New energy security concerns emerge, and old ones remain

The contraction of oil and natural gas production will have far-reaching implications for all the countries and companies that produce these fuels. No new oil and natural gas fields are needed in our pathway, and oil and natural gas supplies become increasingly concentrated in a small number of low-cost producers. For oil, the OPEC share of a much-reduced global oil supply increases from around 37% in recent years to 52% in 2050, a level higher than at any point in the history of oil markets. Yet annual per capita income from oil and natural gas in producer economies falls by about 75%, from USD 1 800 in recent years to USD 450 by the 2030s, which could have knock-on societal effects. Structural reforms and new sources of revenue are needed, even though these are unlikely to compensate fully for the drop in oil and gas income. While traditional supply activities decline, the expertise of the oil and natural gas industry fits well with technologies such as hydrogen, CCUS and offshore wind that are needed to tackle emissions in sectors where reductions are likely to be most challenging.

The energy transition requires substantial quantities of critical minerals, and their supply emerges as a significant growth area. The total market size of critical minerals like copper, cobalt, manganese and various rare earth metals grows almost sevenfold between 2020 and 2030 in the net zero pathway. Revenues from those minerals are larger than revenues from coal well before 2030. This creates substantial new opportunities for mining companies. It also creates new energy security concerns, including price volatility and additional costs for transitions, if supply cannot keep up with burgeoning demand.

The rapid electrification of all sectors makes electricity even more central to energy security around the world than it is today. Electricity system flexibility – needed to balance wind and solar with evolving demand patterns – quadruples by 2050 even as retirements of fossil fuel capacity reduce conventional sources of flexibility. The transition calls for major increases in all sources of flexibility: batteries, demand response and low-carbon flexible power plants, supported by smarter and more digital electricity networks. The resilience of electricity systems to cyberattacks and other emerging threats needs to be enhanced.

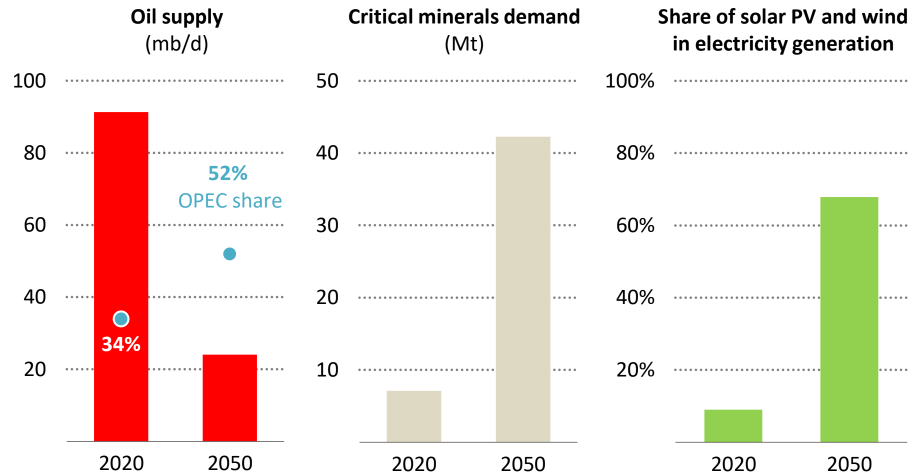
PRIORITY ACTION

Address emerging energy security risks now

Ensuring uninterrupted and reliable supplies of energy and critical energy-related commodities at affordable prices will only rise in importance on the way to net zero.

The focus of energy security will evolve as reliance on renewable electricity grows and the role of oil and gas diminishes. Potential vulnerabilities from the increasing importance of electricity include the variability of supply and cybersecurity risks. Governments need to create markets for investment in batteries, digital solutions and electricity grids that reward flexibility and enable adequate and reliable supplies of electricity. The growing dependence on critical minerals required for key clean energy technologies calls for new international mechanisms to ensure both the timely availability of supplies and sustainable production. At the same time, traditional energy security concerns will not disappear, as oil production will become more concentrated.

Global energy security indicators in the net zero pathway



Note: mb/d = million barrels per day; Mt = million tonnes.

International co-operation is pivotal for achieving net-zero emissions by 2050

Making net-zero emissions a reality hinges on a singular, unwavering focus from all governments – working together with one another, and with businesses, investors and citizens. All stakeholders need to play their part. The wide-ranging measures adopted by governments at all levels in the net zero pathway help to frame, influence and incentivise the purchase by consumers and investment by businesses. This includes how energy companies invest in new ways of producing and supplying energy services, how businesses invest in equipment, and how consumers cool and heat their homes, power their devices and travel.

Underpinning all these changes are policy decisions made by governments. Devising cost-effective national and regional net zero roadmaps demands co-operation among all parts of government that breaks down silos and integrates energy into every country's policy making on finance, labour, taxation, transport and industry. Energy or environment ministries alone cannot carry out the policy actions needed to reach net zero by 2050.

Changes in energy consumption result in a significant decline in fossil fuel tax revenues. In many countries today, taxes on diesel, gasoline and other fossil fuel consumption are an important source of public revenues, providing as much as 10% in some cases. In the net zero pathway, tax revenue from oil and gas retail sales falls by about 40% between 2020 and 2030. Managing this decline will require long-term fiscal planning and budget reforms.

The net zero pathway relies on unprecedented international co-operation among governments, especially on innovation and investment. The IEA stands ready to support governments in preparing national and regional net zero roadmaps, to provide guidance and assistance in implementing them, and to promote international co-operation to accelerate the energy transition worldwide.

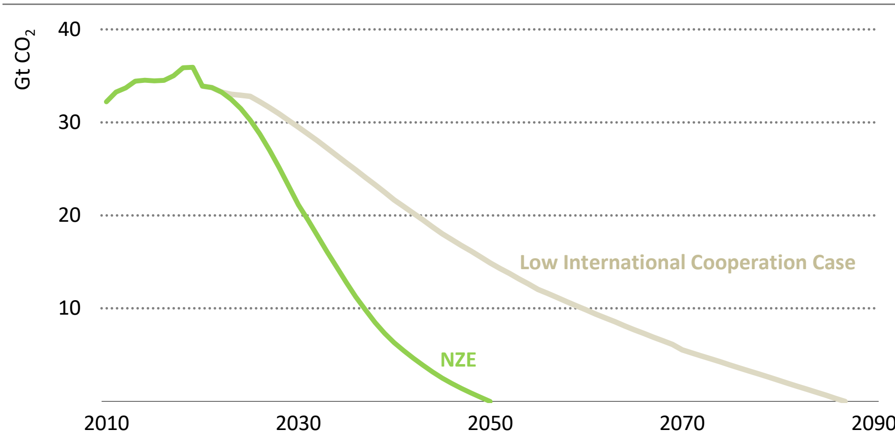
PRIORITY ACTION

Take international co-operation to new heights

This is not simply a matter of all governments seeking to bring their national emissions to net zero – it means tackling global challenges through co-ordinated actions.

