷ Impact of behavioural change and materials efficiency by sector and scenario, 2030



Only limited behavioural changes are included in the APS, while the NZE projects far more, but needs targeted policies to realise them

Note: Materials efficiency gains in industry involve a mixture of technical innovation, standards and regulations to support best practice, as well as behavioural changes by manufacturers and the consumers of manufactured goods alike, such as increased recycling. Given the ambiguity in attributing materials efficiency gains to technology-driven avoided demand or behavioural change, the distinction between avoided demand and behaviour is not clear cut. We have allocated materials efficiency to avoided demand in Figure 3.9, which also includes structural and economic effects, such as the response of consumers to higher prices. In this figure 3.29 we include aspects of avoided demand in industry related to materials efficiency under behaviour.

In 2030, the impacts of specific behavioural changes include:

- **Road transport**: The most important measures for reducing emissions include phasing out the use of ICE cars in large cities, increasing the use of ridesharing for urban car trips and reducing speed limits on motorways. Together these save around 450 Mt CO_2 in 2030, which is two-thirds of the emissions saved by behavioural change in road transport.
- **Passenger aviation**: In advanced economies, keeping air travel for business purposes at 2019 levels by increasing the use of teleconferencing contributes 30% of the savings in emissions from international aviation in the NZE in 2030 compared to the APS; a lack of growth in long-haul flights for holidays delivers a further 20%.
- **Buildings**: Setting air conditioning at or above 24 °C plays a significant part in bringing emissions from space cooling down to the level in the NZE, generating around 15% of the savings in emissions from space cooling in the NZE compared to the APS in advanced economies and around 5% of the savings in emerging market and developing economies. Reducing space heating temperatures to 19-20 °C plays a similarly important part in cutting emissions from space heating to the level in the NZE in almost all regions: this measure alone reduces emissions by 200 Mt CO_2.

- **Industry**: Extending the lifetime of buildings reduces materials demand and helps cut emissions in industry. There are nine-times more lifetime extensions in the NZE than in the APS. This accounts for nearly 20% of the difference in emissions from cement production between scenarios in advanced economies, and more than 30% of the difference in emerging market and developing economies.

Table 3.2 ▷ Role of behavioural change in closing the ambition gap

End-use	Behavioural change	Advanced economies	Emerging market and developing economies	Co-benefits
Transport				
Cars	• Phase out ICE cars from large cities.	Significant	Significant	• Air pollution mitigation • Public health • Reduced congestion • Road safety • Reduced noise pollution • Improved oil security
	• Rideshare all urban car trips.	Significant	Significant	
	• Reduce motorway speed limits to 100 km/h.	Significant	Moderate	
	• Work from home three days each week.[21]	Moderate	Moderate	
Aviation	• Replace all flights where high-speed rail can be a feasible alternative.[22]	Moderate	Moderate	• Lower air pollution • Lower noise pollution
	• Keep air travel for business purposes at 2019 levels.	Critical	Significant	
	• Keep long-haul flights for leisure purposes at 2019 levels.	Critical	Moderate	
Buildings				
Space heating	• Target average set-point temperatures of 19-20 °C.	Critical	Critical	• Public health • Reduce energy bills
Space cooling	• Target average set-point temperatures of 24-25 °C.	Significant	Moderate	
Water heating	• Reduce set-point temperatures by 10 °C.[23]	Critical	Significant	
Industry				
Iron and steel	• Reuse and recycling.	Moderate	Moderate	• Cost savings • Incentivising R&D • Reduced waste pollution • Wildlife protection
	• Extend lifetime of facilities.	Significant	Moderate	
Cement	• Extend lifetime of facilities.	Critical	Critical	
	• Facility design and construction.	Significant	Significant	
Chemicals	• Reuse and recycling.	Moderate	Significant	

Key behavioural change: ● Critical ● Significant ● Moderate

[21] Only in the 20% of jobs worldwide which can be done from home (IEA, 2020b).

