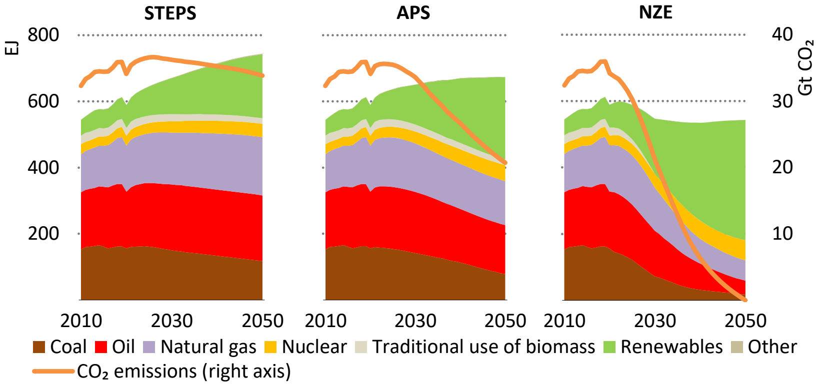
Exploring multiple futures: demand and electricity

No time to waste

SUMMARY

- A lack of adequate supporting policies sees an "implementation gap" emerge between emissions as they would be if today's net zero and other pledges were fully delivered (the Announced Pledges Scenario [APS]) and emissions as they look set to be under current and announced policies (the Stated Policies Scenario [STEPS]). By 2030 this gap reaches 2.6 gigatonnes (Gt) of CO_2, almost 90% of which is in advanced economies where emissions reduction pledges are most prevalent.

Figure 4.1 ▹ **Total primary energy supply by fuel and scenario**



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Closing the implementation gap between STEPS and APS requires achieving current pledges; new pledges are needed to close the "ambition gap" from the APS to NZE

- Closing the implementation gap would fill less than 20% of the emissions gap between the STEPS and the Net Zero Emissions by 2050 Scenario (NZE) pathway through to 2030, but there are important variations. In advanced economies, emissions decline by one-third to 2030 in the APS, closing half of the total gap between the STEPS and the NZE. Limited pledges in emerging market and developing economies mean that their emissions increase by around 10% in the APS to 2030, closing less than 5% of the gap between the STEPS and the NZE. In 2050, announced pledges in advanced economies close three-quarters of the gap between the STEPS and the NZE.
- The largest implementation gaps are in sectors where clean energy technology options are mature but policies to accelerate their deployment are lacking or insufficient. These gaps highlight where additional policy pushes are required to reach targets. Such pushes could take the form of action to accelerate renewables deployment, for example, or to end new sales of internal combustion engine cars by a given date, or to accelerate building retrofits and construction of new buildings at zero carbon-ready standard, or to remove obstacles to heat pump sales.

- There is also an implementation gap in respect of the achievement of universal energy access by 2030. In the STEPS, some 670 million people remain without access to electricity in 2030 and 2.1 billion without access to clean cooking. Improvements in access have been slowed by the Covid-19 crisis: in recent years, the number of people without access to electricity declined by an average 9% per year, but progress stalled between 2019 and 2021. USD 43 billion annually is required to achieve universal access to electricity and clean cooking by 2030. Investment is only 20% of this level in the STEPS for electricity, and even lower for clean cooking.
- Under announced pledges, energy intensity improvements accelerate to 2.5% per year this decade. Announced pledges also lead to a fall in the share of unabated fossil fuels from 75% in the STEPS in 2030 to 72% in the APS. However, the improvements seen in the APS remain far from what is required by the NZE, which by 2030 sees a 4.2% annual improvement in energy intensity and a decline in the share of unabated fossil fuels in the global fuel mix to below 60%.
- Electrification and energy efficiency play central roles in reducing emissions from end-use sectors, avoiding 2.5 Gt CO_2 by 2030 in the STEPS and a further 0.8 Gt in the APS. Total final consumption growth to 2030 in the APS would be three-quarters higher without efficiency improvements. Electrification further slows demand growth: the average efficiency of electric equipment such as electric cars and heat pumps is higher than that of fossil fuel powered alternatives.
- Electricity supply sees major changes as the use of unabated coal falls globally by 10% to 2030 in the STEPS, by 18% in the APS, and by 70% in the NZE. The share of renewables rises from nearly 30% of generation in 2020 to over 40% in 2030 in the STEPS, 45% in the APS and 60% in the NZE. The combined capacity additions of solar PV and wind rise in all scenarios in the 2020s: to 310 gigawatts (GW) in 2030 in the STEPS, nearly 470 GW in the APS and over 1 000 GW in the NZE. The APS and NZE also see greater use of carbon capture, ammonia, hydrogen and nuclear power, while natural gas use rises to 2050 in the STEPS, but peaks by 2025 in the APS, providing system flexibility and displacing coal in emerging market and developing economies.
- The implementation gap for electricity supply between the STEPS and APS is largest in advanced economies, where ambitions were raised recently, for example in the European Union and United States. The ambition gap between the APS and NZE is more significant for emerging market and developing economies: their unabated coal use rises until the mid-2020s before starting a long-term decline, whereas the NZE calls for a near-term peak and 60% reductions by 2030.
- The electricity sector is responsible for 36% of global CO_2 emissions today, which is more than any other sector. Its emissions decline by 10% to 2030 in the STEPS and by nearly 20% in the APS. These reductions are far short of those in the NZE, where electricity sector emissions fall by close to 60% by 2030 on the way to reaching net zero in advanced economies collectively in 2035 and in all countries in 2040.

4.1 Introduction

Global and country level ambitions for energy sector transitions, as represented in the Announced Pledges Scenario (APS), fall short of what is required to be on track in the Net Zero Emissions by 2050 Scenario (NZE). However, there is a risk that the ambitions assumed to be achieved in the APS will not in fact be matched by specific policies and measures, or that any such policies and measures prove inadequate for the job, and as a result that the world falls short even of the pathway set out in the APS.