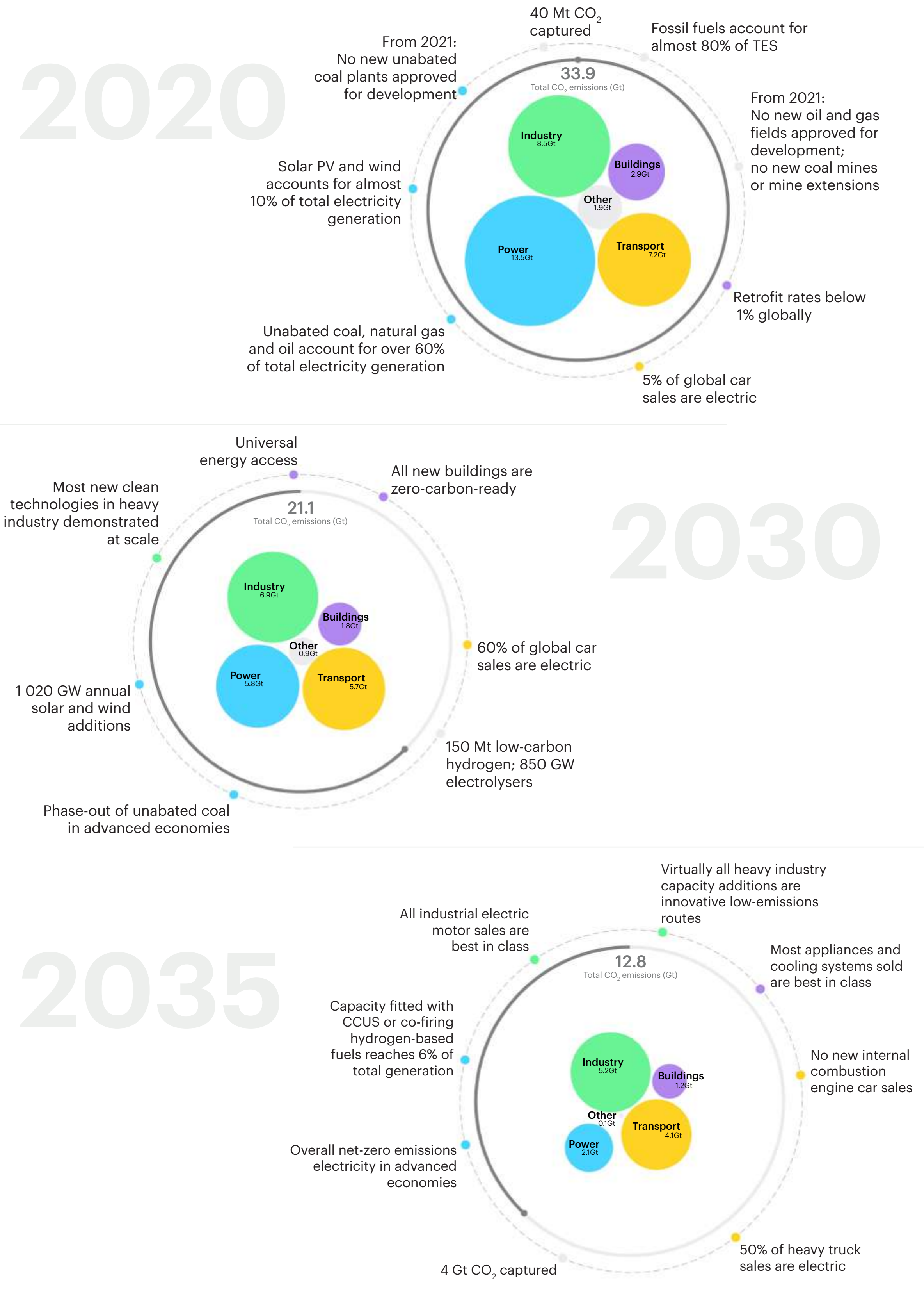
Governments must work together in an effective and mutually beneficial manner to implement coherent measures that cross borders. This includes carefully managing domestic job creation and local commercial advantages with the collective global need for clean energy technology deployment. Accelerating innovation, developing international standards and co-ordinating to scale up clean technologies needs to be done in a way that links national markets. Co-operation must recognise differences in the stages of development of different countries and the varying situations of different parts of society. For many rich countries, achieving net-zero emissions will be more difficult and costly without international co-operation. For many developing countries, the pathway to net zero without international assistance is not clear. Technical and financial support is needed to ensure deployment of key technologies and infrastructure. Without greater international co-operation, global CO_2 emissions will not fall to net zero by 2050.

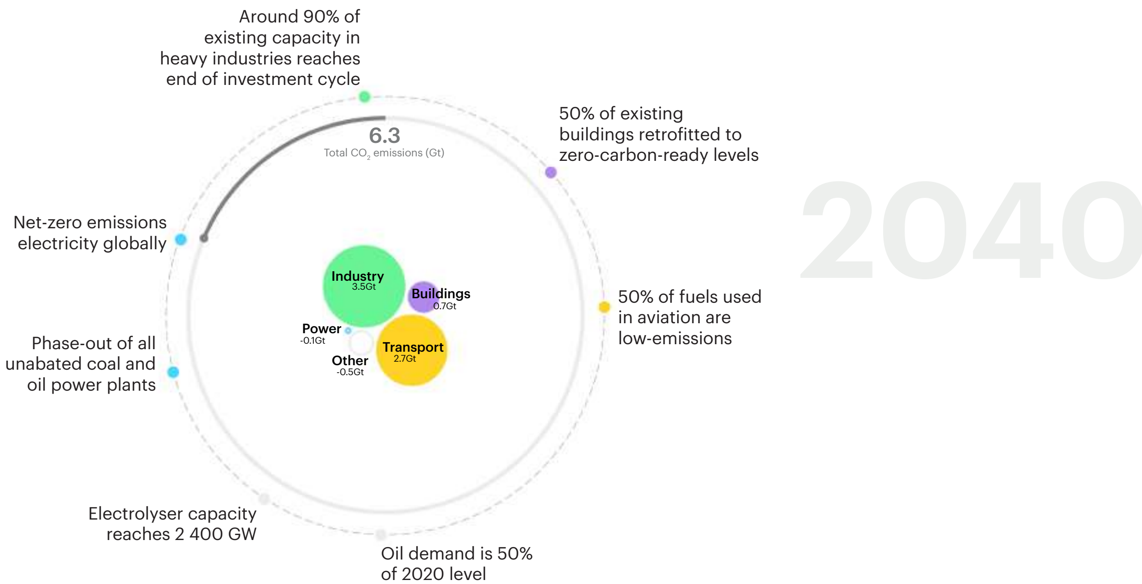
Global energy-related CO_2 emissions in the net zero pathway and Low International Co-operation Case

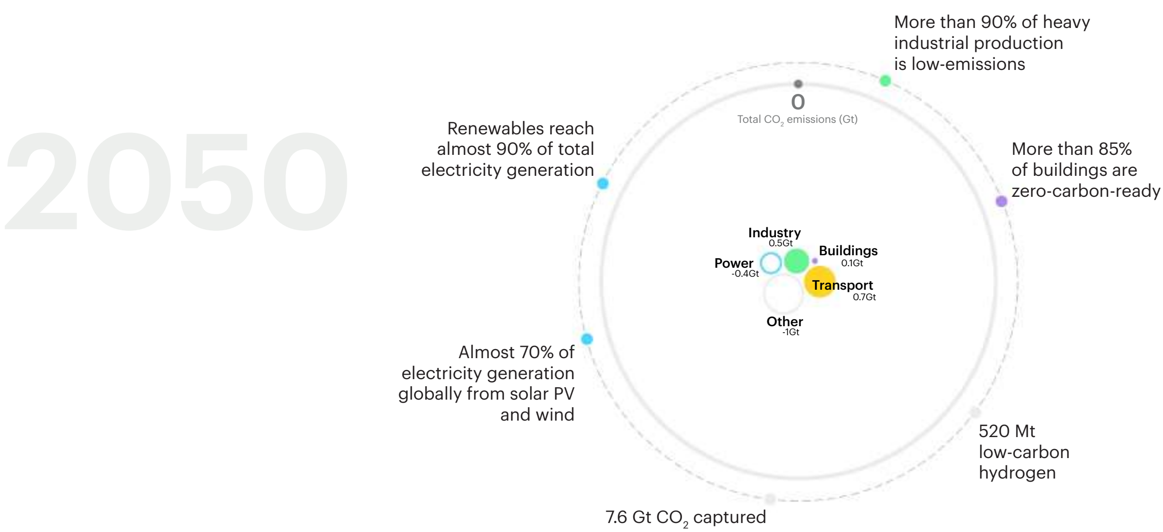


Note: Gt = gigatonnes.