[22] Feasible here means that new rail routes avoid water bodies and elevated terrain; travel times between city centres are similar to flying; centres of demand are sufficiently large to ensure that high-speed rail is economically viable.

[23] Boiler temperatures of at least 60 °C are recommended to kill harmful bacteria (WHO, 2002).

Although the behavioural changes in the NZE would be enacted by people and companies, the onus is on governments to facilitate these changes through transparent and consistent policy support and messaging. Around 70% of the emissions saved by behavioural changes in the NZE in 2030 could be directly influenced or regulated by governments, for example by introducing low emissions zones in cities, or withdrawing licenses to operate regional air routes where a train alternative exists. The remaining emissions savings come from discretionary changes in peoples' lives, such as reducing the water temperature of domestic boilers. Although these types of changes are hard to target through policies or legislation, measures such as awareness campaigns can help to shape routines and habits, and there is a growing focus on how behavioural insights and social science can help shape policies most effectively, (e.g. see IEA, 2021a and IEA, 2021d).

Changes which are perceived as fair and just, particularly those which involve curbing excessive energy use, may be particularly well supported. Citizen assemblies, for example, have revealed widespread support for taxes and quotas to be applied to frequent and long-distance flyers (Climate Assembly UK, 2020). In some cases government legislation may need to lead the way on the basis that public support would strengthen as the co-benefits of the changes became apparent. For example, before congestion charging was introduced in Stockholm, it was supported by around 40% of the public. Five years after its introduction, support had increased to about 70% (Tools of Change, 2014). In other cases, public sentiment can change swiftly and prompt governments to react by introducing legislation and other policy measures. Increased awareness of the harmful environmental effects of single-use plastics is a recent example.

3.7.2 Behavioural changes in advanced economies and emerging market and developing economies

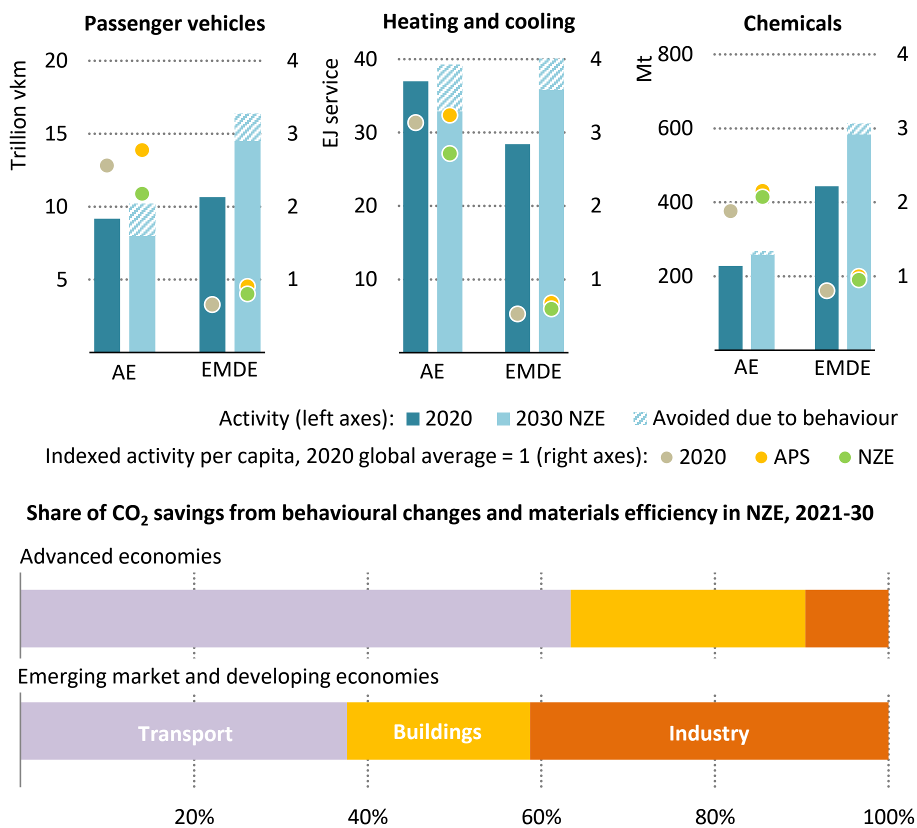
There are large differences in the use of energy services around the world, some of which reflect geographical and climatic variations across regions and others that reflect differing economic and development factors. For example, on a per capita basis, the number of kilometres driven by cars is about eight-times higher in advanced economies than in emerging market and developing economies, and demand for space cooling is more than four-times higher, even though emerging market and developing economies have around four-times more cooling degree days than advanced economies in a typical year.[24] Because of such variations, which for the most part persist in 2030 in spite of strong economic growth in emerging market and developing economies, the opportunities for behavioural change to make a significant impact in curbing energy demand in the near term are greater in advanced economies than emerging market and developing economies (Figure 3.30).