This chapter draws on two scenarios in particular, the Stated Policies Scenario (STEPS) and the APS, though it also refers to the NZE. The STEPS provides a bottom-up sector-by-sector assessment of policies and measures actually in place or under development, and provides insights into how energy demand may evolve if the ambitions of the APS are not realised, and its implications for climate goals. The APS takes account of all the pledges and promises that have been made, and assumes that additional policies and measures will be put in place so as to enable those pledges and promises to be met in full. The chapter examines various aspects of energy in the STEPS and APS and highlights the gaps that may emerge if ambitions are not underpinned by the policy frameworks and measures necessary to make them a reality. In addition, the analyses draw attention to the key changes that would help close the gap, with a particular emphasis on 2030 as a key milestone on the road to 2050.

Section 4.2 highlights the impact on CO_2 emissions of the implementation gap between announced pledges in the APS and where current and stated policies are taking us in the STEPS. It also explores the implementation gap for access to electricity and clean cooking.

Section 4.3 focuses on the evolution of total primary energy supply and total final consumption over the next decade and beyond in the three main scenarios.

Section 4.4 focuses on transitions in the end-use sectors and the increasing role of energy efficiency and electrification to temper energy demand and emissions growth, looking sector-by-sector at key challenges and examples of success.

Section 4.5 explores the possible trajectories for the electricity sector, underlining the scale of change that is required to realise announced pledges, and how far current and announced policies will take us.

4.2 Implementation gap

Pledges need specific policies and measures if they are to be fulfilled. If current pledges are not backed up by the necessary policy frameworks an “implementation gap” (between the STEPS and the APS) will emerge. This implementation gap is different from the “ambition gap” (between the APS and the NZE) which highlights the additional effort required above and beyond current pledges for the energy sector to achieve net zero emissions by 2050. In the case of universal access to energy by 2030, which is at the heart of the United Nations Sustainable Development Goal 7, the key implementation gap is between achieving universal access to energy by 2030 in the NZE and failing to achieve it in the STEPS and APS.

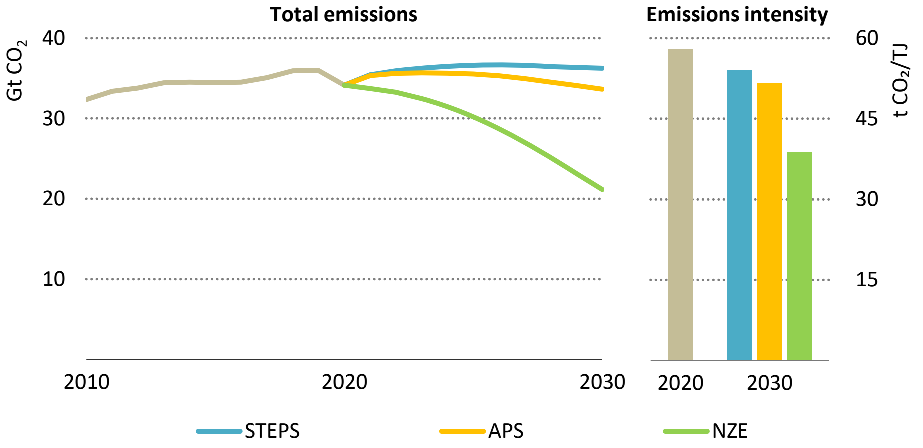
Many governments are in the process of developing specific policies, measures and strategies to deliver on their net zero emissions objectives and new Nationally Determined Contributions under the Paris Agreement. The implementation gap will narrow as they do. Our efforts to identify implementation gaps are intended to provide insights about where additional policies and investment are most needed to help ensure pledges are achieved.

4.2.1 CO_2 emissions

Achieving net zero emissions by 2050 requires a transition of unprecedented speed and scale. Current ambitions – as expressed in the APS – fall short of what is needed to achieve the goals. However, the APS trajectory itself cannot be taken for granted, and the difference in carbon dioxide (CO_2) emissions[1] between the STEPS and the APS illustrates very starkly the size of the policy implementation gap that exists at present.

In the APS, global CO_2 emissions stay below the all-time high of 2019 and return to 2020 levels by 2030 (Figure 4.2). In the STEPS, the policies that are now in force or have been announced are insufficient to prevent emissions surpassing 2019 levels and ending the decade 6% higher than in 2020. Both are far from the NZE trajectory, which sees emissions falling to around 21 gigatonnes (Gt) in 2030. By 2050, the gap between the STEPS and APS widens, with global CO_2 emissions reaching 34 Gt in the STEPS and 21 Gt in the APS in 2050 (two decades later than in the NZE).

Figure 4.2 ▷ CO_2 emissions and intensity by scenario, 2020-2030



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Without additional specific policies to deliver on announced pledges, global CO_2 emissions are set to increase further this decade before plateauing

Note: t CO_2/TJ = tonnes of carbon dioxide per terajoule.