Net Zero Emissions by 2050 Interactive iea.li/nzeroadmap







Net Zero Emissions by 2050 Interactive iea.li/nzeroadmap

Announced net zero pledges and the energy sector

SUMMARY

- There has been a rapid increase over the last year in the number of governments pledging to reduce greenhouse gas emissions to net zero. Net zero pledges to date cover around 70% of global GDP and CO_2 emissions. However, fewer than a quarter of announced net zero pledges are fixed in domestic legislation and few are yet underpinned by specific measures or policies to deliver them in full and on time.
- The Stated Policies Scenario (STEPS) takes account only of specific policies that are in place or have been announced by governments. Annual energy-related and industrial process CO_2 emissions rise from 34 Gt in 2020 to 36 Gt in 2030 and remain around this level until 2050. If emissions continue on this trajectory, with similar changes in non-energy-related GHG emissions, this would lead to a temperature rise of around 2.7 °C by 2100 (with a 50% probability). Renewables provide almost 55% of global electricity generation in 2050 (up from 29% in 2020), but clean energy transitions lag in other sectors. Global coal use falls by 15% between 2020 and 2050; oil use in 2050 is 15% higher than in 2020; and natural gas use is almost 50% higher.
- The Announced Pledges Case (APC) assumes that all announced national net zero pledges are achieved in full and on time, whether or not they are currently underpinned by specific policies. Global energy-related and industrial process CO_2 emissions fall to 30 Gt in 2030 and 22 Gt in 2050. Extending this trajectory, with similar action on non-energy-related GHG emissions, would lead to a temperature rise in 2100 of around 2.1 °C (with a 50% probability). Global electricity generation nearly doubles to exceed 50 000 TWh in 2050. The share of renewables in electricity generation rises to nearly 70% in 2050. Oil demand does not return to its 2019 peak and falls about 10% from 2020 to 80 mb/d in 2050. Coal use drops by 50% to 2 600 Mtce in 2050, while natural gas use expands by 10% to 4 350 bcm in 2025 and remains about that level to 2050.
- Efficiency, electrification and the replacement of coal by low-emissions sources in electricity generation play a central role in achieving net zero goals in the APC, especially over the period to 2030. The relative contributions of nuclear, hydrogen, bioenergy and CCUS vary across countries, depending on their circumstances.
- The divergence in trends between the APC and the STEPS shows the difference that current net zero pledges could make, while underlining at the same time the need for concrete policies and short-term plans that are consistent with long-term net zero pledges. However, the APC also starkly highlights that existing net zero pledges, even if delivered in full, fall well short of what is necessary to reach global net-zero emissions by 2050.

1.1 Introduction

November 2021 will see the most important UN Framework Convention on Climate Change (UNFCCC) Conference of the Parties (COP 26) since the Paris Agreement was signed in 2015. As COP 26 approaches, an increasing number of countries have announced long-term goals to achieve net-zero greenhouse gas (GHG) emissions over the coming decades. On 31 March 2021, the International Energy Agency (IEA) hosted a Net Zero Summit to take stock of the growing list of commitments from countries and companies to reach the goals of the Paris Agreement, and to focus on the actions necessary to start turning those net zero goals into reality.

Achieving those goals will be demanding. The Covid-19 pandemic delivered a major shock to the world economy, resulting in an unprecedented 5.8% decline in CO_2 emissions in 2020. However, our monthly data show that global energy-related CO_2 emissions started to climb again in December 2020, and we estimate that they will rebound to around 33 gigatonnes of carbon dioxide (Gt CO_2) in 2021, only 1.2% below the level in 2019 (IEA, 2021). Sustainable economic recovery packages offered a unique opportunity to make 2019 the definitive peak in global emissions, but the evidence so far points to a rebound in emissions in parallel with renewed economic growth, at least in the near term (IEA, 2020a).

Recent IEA analyses examined the technologies and policies needed for countries and regions to achieve net-zero emissions energy systems. The *World Energy Outlook 2020* examined what would be needed over the period to 2030 to put the world on a path towards net-zero emissions by 2050 in the context of the pandemic-related economic recovery (IEA, 2020b). The Faster Innovation Case in *Energy Technology Perspectives 2020* explored whether net-zero emissions could be achieved globally by 2050 through accelerated energy technology development and deployment alone: it showed that, relative to baseline trends, almost half of the emissions savings needed in 2050 to reach net-zero emissions rely on technologies that are not yet commercially available (IEA, 2020c).

This special report, prepared at the request of the UK President of the COP 26, incorporates the insights and lessons learned from both reports to create a comprehensive and detailed pathway, or roadmap, to achieve net-zero energy-related and industrial process CO_2 emissions globally by 2050. It assesses the costs of achieving this goal, the likely impacts on employment and the economy, and the wider implications for the world. It also highlights the key milestones for technologies, infrastructure, investment and policy that are needed along the road to 2050.

This report is set out in four chapters:

- **Chapter 1** explores the outlook for global CO_2 emissions and energy supply and use based on existing policies and pledges. It sets out projections of global energy use and emissions based on the **Stated Policies Scenario (STEPS)**, which includes only the firm policies that are in place or have been announced by countries, including Nationally

Determined Contributions. It also examines the **Announced Pledges Case (APC)**, a variant of the STEPS that assumes that all of the net zero targets announced by countries around the world to date are met in full.

- **Chapter 2** presents the **Net-Zero Emissions by 2050 Scenario (NZE)**, which describes how energy demand and the energy mix will need to evolve if the world is to achieve net-zero emissions by 2050. It also assesses the corresponding investment needs and explores key uncertainties surrounding technology and consumer behaviour.
- **Chapter 3** examines the implications of the NZE for various sectors, covering fossil fuel supply, the supply of low-emissions fuels (such as hydrogen, ammonia, biofuels, synthetic fuels and biomethane) and the electricity, transport, industry and buildings sectors. It highlights the key changes required to achieve net-zero emissions in the NZE and the major milestones that are needed along the way.
- **Chapter 4** explores the implications of the NZE for the economy, the energy industry, citizens and governments.

1.2 Emissions reduction targets and net zero pledges

1.2.1 Nationally Determined Contributions

Under the Paris Agreement, Parties[1] are required to submit Nationally Determined Contributions (NDCs) to the UNFCCC and to implement policies with the aim of achieving their stated objectives. The process is dynamic; it requires Parties to update their NDCs every five years in a progressive manner to reflect the highest possible ambition. The first round of NDCs, submitted by 191 countries, covers more than 90% of global energy-related and industrial process CO_2 emissions.[2] The first NDCs included some targets that were unconditional and others that were conditional on international support for finance, technology and other means of implementation.

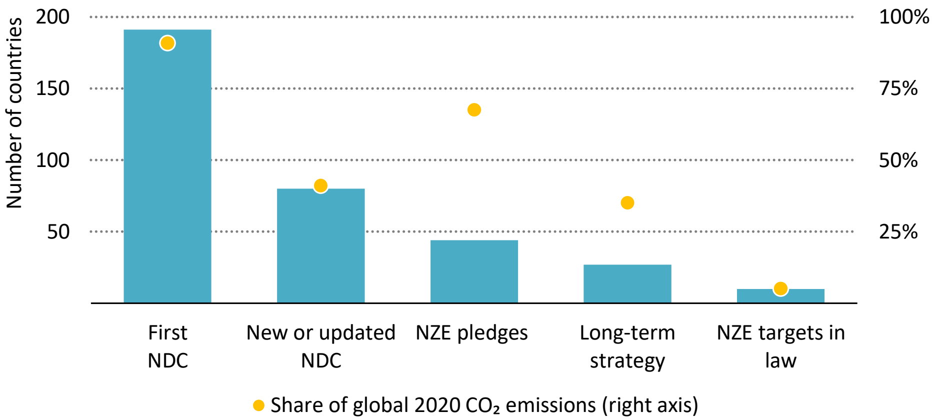
As of 23 April 2021, 80 countries have submitted new or updated NDCs to the UNFCCC, covering just over 40% of global CO_2 emissions (Figure 1.1).[3] Many of the updated NDCs include more stringent targets than in the initial round of NDCs, or targets for a larger number of sectors or for a broader coverage of GHGs. In addition, 27 countries and the European Union have communicated long-term low GHG emissions development strategies to the UNFCCC, as requested by the Paris Agreement. Some of these strategies incorporate a net zero pledge.