In the NZE, behavioural changes in road transport in advanced economies reduce passenger vehicle-kilometres by 22% in 2030, taking activity to just below the level in 2020. In contrast, the impact of behavioural changes in emerging market and developing economies is half of

[24] The number of cooling degree days is a measure of cooling demand. It represents the number of degrees that the average temperature during a day is above a given threshold temperature.

this in 2030, and per capita activity continues to expand from current levels by more than 35%. There is a similar split between the two groupings in the impact of behavioural changes on heating and cooling demand and other end-uses, with the result that behavioural changes in the NZE tend to reduce global inequalities in per capita energy consumption by 2030. In contrast to the transport and buildings sectors, the biggest opportunities for gains in materials efficiency are in emerging market and developing economies. For example, improvements in the design and construction of buildings and other infrastructure reduce demand for chemicals in emerging market and developing economies by 5%, or around 30 Mt, in 2030.

Figure 3.30 ▷ Behavioural change impact on energy-related activity and CO_2 emissions



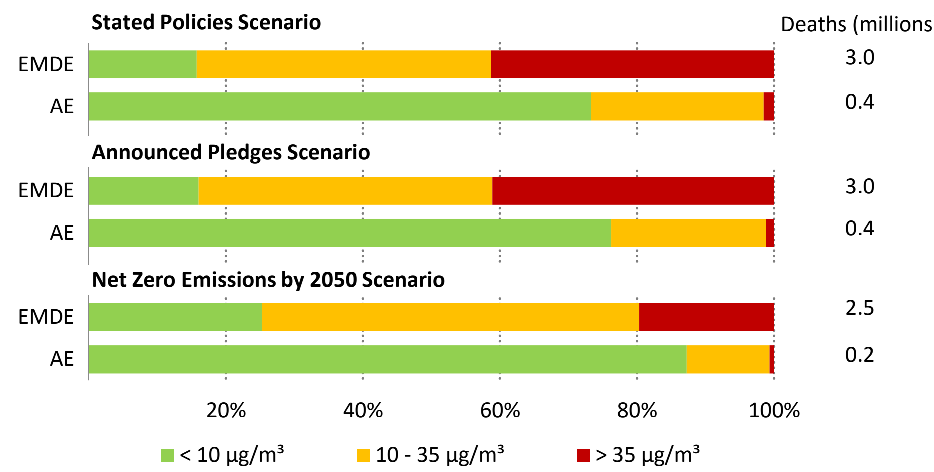
Behavioural changes play different roles at different levels of development, with materials efficiency particularly important in emerging market and developing economies

Notes: vkm = vehicle kilometre; EJ service = useful energy demand in EJ; Mt = million tonnes; AE = advanced economies; EMDE = emerging market and developing economies. Chemicals include ethylene, propylene, BTX, ammonia and methanol.