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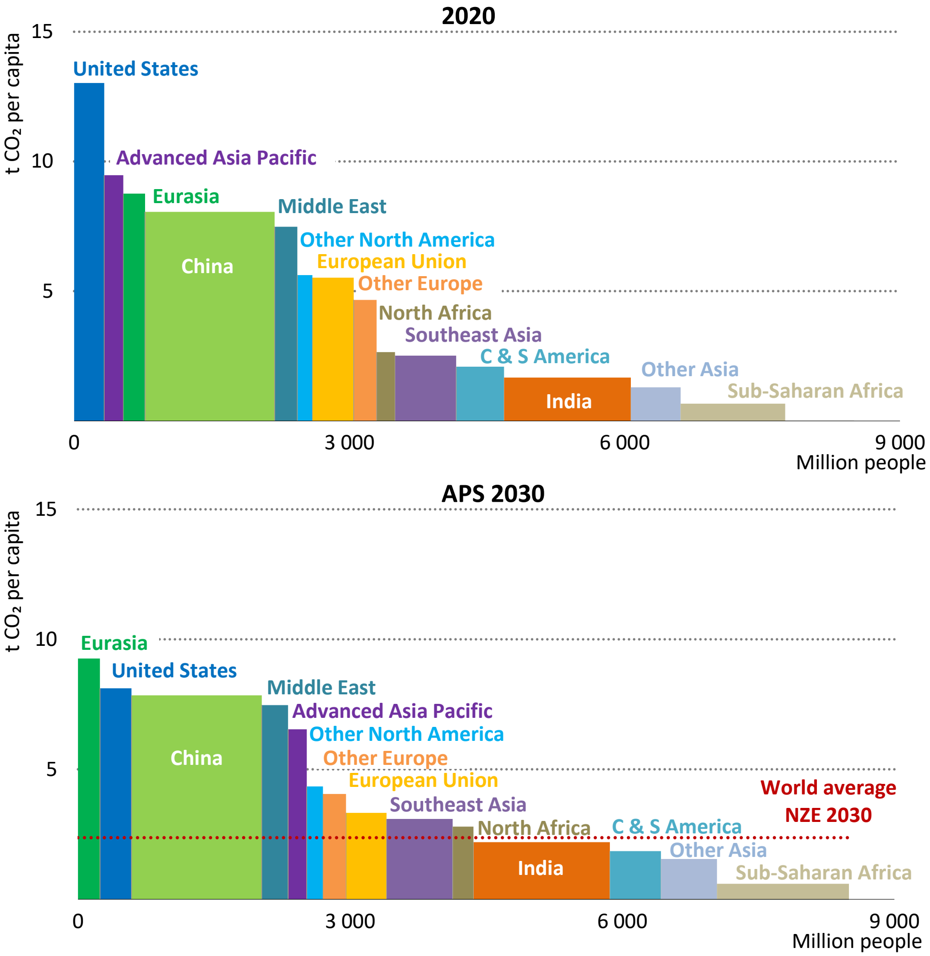
[1] Unless otherwise stated, carbon dioxide (CO_2) emissions in this section refer to energy-related and industrial process emissions.

Distribution of the implementation gap reflects the announced emissions reductions pledges and their inherent level of ambition. To date, most advanced economies and the European Union have announced net zero objectives, covering the vast majority of CO_2 emissions from advanced economies. Across emerging market and developing economies, fewer countries have net zero pledges, representing around half of emissions, with the majority from China.

Figure 4.3 ▹ **CO_2 emissions per capita by region in 2020 and 2030 in the Announced Pledges Scenario**



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Announced pledges lower average CO_2 emissions per capita in advanced economies, but emissions remain well above what is required in the NZE pathway

Notes: C & S America = Central and South America. The world average NZE 2030 excludes CO_2 emissions from international aviation and shipping.

Advanced economies today account for around one-third of global CO_2 emissions, but for almost 90% of the global emissions gap between the APS and STEPS by 2030. This reflects that they are responsible for the majority of commitments to achieve net zero emissions, but it is also an indication that policies are not yet in place across all sectors to make good on the commitments. Two advanced economies are highlighted:

- The United States accounts for about 45% of the total emissions implementation gap between the APS and STEPS, reflecting the ambitious nature of its pledges. By 2030, CO_2 emissions in the United States in the APS are 30% lower than in the STEPS, with per capita emissions falling to 8 tonnes CO_2 per capita (t CO_2 per capita) (Figure 4.3). Despite this decline, per capita emissions in the APS in the United States remain more than three-times higher than the world average in the NZE in 2030.
- The implementation gap in the European Union is less pronounced due to the steps already taken to support the target of a 55% emissions reduction by 2030 relative to 1990 and an objective of net zero by 2050. Nonetheless, current policy measures are not sufficient to achieve these goals, and an implementation gap of 470 million tonnes (Mt) CO_2 is apparent by 2030,[2] equivalent to about a fifth of current emissions in the European Union. Full implementation of its proposed Fit for 55 package would reduce this implementation gap and shift per capita emissions in the European Union toward the global average seen in the NZE in 2030.

Emerging market and developing economies are responsible for a much smaller share of the implementation gap because they have made fewer emissions reductions pledges and they are less ambitious than those of advanced economies. By 2030, the implementation gap across emerging market and developing economies is equivalent to around 1% of current emissions from the group. Despite limited emissions reduction pledges, in many emerging market and developing economies per capita CO_2 emissions remain two-thirds below the advanced economy average by 2030 in the APS. Eurasia, China and producer economies across the Middle East are the exception and they are among the highest emitting regions on a per capita basis by 2030 in the APS. China and some Central and South American countries are among those with pledges in place:

- Current and announced policies enable China to meet its target of peak emissions by 2030, but its pledge to reach net zero emissions by 2060 requires further policies for the period after 2030, which creates a widening implementation gap. In the APS, per capita CO_2 emissions in China in 2030 remain similar to today: this means that they are roughly on a par with those in the United States, with per capita emissions in the United States declining by 40% between now and 2030 in the APS.
- In Central and South America, per capita CO_2 emissions in 2030 decline by more than 10% from 2020 levels, with ambitious climate pledges in several countries such as Argentina, Brazil, Chile and Colombia more than offsetting growth of emissions in other countries in the region which lack a strict climate policy framework.[3]

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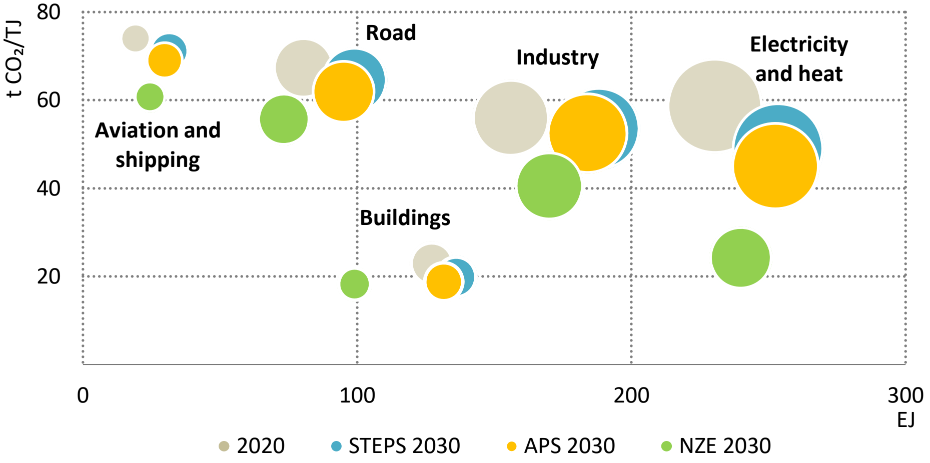
[2] Excluding emissions from international aviation and navigation bunkers.