[1] Parties refers to the 197 members of the UNFCCC which includes all United Nations member states, United Nations General Assembly Observer State of Palestine, UN non-member states Niue and the Cook Islands and the European Union.

[2] Unless otherwise stated, CO_2 emissions in this report refer to energy-related and industrial process CO_2 emissions.

[3] Several countries have indicated that they intend to submit new or updated NDCs later in 2021 or in 2022.

Figure 1.1 ▷ Number of countries with NDCs, long-term strategies and net zero pledges, and their shares of 2020 global CO_2 emissions



Around 40% of countries that have ratified the Paris Agreement have updated their NDCs, but net zero pledges cover around 70% of global CO_2 emissions

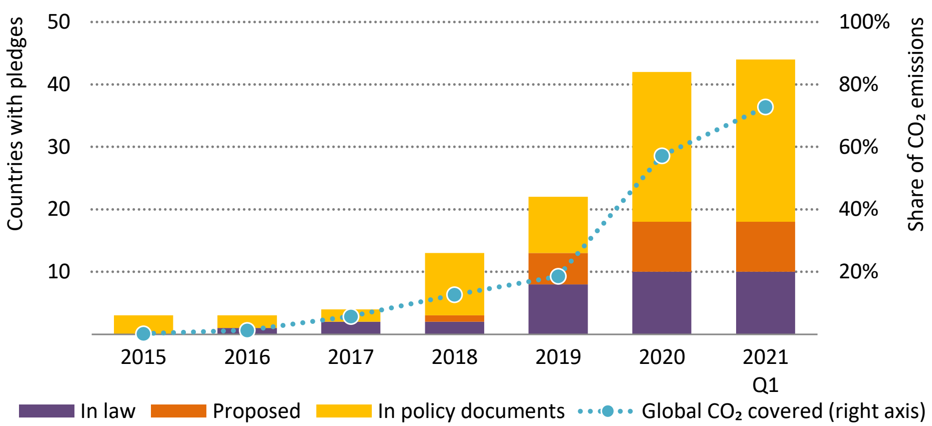
1.2.2 Net-zero emissions pledges

There has been a rapid increase in the number of governments making pledges to reduce GHG emissions to net zero (Figure 1.2). In the Paris Agreement, countries agreed to "achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second-half of the century". The Intergovernmental Panel on Climate Change (IPCC) *Special Report on Global Warming of 1.5 °C* highlighted the importance of reaching net-zero CO_2 emissions globally by mid-century or sooner to avoid the worst impacts of climate change (IPCC, 2018).

Net-zero emissions pledges have been announced by national governments, subnational jurisdictions, coalitions[4] and a large number of corporate entities (see Spotlight). As of 23 April 2021, 44 countries and the European Union have pledged to meet a net-zero emissions target: in total they account for around 70% of global CO_2 emissions and GDP (Figure 1.3). Of these, ten countries have made meeting their net zero target a legal obligation, eight are proposing to make it a legal obligation, and the remainder have made their pledges in official policy documents.

[4] Examples include: the UN-led Climate Ambition Alliance in which signatories signal they are working towards achieving net-zero emissions by 2050; and the Carbon Neutrality Coalition launched at the UN Climate Summit in 2017, in which signatories commit to develop long-term low GHG emissions strategies in line with limiting temperature rises to 1.5 °C.

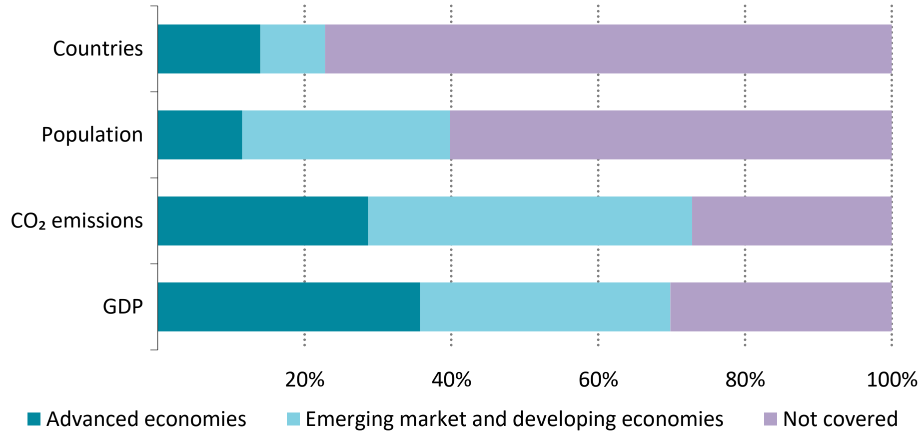
Figure 1.2 ▷ **Number of national net zero pledges and share of global CO_2 emissions covered**



There has been a significant acceleration in net-zero emissions pledges announced by governments, with an increasing number enshrined in law

Notes: In law = a net zero pledge has been approved by parliament and is legally binding. Proposed = a net zero pledge has been proposed to parliament to be voted into law. In policy document = a net zero pledge has been proposed but does not have legally binding status.

Figure 1.3 ▷ **Coverage of announced national net zero pledges**



Countries accounting for around 70% of global CO_2 emissions and GDP have set net zero pledges in law, or proposed legislation or in an official policy document

Note: GDP = gross domestic product at purchasing power parity.

In contrast to some of the shorter term commitments contained within NDCs, few net zero pledges are supported by detailed policies and firm routes to implementation. Net-zero emissions pledges also vary considerably in their timescale and scope. Some key differences include:

- **GHG coverage.** Most pledges cover all GHG emissions, but some include exemptions or different rules for certain types of emissions. For example, New Zealand's net zero pledge covers all GHGs except biogenic methane, which has a separate reduction target.
- **Sectoral boundaries**. Some pledges exclude emissions from specific sectors or activities. For example, the Netherlands aims to achieve net-zero GHG emissions only in its electricity sector (as part of an overall aim to reduce total GHG emissions by 95%), and some countries, including France, Portugal and Sweden, exclude international aviation and shipping.
- **Use of carbon dioxide removal (CDR)**. Pledges take varying approaches to account for CDR within a country's sovereign territory. CDR options include natural CO_2 sinks, such as forests and soils, as well as technological solutions, such as direct air capture or bioenergy with carbon capture and storage. For example, Uruguay has stated that natural CO_2 sinks will be used to help it reach net-zero emissions, while Switzerland plans to use CDR technologies to balance a part of its residual emissions in 2050.
- **Use of international mitigation transfers**. Some pledges allow GHG mitigation that occurs outside a country's borders to be counted towards the net zero target, such as through the transfer of carbon credits, while others do not. For example, Norway allows the potential use of international transfers, while France explicitly rules them out. Some countries, such as Sweden, allow such transfers but specify an upper limit to their use.
- **Timeframe**. The majority of pledges, covering 35% of global CO_2 emissions in 2020, target net-zero emissions by 2050, but Finland aims to reach that goal by 2035, Austria and Iceland by 2040 and Sweden by 2045. Among others, the People's Republic of China (hereafter China) and Ukraine have set a target date after 2050.

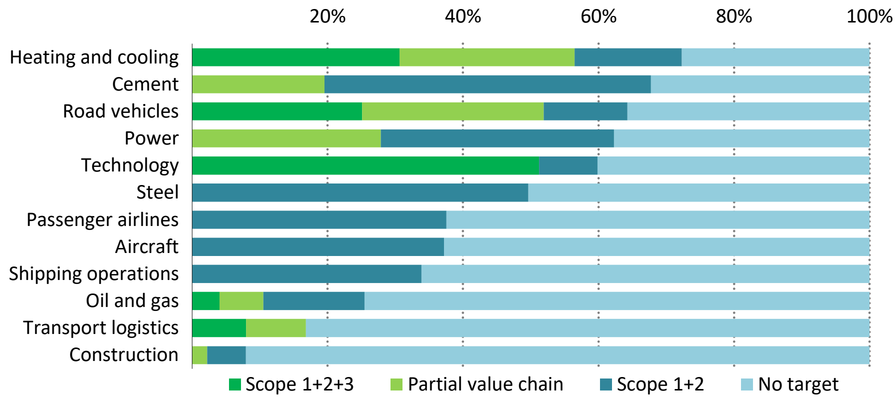
S P O T L I G H T

How are businesses responding to the need to reach net-zero emissions?