3.8 Announced pledges and air pollution

Over 90% of the world's population breathe polluted air on a daily basis, leading to more than 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. Almost 3 million premature deaths a year are caused by breathing polluted air from outdoor sources (ambient air pollution), and around 2.5 million are the result of breathing polluted air from household sources (household air pollution), due mainly to the traditional use of biomass for heating and cooking. The majority of premature deaths from ambient air pollution and almost all of those from household air pollution happen in emerging market and developing economies, where air pollution also comes with a significant economic cost: it is estimated to reduce the GDP of the largest emerging and developing economies by more than 5% per year (CREA, 2020).

Figure 3.31 ▷ Share of population exposed to various $PM_{2.5}$ concentrations and premature deaths from ambient air pollution in 2030



Exposure to high concentrations of $PM_{2.5}$ is reduced by more than half in the NZE relative to both the STEPS and APS, contributing to a 20% drop in premature deaths

Note: AE = advanced economies; EMDE = emerging market and developing economies; µg/m^3 = microgrammes per cubic metre.

Source: IEA analysis based on IIASA modelling.

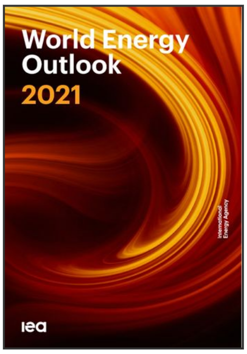
In the STEPS, the number of people exposed to polluted air continues to rise in emerging market and developing economies, where in 2030 over 40% of the population breathes air with concentrations of fine particulate matter ($PM_{2.5}$) exceeding 35 microgrammes per cubic metre (µg/m^3).[25] In contrast, only around 2% of people in advanced economies have long-term exposure to such $PM_{2.5}$ concentrations today, and this remains largely unchanged by 2030 in the STEPS. The annual number of premature deaths from ambient sources increases by around half a million in emerging market and developing economies by 2030, whereas it falls by around 25 000 in advanced economies. Premature deaths from household air pollution in emerging market and developing economies fall by just over 200 000 by 2030.

In the APS, announced pledges mean that slightly fewer people are exposed to high concentrations of $PM_{2.5}$ in 2030 than in the STEPS, mainly due to reductions in the traditional use of biomass to heat buildings and reduced emissions from industry. There is also an 8% drop in emissions of nitrogen oxides (NO_X), which reflects reductions in NO_X emissions in the industry and road transport sectors, and a 6% drop in sulphur dioxide (SO_2) emissions, which reflects a reduction in the use of coal in industrial facilities and electricity generation. This contributes to around 45 000 fewer premature deaths from ambient air pollution in 2030 than in the STEPS, with just over one-third of this reduction happening in emerging market and developing economies.

While the STEPS and APS see rising numbers 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, and around 250 000 fewer premature deaths from ambient air pollution. The number of people exposed to the highest concentrations of $PM_{2.5}$ halves compared to both the STEPS and the APS, while at the same time the number of people exposed to concentrations lower than 10 µg/m^3 – the threshold below which there is no identifiable impact on increased mortality – increases by around 40% (Figure 3.31).

The steep reduction in early mortality associated with air pollution in the NZE is a consequence of rapid cuts in all the main air pollutants. Even though emissions were suppressed in 2020 due to Covid-19 lockdowns and restrictions, both SO_2 and $PM_{2.5}$ emissions are almost two-thirds lower by 2030 than they were in 2020, and NO_X emissions are down by 40%. Reduced coal in electricity generation is the single biggest contributor to the reduction in SO_2 emissions, while burning less biomass in the buildings sector has the biggest impact on $PM_{2.5}$ emissions, and electrification of road transport reduces NO_X emissions the most.

[25] Fine particulate matter of less than 2.5 micrometres in diameter is known as $PM_{2.5}$. Concentrations greater than 35 µg/m^3 correspond to the least stringent air quality standard by the World Health Organisation and have been shown to be associated with significant mortality (WHO, 2006).



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