[3] Clean energy transitions in Central and South America will be examined in depth in a forthcoming publication by the IEA and the Inter-American Development Bank.

All **sectors** see an implementation gap between current ambitions, the APS, and stated or current policies, the STEPS. Measures to close implementation gaps in the 2020s generally involve scaling up mature technologies to boost the use of renewables, electric vehicles (EVs), building retrofits and efficient industrial motors. Many of the policies needed to achieve the required roll-out of these technologies are tried and tested. Some countries are already taking policy action and some are introducing specific targets in particular sectors. Examples include proposals to halt the sale of internal combustion engine (ICE) cars and vans by 2035 in the European Union and Canada, decarbonise the power sector by 2035 in the United States, and end fossil fuel heating for new homes from 2025 in the United Kingdom. However, the actions being taken are not yet sufficiently widespread or hard-hitting to deliver what is needed in the APS.

Many of the hard-to-abate sectors, such as heavy trucking and heavy industry sectors and process emissions, have smaller implementation gaps than other sectors. This is primarily because the lack of available mature technological solutions means that hard-to-abate sectors do not see a significant declines in their CO_2 content and total CO_2 emissions by 2030 in the APS (Figure 4.4). Beyond 2030, achieving economy-wide net zero objectives in the APS is dependent on reducing emissions across the board, including in hard-to-abate sectors. As a result, their emissions fall sharply post-2030 in countries with net zero pledges, although the declines are far from sufficient to achieve net zero in these sectors globally.

Figure 4.4 ▹ Energy use, carbon intensity and CO_2 emissions by sector and scenario, 2020-2030



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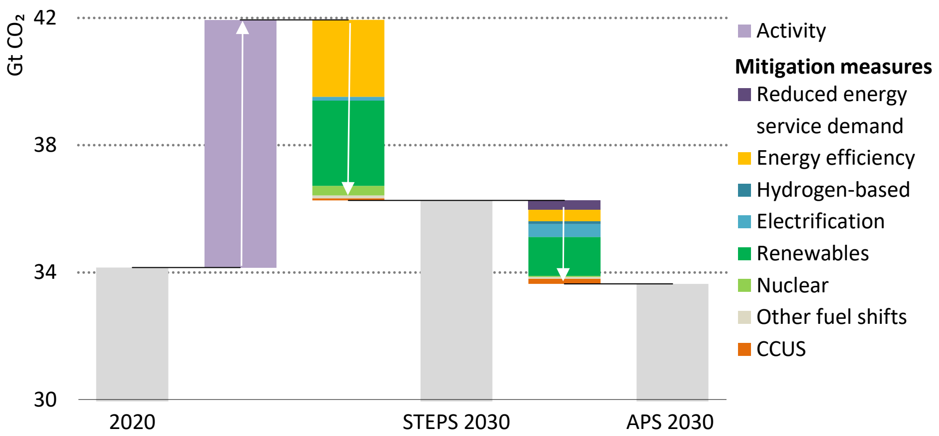
Closing the implementation gap requires parallel efforts to improve energy efficiency and reduce the CO_2 intensity of energy use by electrifying or switching to low-carbon fuels

Notes: t CO_2/TJ = tonnes of carbon dioxide per terajoule; EJ = exajoule. The size of the bubble represents the overall CO_2 emissions by sector. Industry emissions include industrial process emissions.

Closing the emissions gap between the STEPS and the APS is underpinned by the decarbonisation of electricity supply (see section 4.5). Around 40% of the 2.6 Gt implementation gap in 2030 could be closed by the power sector, notably by increasing the role of **renewables** in meeting demand growth and in replacing existing fossil fuel generation assets. Decarbonisation of the power sector happens in parallel to widespread **electrification**, with sectors from passenger and freight transport to industrial processes and heating in the buildings sector all seeing an increase in the role electricity plays in meeting demand. Not all energy uses can be easily electrified, however, and **energy efficiency** is central to efforts to moderate increased demand and thus to ensure that additional electricity demand does not compromise the decarbonisation of electricity supply. Direct use of renewables such as bioenergy, solar thermal and geothermal provides an alternative to electrification and contributes 15% to closing the implementation gap (Figure 4.5). Carbon capture, utilisation and storage (CCUS) provides a way to tackle remaining emissions in both the power and industry sectors, especially beyond 2030. CCUS also provides an opportunity to scale up low-carbon hydrogen production and CO_2 removal (Box 4.1).

Figure 4.5 ▷ Energy and industrial process CO_2 emissions and mitigation levers in the Stated Policies and Announced Pledges scenarios, 2020-2030



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Closing the emissions gap between the scenarios requires rapid growth of renewables in the power sector, increased energy efficiency and electrification

Box 4.1 ▹ Scale up CCUS to close the implementation gap

Carbon capture, utilisation and storage (CCUS) has the potential to contribute to emissions reductions in many regions. Momentum is growing, driven by strengthened climate commitments from governments and industry. The capture capacity of projects announced since the beginning of 2020 exceeds total capacity operating today. This momentum has led to support for investment. It has also increased recognition of the need to establish legal and regulatory frameworks for CCUS, develop CO_2 transport and storage infrastructure, and to put in place targeted policy and financing support.