There has been a rapid rise in net-zero emissions announcements from companies in recent years: as of February 2021, around 110 companies that consume large amounts of energy directly or produce energy-consuming goods have announced net-zero emissions goals or targets.

Around 60-70% of global production of heating and cooling equipment, road vehicles, electricity and cement is from companies that have announced net-zero emissions targets (Figure 1.4). Nearly 60% of gross revenue in the technology sector is also generated by companies with net-zero emission targets. In other sectors, net zero pledges cover 30-40% of air and shipping operations, 15% of transport logistics and 10% of construction. All these shares are likely to keep growing as more companies make pledges.

Figure 1.4 ▷ Sectoral activity of large energy-related companies with announced pledges to reach net-zero emissions by 2050



Some sectors are more advanced in terms of the extent of net zero targets by companies active in the sector

Notes: Scope 1 = direct emissions from energy and other sources owned or controlled. Scope 2 = indirect emissions from the production of electricity and heat, and fuels purchased and used. Scope 3 = indirect emissions from sources not owned or directly controlled but related to their activities (such as employee travel, extraction, transport and production of purchased materials and fuels, and end-use of fuels, products and services). Partial value chain includes Scope 1 and 2 emissions and Scope 3 emissions in specific geographic locations or sections of a company's value chain.

Source: IEA analysis based on company reports from the largest 10-25 companies within each sector.

Company pledges may not be readily comparable. Most companies account for emissions and set net zero pledges based on the GHG Protocol (WRI, WBCSD, 2004), but the coverage and timeframe of these pledges varies widely. Some cover only their own emissions, for example by shifting to the use of zero-emissions electricity in offices and production facilities, and by eliminating the use of oil in transport or industrial operations, e.g. FedEx, ArcelorMittal and Maersk. Others also cover wider emissions from certain parts of their values chains, e.g. Renault in Europe, or all indirect emissions related to their activities, e.g. Daikin, Toyota, Shell, Eni and Heidelberg. Around 60% of pledges aim to achieve net-zero emissions by 2050, but several companies have set an earlier deadline of 2030 or 2040.

Around 40% of companies that have announced net zero pledges have yet to set out how they aim to achieve them. For those with detailed plans, the main options include direct emissions reductions, use of CO_2 removal technologies, such as afforestation, bioenergy with carbon capture, utilisation and storage (CCUS), or direct air capture with CO_2 storage, and purchasing emissions (credits generated through emissions reductions that occur elsewhere). The use of offsets could be a cost-effective mechanism to eliminate emissions from parts of value chains where emissions reductions are most challenging, provided that schemes to generate emissions credits result in permanent, additional and verified emissions reductions. However, there is likely to be a limited supply of emissions credits consistent with net-zero emissions globally and the use of such credits could divert investment from options that enable direct emissions reductions.

1.3 Outlook for emissions and energy in the STEPS

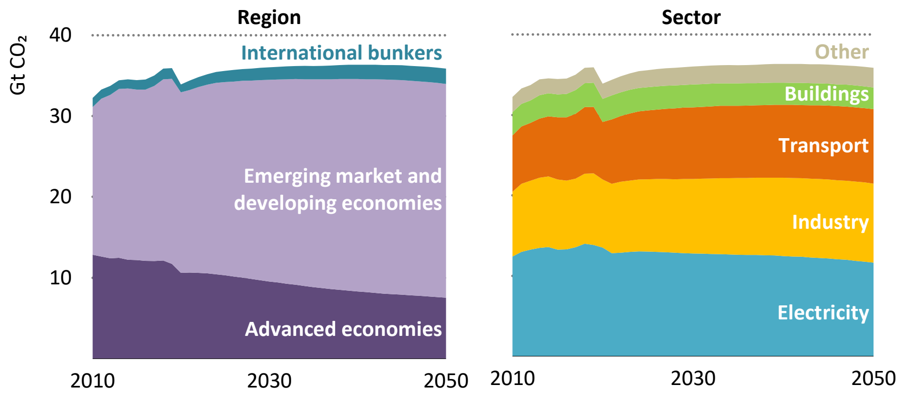
The IEA Stated Policies Scenario (STEPS) illustrates the consequences of existing and stated policies for the energy sector. It draws on the latest information regarding national energy and climate plans and the policies that underpin them. It takes account of all policies that are backed by robust implementing legislation or regulatory measures, including the NDCs that countries have put forward under the Paris Agreement up to September 2020 and the energy components of announced economic stimulus and recovery packages. So far, few net-zero emissions pledges have been backed up by detailed policies, implementation plans or interim targets: most net zero pledges therefore are not included in the STEPS.

1.3.1 CO_2 emissions

Global CO_2 emissions in the STEPS bring about only a marginal overall improvement in recent trends. Switching to renewables leads to an early peak in emissions in the electricity sector, but reductions across all sectors fall far short of what is required for net-zero emissions in 2050. Annual CO_2 emissions rebound quickly from the dip caused by the Covid-19 pandemic in 2020: they increase from 34 Gt in 2020 to 36 Gt in 2030 and then remain around this level until 2050 (Figure 1.5). If emissions trends were to continue along the same trajectory after 2050, and with commensurate changes in other sources of GHG emissions, the global average surface temperature rise would be around 2.7 °C in 2100 (with a 50% probability).

There is strong divergence between the outlook for emissions in advanced economies on one hand and the emerging market and developing economies on the other. In advanced economies, despite a small rebound in the early 2020s, CO_2 emissions decline by about a third between 2020 and 2050, thanks to the impact of policies and technological progress in reducing energy demand and switching to cleaner fuels. In emerging market and developing economies, energy demand continues to grow strongly because of increased population, brisk economic growth, urbanisation and the expansion of infrastructure: these effects outweigh improvements in energy efficiency and the deployment of clean technologies, causing CO_2 emissions to grow by almost 20% by the mid-2040s, before declining marginally to 2050.

Figure 1.5 ▷ Energy-related and industrial process CO_2 emissions by region and sector in the STEPS



Global CO_2 emissions rebound quickly after 2020 and then plateau, with declines in advanced economies offset by increases elsewhere

Note: Other = agriculture and own use in the energy sector.

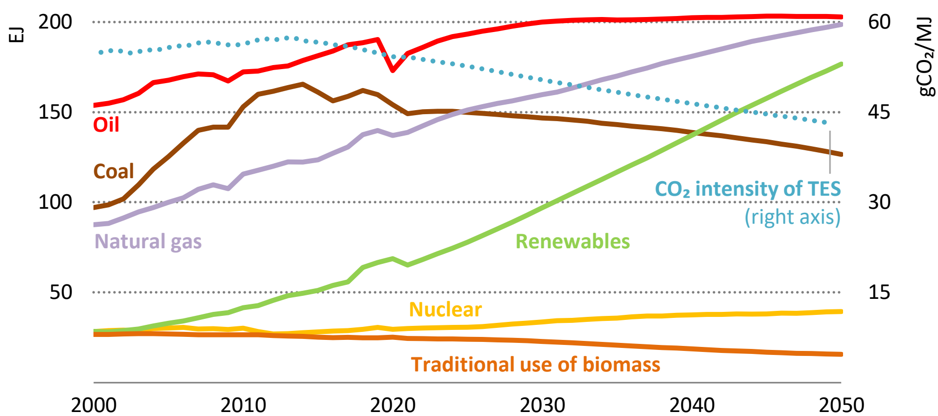
1.3.2 Total energy supply, total final consumption and electricity generation

The projected trends in CO_2 emissions in the STEPS result from changes in the amount of energy used and the mix of fuels and technologies. Total energy supply (TES)[5] worldwide rises by just over 30% between 2020 and 2050 in the STEPS (Figure 1.6). Without a projected annual average reduction of 2.2% in energy intensity, i.e. energy use per unit of GDP, TES in 2050 would be around 85% higher. In advanced economies, energy use falls by around 5% to 2050, despite a 75% increase in economic activity over the period. In emerging market and developing economies, energy use increases by 50% to 2050, reflecting a tripling of economic output between 2020 and 2050. Despite the increase in GDP and energy use in emerging market and developing economies, 750 million people still have no access to electricity in 2050, more than 95% of them in sub-Saharan Africa, and 1.5 billion people continue to rely on the traditional use of bioenergy for cooking.

The global fuel mix changes significantly between 2020 and 2050. Coal use, which peaked in 2014, falls by around 15%. Having fallen sharply in 2020 due to the pandemic, oil demand rebounds quickly, returning to the 2019 level of 98 million barrels per day (mb/d) by 2023 and reaching a plateau of around 104 mb/d shortly after 2030. Natural gas demand increases from 3 900 billion cubic metres (bcm) in 2020 to 4 600 bcm in 2030 and 5 700 bcm in 2050. Nuclear energy grows by 15% between 2020 and 2030, mainly reflecting expansions in China.

[5] Total primary energy supply (or total primary energy demand) has been renamed total energy supply in accordance with the International Recommendations for Energy Statistics (IEA, 2020d).

Figure 1.6 ▷ Total energy supply and CO_2 emissions intensity in the STEPS

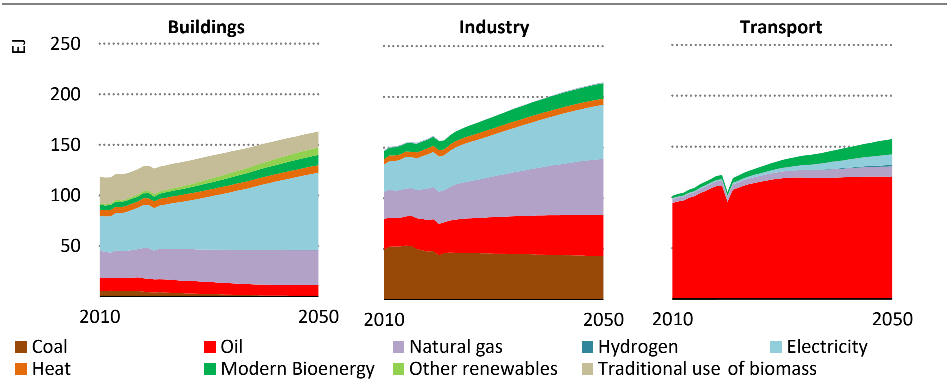


Coal use declines, oil plateaus and renewables and natural gas grow substantially to 2050

Note: EJ = exajoule; MJ = megajoule; TES = total energy supply.

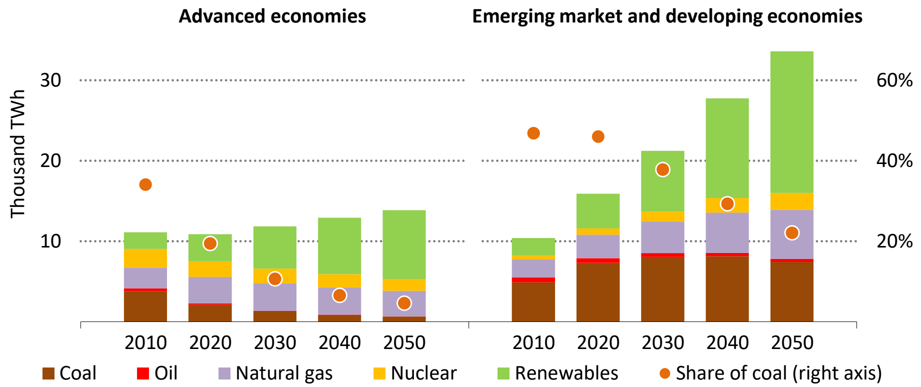
Total final consumption increases in all sectors in the STEPS, led by electricity and natural gas (Figure 1.7). All the growth is in emerging market and developing economies. The biggest change in energy use is in the electricity sector (Figure 1.8). Global electricity demand increases by 80% between 2020 and 2050, around double the overall rate of growth in final energy consumption. More than 85% of the growth in global electricity demand comes from emerging market and developing economies. Coal continues to play an important role in electricity generation in those economies to 2050, despite strong growth in renewables: in advanced economies, the use of coal for electricity generation drops sharply.

Figure 1.7 ▷ Total final consumption by sector and fuel in the STEPS



Final energy consumption grows on average by 1% per year between 2020 and 2050, with electricity and natural gas meeting most of the increase

Figure 1.8 ▹ Electricity generation by fuel and share of coal in the STEPS



Emerging market and developing economies drive most of the increase in global electricity demand, met mainly by renewables and gas, though coal remains important

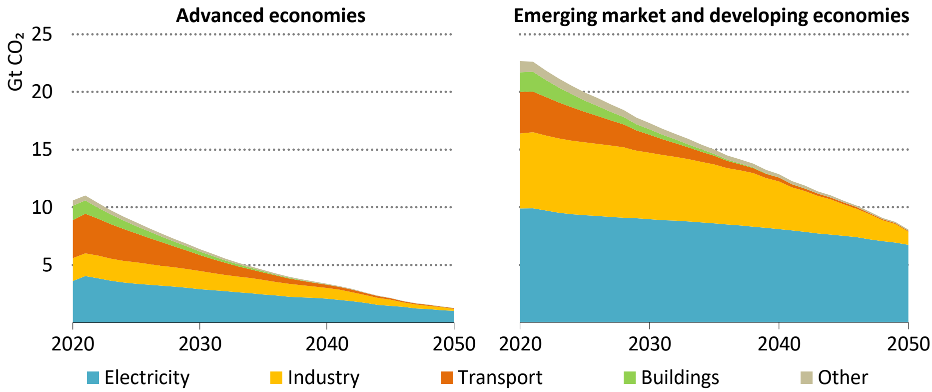
1.3.3 Emissions from existing assets

The energy sector contains a large number of long-lived and capital-intensive assets. Urban infrastructure, pipelines, refineries, coal-fired power plants, heavy industrial facilities, buildings and large hydro power plants can have technical and economic lifetimes of well over 50 years. If today's energy infrastructure was to be operated until the end of the typical lifetime in a manner similar to the past, we estimate that this would lead to cumulative energy-related and industrial process CO_2 emissions between 2020 and 2050 of just under 650 Gt CO_2. This is around 30% more than the remaining total CO_2 budget consistent with limiting global warming to 1.5 °C with a 50% probability (see Chapter 2).

The electricity sector accounts for more than 50% of the total emissions that would come from existing assets; 40% of total emissions would come from coal-fired power plants alone. Industry is the next largest sector, with steel, cement, chemicals and other industry accounting for around 30% total emissions from existing assets. The long lifetime of production facilities in these sub-sectors (typically 30-40 years for a blast furnace or cement kiln) and the relatively young age of the global capital stock explain their large contribution. Transport accounts for just over 10% of emissions from existing assets and the buildings sector accounts for just under 5%. The lifetime of vehicles and equipment in the transport and buildings sectors is generally much shorter than is the case in electricity and industry – passenger cars, for example, are generally assumed to have a lifetime of around 17 years – but associated infrastructure networks such as roads, electricity networks and gas grids have very long lifetimes.

There are some large regional differences in emissions levels from existing assets (Figure 1.9). Advanced economies tend to have much older capital stocks than emerging market and developing economies, particularly in the electricity sector, and existing assets will reach the end of their lifetimes earlier. For example, the average age of coal-fired power plants in China is 13 years and 16 years in the rest of Asia, compared to around 35 years in Europe and 40 years in the United States (IEA, 2020e).

Figure 1.9 ▷ Emissions from existing infrastructure by sector and region



Emerging market and developing economies account for three-quarters of cumulative emissions from existing infrastructure through to 2050

1.4 Announced Pledges Case

The Announced Pledges Case (APC) assumes that all national net-zero emissions pledges are realised in full and on time. It therefore goes beyond the policy commitments incorporated in the STEPS. The aim of the APC is to see how far full implementation of the national net-zero emissions pledges would take the world towards reaching net-zero emissions, and to examine the scale of the transformation of the energy sector that such a path would require.