A variety of CCUS projects are operating or being planned in different sectors. Examples include:

- **Industry:** CO_2 capture is already an integral part of fertiliser production and other industrial processes. Deployment is expanding to the production of steel, chemicals and cement. Today a commercial steel plant is operating with CO_2 capture in Abu Dhabi and work is in progress to retrofit a cement plant in Norway. In the STEPS, capture expands to 30 Mt CO_2 by 2030, while in the APS net zero commitments increase capture to around 60 Mt CO_2. In the NZE, 375 Mt CO_2 are captured in 2030.
- **Electricity and heat:** Two coal-fired power plants are equipped with CCUS, one in Canada and one in the United States, with a combined capture capacity of around 2.4 Mt CO_2 per year.[4] Several other CCUS-equipped plants have been announced or are in various stages of development. By 2030 capture expands to 13 Mt CO_2 in the STEPS, to over 100 Mt CO_2 in the APS and to more than 400 Mt CO_2 in the NZE.
- **Fuel supply:** The majority of current commercial CCUS facilities, which capture about 30 Mt CO_2 per year, are associated with natural gas processing, which offer relatively low-cost capture opportunities. A range of CCUS projects are planned which would capture CO_2 from low-carbon hydrogen and biofuels production, refining and liquefied natural gas. Several involve the development of regional CCUS and/or hydrogen hubs. Capture associated with fuel supply increases to 50 Mt CO_2 by 2030 in the STEPS and to 190 Mt CO_2 in the APS (compared with 780 Mt CO_2 in the NZE).
- **Direct air capture** (DAC): A number of small pilot and demonstration DAC plants are operating around the world today, including some that are providing CO_2 on a commercial basis for beverage carbonation and greenhouses. In Iceland, a facility came online in September 2021, with capacity to capture 4 000 tonnes per year for storage. Large-scale (up to 1 Mt/year) DAC facilities are in development in the United States and the United Kingdom. There is limited deployment of DAC by 2030 in the STEPS and APS, but it grows to around 90 Mt CO_2 in the NZE. This reflects the significance of DAC with storage as a key technology to offset residual emissions and remove legacy CO_2 emissions, as well as its ability to provide a carbon neutral CO_2 input for the production of synthetic fuels.

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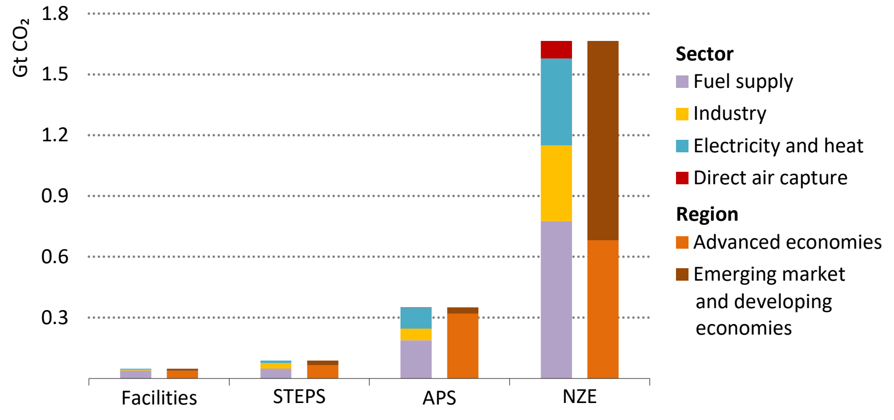
[4] The Petra Nova coal-fired power generation plant in the United States has suspended CO_2 capture operations in response to low oil prices.

Achieving the level of CCUS deployment needed in the APS requires additional concerted efforts to implement supportive policies and financing measures. Projects that are operational today or in construction have the capacity to capture over 40 Mt CO_2 per year (Figure 4.6). This is well short of what is needed in the APS, where deployment in 2030 reaches 350 Mt CO_2 per year, mainly in advanced economies.

Figure 4.6 ▷ **CO_2 capture capacity by project and scenario, 2030**



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Achieving the level of CCUS needed to reach ambitions in the APS requires targeted policy support and more than a tenfold increase in current capacity

Note: Facilities = operating commercial CO_2 capture projects or under construction (including two with operations currently suspended).

Source: IEA analysis and GCCSI (2021).

The investment environment for CCUS has substantially improved in many places, with significant policy support emerging in Canada, Europe, United States and elsewhere. This includes, for example, grant funding programmes, tax credits and increased carbon prices. Nonetheless, challenges to investment remain. Several characteristics of CCUS projects, such as the need for counterparty arrangements arising from complex chains of capture-transport-storage and the need for regulatory frameworks for long-term ownership/liability of stored CO_2, bring a set of distinct risks, and these are amplified in emerging market and developing economies. Governments and financial institutions have a critical role to play in improving CCUS financing opportunities with policies that help to establish revenue streams, reduce investment risks and ultimately create a sustainable market for CCUS investment.

4.2.2 Energy access

In 2015, all United Nations (UN) members adopted the 2030 Agenda for Sustainable Development, which includes an objective (SDG 7.1) to "ensure universal access to affordable, reliable and modern energy services" by 2030 (United Nations, 2020). This global goal is achieved in full in the NZE, but not in the STEPS or APS. Current and announced policies are insufficient to deliver universal access to electricity and clean cooking by 2030 in the STEPS, while the APS assumes that country level targets are achieved, but not the UN goal. The gap in realising access is one of implementation rather than ambition, and accordingly this section compares how many people gain access to electricity and clean cooking in the STEPS with the outcome in the NZE, where universal access is reached.

Access to electricity

Today 770 million people worldwide still live without access to electricity, mostly in Africa and developing countries in Asia. The Covid-19 crisis delivered a setback, slowing progress on new connections while also weakening the ability of households to pay for electricity (Figure 4.7). Preliminary data show that the global number of people without access was broadly stuck at where it was between 2019 and 2021, after improving 9% annually on average between 2015 and 2019. In sub-Saharan Africa the number of people without access increased in 2020 for the first time since 2013.

Many new connections via networks and mini-grids that were in the pipeline before the pandemic were finalised in 2020, but procurement delays and the need to tackle the public health emergency have held up new project developments. In addition, the deployment of solar stand-alone systems declined by more than 20% in 2020 as lockdowns prevented off-grid companies from reaching new customers and supply chains were disrupted (GOGLA, 2021). Some of the major distributors are seeing sales rebound in 2021, but the impact of the pandemic on household incomes together with price increases for solar cells and other electronic components may continue to impact sales. There is evidence that affordability has become more of a problem than before the pandemic. In 2019, in sub-Saharan Africa, almost half of people without access could not afford electricity for an essential bundle of services, even if provided with a connection.[5] In 2020, due to the pandemic, up to 90 million people with electricity connections in Africa and developing countries in Asia lost the ability to afford an extended bundle of services.[6] Even where households can afford access, now they may opt for cheaper and smaller systems that provide fewer energy services than would have been the case before the Covid-19 pandemic.