The way these pledges are assumed to be implemented in the APC has important implications for the energy system. A net zero pledge for all GHG emissions does not necessarily mean that CO_2 emissions from the energy sector need to reach net zero. For example, a country's net zero plans may envisage some remaining energy-related emissions are offset by the absorption of emissions from forestry or land use, or by negative emissions arising from the use of bioenergy or direct capture of CO_2 from the air (DAC) with CCUS.[6] It is not possible to know exactly how net zero pledges will be implemented, but the design of the APC, particularly with respect to the details of the energy system pathway, has been informed by the pathways that a number of national bodies have developed to support net zero pledges (Box 1.1). Policies in countries that have not yet made a net zero pledge are assumed to be the same as in the STEPS. Non policy assumptions, including population and economic growth, are the same as in the STEPS.

[6] For example, in recent economy-wide net zero mitigation pathways for the European Union, around 140-210 million tonnes CO_2 of emissions from the energy sector remain in 2050, which are offset by CDR from managed land-use sinks, and bioenergy and DAC with CCUS (European Commission, 2018).

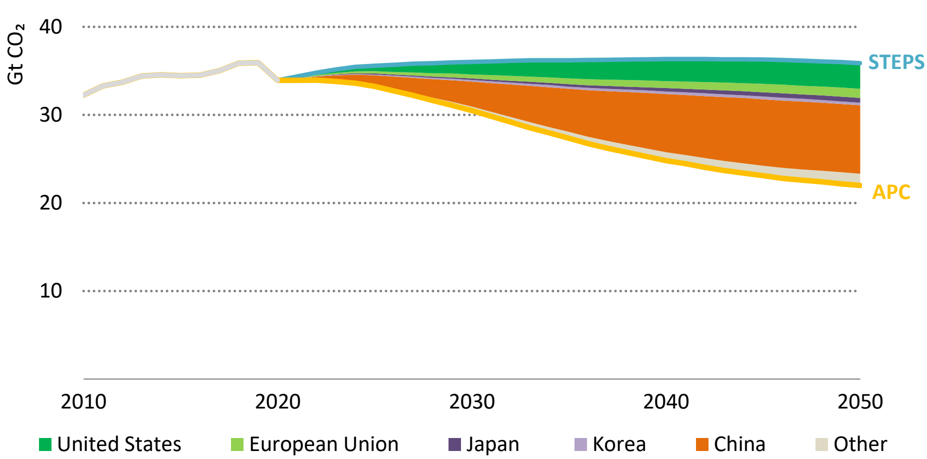
Box 1.1 ▹ Consultations with national bodies on achieving national net-zero emissions goals

To help inform its work on net zero pathways, the IEA engaged in extensive consultations with experts in academia and national bodies that have developed pathways to support net zero pledges made by governments. This includes groups that have developed net-zero emissions pathways for several countries including China, European Union, Japan, United Kingdom and United States, as well as the IPCC. These pathways were not used directly as input for the APC, but the discussions informed our modelling of national preferences and constraints within each jurisdiction and to benchmark the overall level of energy-related CO_2 emissions reductions that are commensurate with economy-wide net zero goals.

1.4.1 CO_2 emissions

In the APC, there is a small rebound in emissions to 2023, although this is much smaller than the increase that immediately followed the financial crisis in 2008-09. Emissions never reach the previous peak of 36 Gt CO_2. Global CO_2 emissions fall around 10% to 30 Gt in 2030 and to 22 Gt in 2050. This is around 35% below the level in 2020 and 14 Gt CO_2 lower than in the STEPS (Figure 1.10). If emissions continue this trend after 2050, and with a similar level of changes in non-energy-related GHG emissions, the global average surface temperature rise in 2100 would be around 2.1 °C (with a 50% probability).

Figure 1.10 ▹ Global energy-related and industrial process CO_2 emissions by scenario and reductions by region, 2010-2050

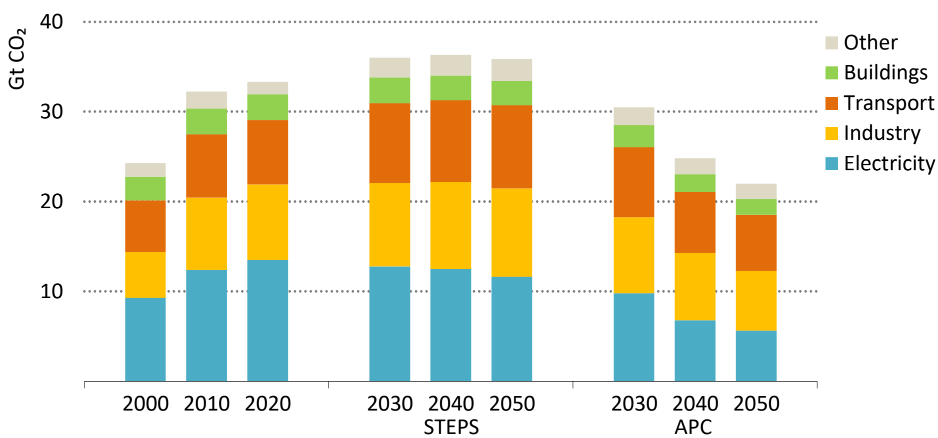


Achieving existing net zero pledges would reduce emissions globally to 22 Gt CO_2 in 2050, a major reduction compared with current policies but still far from net-zero emissions

The net zero pledges that have been made to date therefore make a major difference to the current trajectory for CO_2 emissions. Equally, however, existing net zero pledges fall well short of what is necessary to reach net-zero emissions globally by 2050. This highlights the importance of concrete policies and plans to deliver in full long-term net zero pledges. It also underlines the value of other countries making (and delivering on) net zero pledges: the more countries that do so, and the more ambitious those pledges are, the more the gap will narrow with what is needed to reach net-zero emissions by 2050.

The largest drop in CO_2 emissions is in the APC is in the electricity sector with global emissions falling by nearly 60% between 2020 and 2050. This occurs despite a near-doubling of electricity demand as energy end-uses are increasingly electrified, notably in transport and buildings (Figure 1.11). This compares with a fall in emissions of less than 15% in the STEPS.

Figure 1.11 ▷ Global CO_2 emissions by sector in the STEPS and APC



Announced net zero pledges would cut emissions in 2050 by 60% in the electricity sector, 40% in buildings, 25% in industry and just over 10% in transport

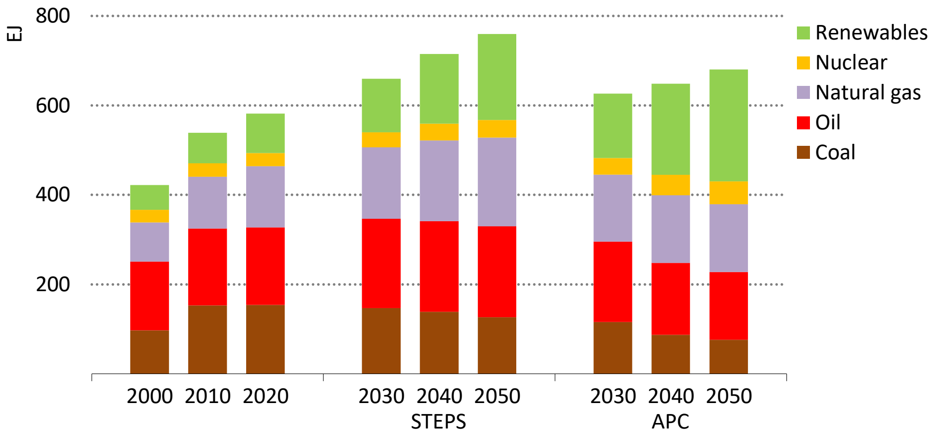
The transport and industry sectors see a less marked fall in CO_2 emissions to 2050 in the APC, with increases in energy demand in regions without net zero pledges partially offsetting emissions reduction efforts in other regions. Emissions from the buildings sector decline by around 40% between 2020 and 2050, compared with around 5% in the STEPS: fossil fuel use in buildings is mostly to provide heating, and countries that have made pledges account for a relatively high proportion of global heating demand.

Even in regions with net zero pledges, there are some residual emissions in 2050, mainly in industry and transport. This reflects the scarcity of commercially available options to eliminate all emissions from heavy-duty trucks, aviation, shipping and heavy industry.

1.4.2 Total energy supply

Global total energy supply increases by more than 15% between 2020 and 2050 in the APC, compared with a third in the STEPS (Figure 1.12). Energy intensity falls on average by around 2.6% per year to 2050 compared with 2.2% in the STEPS. There is a substantial increase in energy demand in emerging market and developing economies, where economic and population growth is fastest and where there are fewer net zero pledges, which outweighs the reductions in energy demand in the countries with net zero pledges.

Figure 1.12 ⊳ Total energy supply by source in STEPS and APC



Announced net zero pledges lift renewables in the APC from 12% of total energy supply in 2020 to 35% in 2050, mainly at the expense of coal and oil

The global increase in energy supply in the APC is led by renewables, which increase their share in the energy mix from 12% in 2020 to 35% by 2050 (compared with 25% in 2050 in the STEPS). Solar photovoltaics (PV) and wind in the electricity sector together contribute about 50% of the growth in renewables supply, and bioenergy contributes around 30%. Bioenergy use doubles in industry, triples in electricity generation and grows by a factor of four in transport: it plays an important role in reducing emissions from heat supply and removing CO_2 from the atmosphere when it is combined with CCUS. Nuclear maintains its share of the energy mix, its output rising by a quarter to 2030 (compared with a 15% increase in the STEPS), driven by lifetime extensions at existing plants and new reactors in some countries.

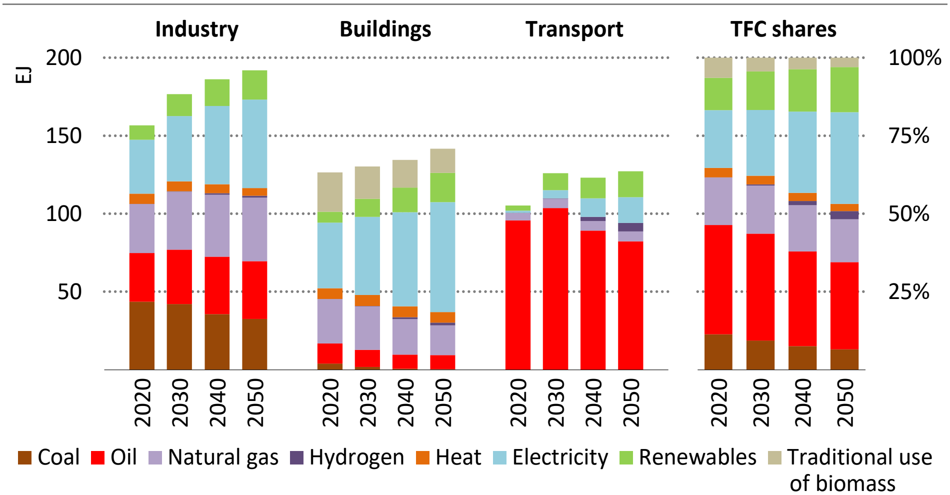
Global coal use falls significantly more rapidly in the APC than in the STEPS. It drops from 5 250 million tonnes of coal equivalent (Mtce) in 2020 to 4 000 Mtce in 2030 and 2 600 Mtce in 2050 (compared with 4 300 Mtce in the STEPS in 2050). Most of this decline is due to reduced coal-fired electricity generation in countries with net zero pledges as plants are repurposed, retrofitted or retired. In advanced economies, unabated coal-fired power plants are generally phased out over the next 10-15 years. China's coal consumption for electricity declines by 85% between 2020 and 2050 on its path towards carbon neutrality in 2060. These declines more than offset continued growth for coal in countries without net zero pledges. Globally, coal use in industry falls by 25% between 2020 and 2050, compared with a 5% decline in the STEPS.

Oil demand recovers slightly in the early 2020s but never again reaches its historic peak in 2019. It declines to 90 mb/d in the early 2030s and to 80 mb/d in 2050, around 25 mb/d lower than in the STEPS, thanks to a strong push to electrify transport and shifts to biofuels and hydrogen, especially in regions with pledges. Natural gas demand increases from about 3 900 bcm in 2020 to around 4 350 bcm in 2025, but is then broadly flat to 2050 (it continues to grow to around 5 700 bcm in the STEPS).

1.4.3 Total final consumption

Global energy use continues to grow in all major end-use sectors in the APC, albeit substantially more slowly than in the STEPS (Figure 1.13). Total final consumption (TFC) increases by around 20% in 2020-50, compared with a 35% increase globally in the STEPS. Measures to improve energy efficiency play a major role in the APC in reducing demand growth in countries with net zero pledges. Without those efficiency gains, electricity demand growth would make it much harder for renewables to displace fossil fuels in electricity generation. The biggest reduction in energy demand relative to the STEPS is in transport, thanks to an accelerated shift to electric vehicles (EVs), which are around three-times as energy efficient as conventional internal combustion engine vehicles.

Figure 1.13 ▷ Total final consumption in the APC



Announced net zero pledges lead to a shift away from fossil fuels globally to electricity, renewables and hydrogen. Electricity's share rises from 20% to 30% in 2050

The fuel mix in final energy use shifts substantially in the APC. By 2050, electricity is the largest single fuel used in all sectors except transport, where oil remains dominant. The persistence of oil in transport stems partly from the extent of its continued use in countries without net zero pledges, and partly from the difficulty of electrifying substantial parts of the transport sector, notably trucking and aviation. Electricity does make inroads into transport, however, and rapid growth in the uptake of EVs puts oil use into decline after 2030, with EVs accounting for around 35% of global passenger car sales by 2030 and nearly 50% in 2050 in the APC (versus around 25% in the STEPS in 2050). Electrification in the buildings sector is also much faster in the APC than in the STEPS.

The direct use of renewables expands in all end-use sectors globally through to 2050. Modern bioenergy accounts for the bulk of this growth, predominantly through the blending of biomethane into natural gas networks and liquid biofuels in transport. This occurs mainly in regions with net zero pledges. Hydrogen and hydrogen-based fuels play a larger role in the APC than in the STEPS, reaching almost 15 exajoules (EJ) in 2050, though they still account for only 3% of total final consumption worldwide in 2050. Transport accounts for more than two-thirds of all hydrogen consumption in 2050. In parallel, on-site hydrogen production in the industry and refining sectors gradually shifts towards low-carbon technologies.

1.4.4 Electricity generation

Global electricity generation nearly doubles during the next three decades in the APC, rising from about 26 800 terawatt-hours (TWh) in 2020 to over 50 000 TWh in 2050, some 4 000 TWh higher than in the STEPS. Low-emissions energy sources provide all the increase. The share of renewables in electricity generation rises from 29% in 2020 to nearly 70% in 2050, compared with about 55% in the STEPS, as solar PV and wind race ahead of all other sources of generation (Figure 1.14). By 2050, solar PV and wind together account for almost half of electricity supply. Hydropower also continues to expand, emerging as the third-largest energy source in the electricity mix by 2050. Nuclear power increases steadily too, maintaining its global market share of about 10%, led by increases in China. Natural gas use in electricity increases slightly to the mid-2020s before starting to fall back, while coal's share of electricity generation falls from around 35% in 2020 to below 10% in 2050. At that point, 20% of the remaining coal-fired output comes from plants equipped with CCUS.

Hydrogen and ammonia start to emerge as fuel inputs to electricity generation by around 2030, used largely in combination with natural gas in gas turbines and with coal in coal-fired power plants. This extends the life of existing assets, contributes to electricity system adequacy and reduces the overall costs of transforming the electricity sectors in many countries. Total battery capacity also rises substantially, reaching 1 600 gigawatts (GW) in 2050, 70% more than in the STEPS.