Governments and development agencies have provided emergency financial relief to reduce these impacts. Nigeria, for instance, has implemented a recovery plan that includes financing

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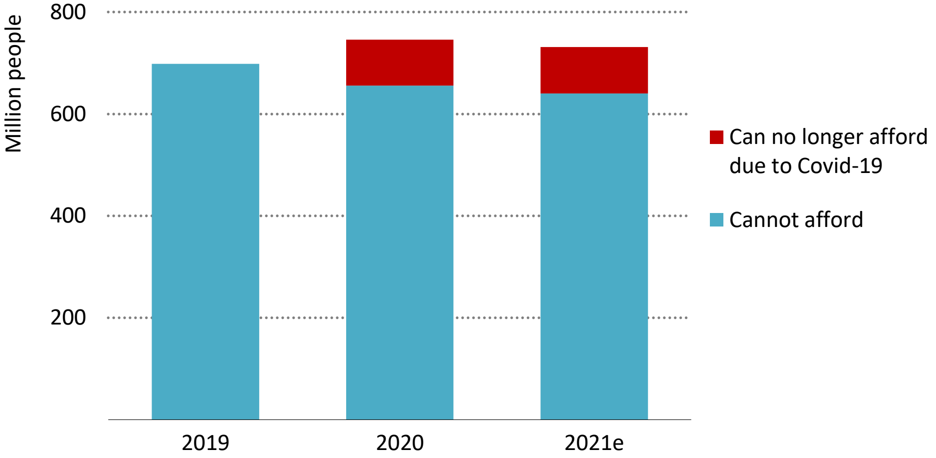
[5] An essential bundle includes four lightbulbs operating for four hours per day, a television for two hours and a fan for three hours.

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

to connect 25 million people through solar home systems and provides monetary incentives for off-grid solar businesses. Poverty or lifeline electricity tariffs – a common tool to target subsidies to those most in need – were expanded during the pandemic. Such tariffs may be required by utility regulators. However, policy support is often limited to grid electricity, even though the reality is that an increasing number of people initially gain access through off-grid solutions.

Figure 4.7 ▹ Population with an electricity connection unable to afford an extended bundle of services in Africa and developing Asia



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Even before the pandemic, 700 million people could not afford an extended bundle of electricity services; Covid-19 increased this number by 90 million

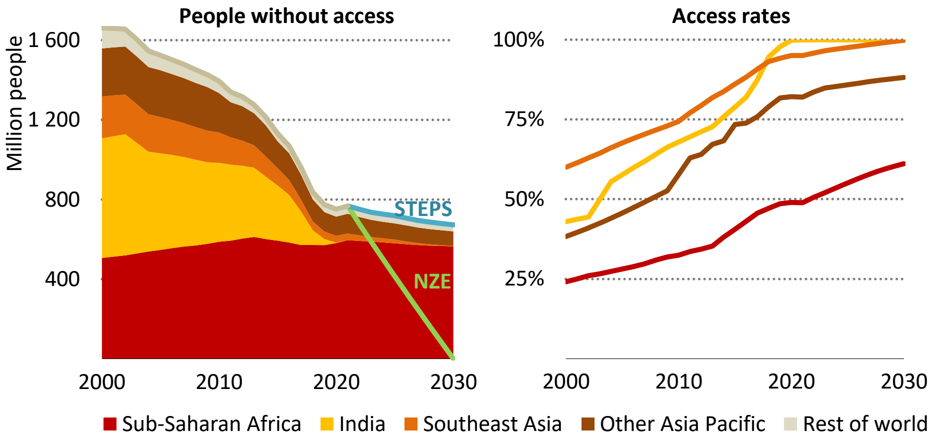
Notes: e = estimated. Affordability refers to the ability to pay for an extended bundle of electricity services.

Source: IEA analysis based on World Bank estimates of the impact of Covid-19 on global poverty (World Bank, 2021).

Achieving full access by 2030 will require connecting almost 100 million people every year, but the world is not on track to reach this goal. In the STEPS, some 670 million are projected to remain without access in 2030 (projections are similar in the APS). Most developing countries in Asia, especially India and countries in Southeast Asia, are on track to achieve near universal access by 2030, but the access rate in sub-Saharan Africa reaches only 60% by the end of the decade, up from 50% in 2019 (Figure 4.8).

Countries with the lowest electricity access rates often lack strong electrification plans and regulatory frameworks (see Table 4.1). These countries make only small improvements in access in the STEPS, and their electricity access rates stay below 30% by 2030. On the other hand, countries with official national electrification plans, clear targets, tracking mechanisms and holistic frameworks for both grid and off-grid solutions already have higher access levels, and move closer to full implementation in the STEPS.

Figure 4.8 ▷ People without access to electricity and access rates by region in the Stated Policies and Net Zero Emissions by 2050 scenarios, 2020-2030



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After significant progress in recent years, led by India, the Covid-19 crisis has stalled improvements in extending access; regaining momentum is vital to achieve the SDG 7.1

Note: Other Asia Pacific includes Bangladesh, Democratic Republic of Korea, Mongolia, Nepal, Pakistan, Sri Lanka, Chinese Taipei, Afghanistan, Bhutan, Cook Islands, East Timor, Fiji, French Polynesia, Kiribati, Lao PDR, Macau, Maldives, New Caledonia, Papua New Guinea, Samoa, Solomon Islands, Tonga and Vanuatu.

The NZE offers a pathway to deliver electricity to all by 2030. Just under half of households gaining access to electricity do so with a grid connection, while mini-grid and stand-alone systems account for 30% and 25% of new connections respectively. Over 90% of off-grid and around 70% of grid solutions deployed between now and 2030 are sourced from renewables. After 2030, grids will eventually reach most of the customers using off-grid solutions, emphasising the importance of interoperability for off-grid and mini-grid systems built today. Only the most remote users will not have a grid connection by 2050.

Achieving full electricity access by 2030 requires annual investment of over USD 35 billion. This is a tiny fraction of global total energy investment, but well above what is being spent today: investment in electricity access in sub-Saharan Africa is only around 15% of what will be required (SE4ALL and CPI, 2020). Financing is a significant obstacle, since many of the projects – especially those serving rural areas and very poor communities – require public financial support via concessional and blended finance structures (IEA, 2021a) together with improvements in tendering and administrative processes, while at the same time low demand can make it hard to attract private capital.

Table 4.1 ▷ **Implementation of access to electricity policies for countries without universal access in sub-Saharan Africa and Asia**

	Countries with access rate:			
	Low (<40%)	Medium (40% - 80%)	High (>80%)	Average
Electricity access regulatory provisions				
Is there a credible electrification plan?	🔴	🟡	🟢	🟡
Does the plan set a minimum service level?	🔴	🟡	🟡	🟡
Are funding support schemes for grid connection available?	🔴	🟡	🟢	🟡
Are mini-grids included in policy support schemes?	🟡	🟡	🟢	🟡
Are stand-alone systems included in policy support schemes?	🟡	🟡	🟢	🟡
Are affordability provisions available?	🟡	🟢	🟢	🟢
IEA average access rate				
2020	21%	59%	96%	57%
STEPS 2030	27%	76%	99%	66%

Level of implementation: 🔴 Low 🟡 Moderate 🟢 Significant

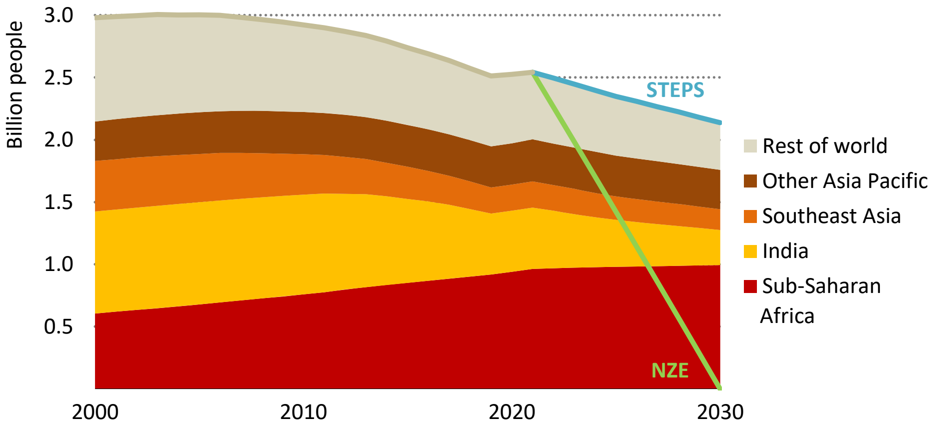
Source: Based on the ESMAP-RISE indicators (ESMAP, 2021) and IEA electricity access data.

Access to clean cooking

More than 2.5 billion people lack access to clean cooking worldwide and, as with electricity, the Covid-19 crisis reversed recent progress towards universal access. Cooking with the traditional use of biomass, coal or kerosene causes 2.5 million premature deaths annually (see section 3.8), slowing social and economic development and entrenching gender inequality. Between 2015 and 2019, the global population without clean cooking access decreased on average by 2% per year, led by efforts in developing countries in Asia.

We estimate that the number of people without access increased by 30 million, or slightly more than 1%, between 2019 and 2021 (Figure 4.9). The pandemic slowed the deployment of clean cooking stoves and fuels, and diminished the ability of households to pay for clean fuels. It also made it more difficult for existing liquefied petroleum gas (LPG) users to travel to refilling stations. In 2020, around 50 million people in developing countries in Asia and Africa reverted to the traditional use of solid biomass for cooking. This shift, together with the increased time spent at home due to Covid-19 lockdown measures, increased exposure to air pollution and the associated health risks. Some governments enacted policies to help manage this issue and ensure continued delivery amid the pandemic. In India, for example, the government provided support for free refills of LPG cylinders. Many of these support schemes may need to be extended to offset the continuing impact of the pandemic.

Figure 4.9 ▷ **Population without access to clean cooking in the Stated Policies and Net Zero Emissions by 2050 scenarios**



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In the STEPS, some 2.1 billion people remain without access to clean cooking in 2030; reaching universal access by 2030 will require significant acceleration of progress

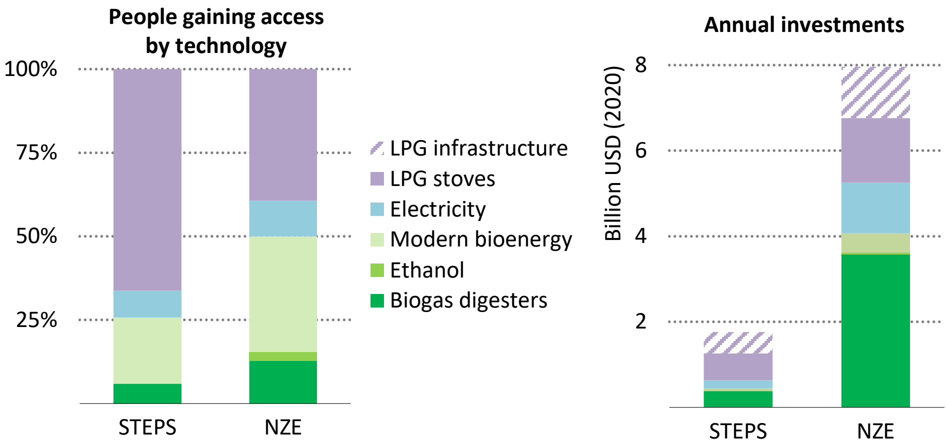
Note: Recent survey data from the World Health Organization for India revised the historic clean cooking access rates. This is due to faster progress than previously assumed, in large part due to the Pradhan Mantri Ujjwala Yojana LPG distribution scheme.

Source: IEA estimates based on historical data (up to 2019) from the World Health Organization household air pollution database (WHO, 2021).

To reach full access to clean cooking by 2030, around 280 million people each year need to gain access – a fivefold acceleration compared with pre-pandemic improvement levels. This does not happen in the STEPS, where 2.1 billion people are still without access to clean cooking in 2030, nor in the APS. The annual investment needed to achieve full clean cooking access by 2030 is around USD 8 billion (Figure 4.10), including about USD 1.2 billion to finance downstream LPG infrastructure such as primary storage units, refilling stations and cylinders (excluding transport). Current investment in clean cooking in sub-Saharan Africa represents only about 3% of the capital expenditure required to reach full access (SE4ALL and CPI, 2020).

In the NZE, a variety of low-carbon technologies are deployed to end the harmful use of solid fuels for cooking and to reduce greenhouse gas (GHG) emissions and other climate forcing agents (e.g. black carbon). The NZE sees faster uptake of electric cooking and biogas digesters than the STEPS, however, LPG remains important in the years to 2030. During that period, the total demand for LPG does not grow rapidly in the NZE, as urban LPG users increasingly switch to electricity, offsetting increased demand from those gaining access (IEA, 2021b). Rural communities gradually make a similar switch in the two decades after 2030 as they gain a more reliable electricity connection.

Figure 4.10 ▷ Access to clean cooking by technology and related investment in the Stated Policies and Net Zero Emissions by 2050 scenarios, 2021-2030



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Half of those gaining access to clean cooking in the NZE do so with renewables, and a further 10% with electricity; investments are five-times higher than in the STEPS

Notes: Annual investments = average annual investment in the 2021-2030 period. Biogas digester investment refers to decentralised systems and includes both the biodigester and the cost of the stove.

4.3 Energy demand

4.3.1 Energy demand trends to 2030

Total energy supply grows by 1.3% per year from 2020 to 2030 in the STEPS, reaching 670 exajoules (EJ) by 2030 (Figure 4.11). Announced pledges trim the annual growth rate to 1.0% in the APS (650 EJ in 2030). Both scenarios stand in contrast to the NZE where demand declines by an average 0.7% annually to 550 EJ by 2030.

In the STEPS, the world is set to save more energy on an annual basis in the 2020s than it did in the previous decade, with annual intensity improvements averaging 2.2%.[7] In the APS, announced targets lead to annual intensity improvement rate averaging 2.5% over the next decade, which is closer to the objective championed by governments in the Three Percent Club,[8] but still below it, and far from the 4.2% annual improvement rate required in the NZE.

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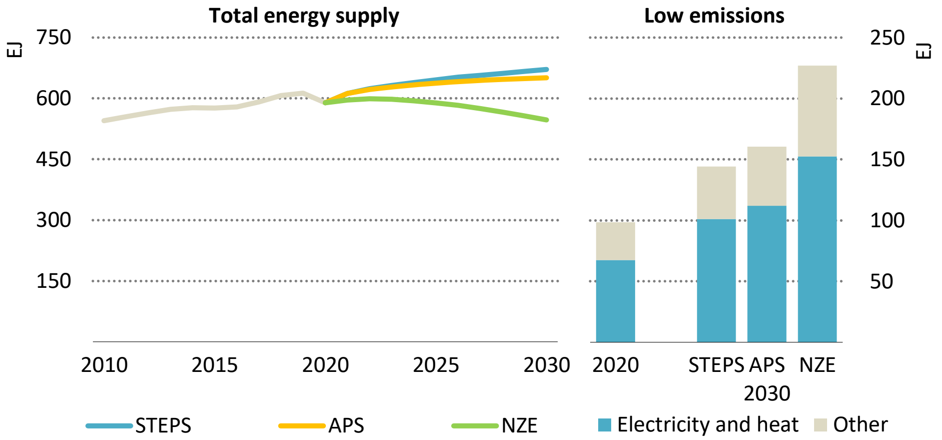
[7] Energy intensity is defined as the ratio of energy supply to GDP in purchasing power parity (PPP) terms to enable differences in price levels among countries to be taken into account. In our scenarios, PPP factors are adjusted as developing countries become richer. Global energy intensity is defined as the ratio of energy supply to GDP. Energy intensity improvement rate is defined as the annual reduction of energy intensity.

[8] The Three Percent Club is a collaboration of governments and supporting organisations committed to putting the world on a path to 3% annual energy efficiency improvements.

Figure 4.11 ▹ Global total energy supply by scenario and low emissions energy supply sources by sector, 2010-2030



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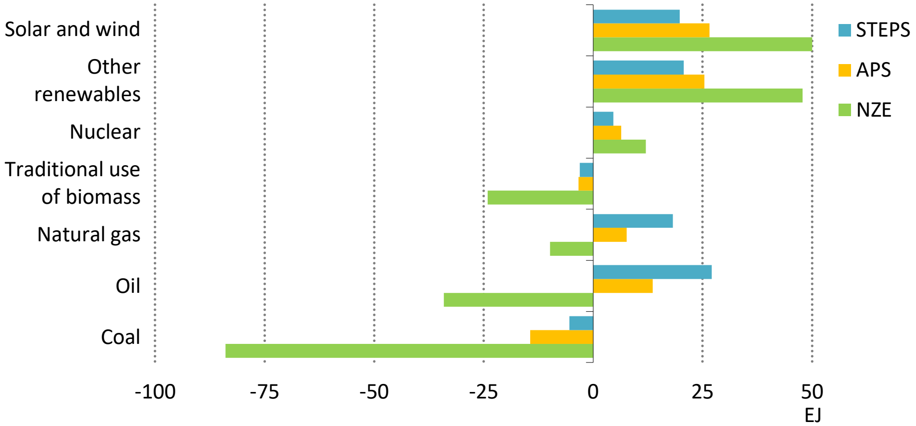
Global energy supply increases 1% per year to 2030 in the APS and 1.3% in the STEPS; the total supply gap between the APS and the STEPS reaches 20 EJ by 2030

Notes: Low emissions sources include renewables, nuclear power and fossil fuels fitted with CCUS, but exclude the traditional use of solid biomass and non-energy use of fossil fuels. Electricity and heat refer to low-carbon energy supply to provide electricity and district heat. Other refers to end-use sectors and the other energy sector.

Figure 4.12 ▹ Change in global total energy supply by fuel and scenario, 2020-2030



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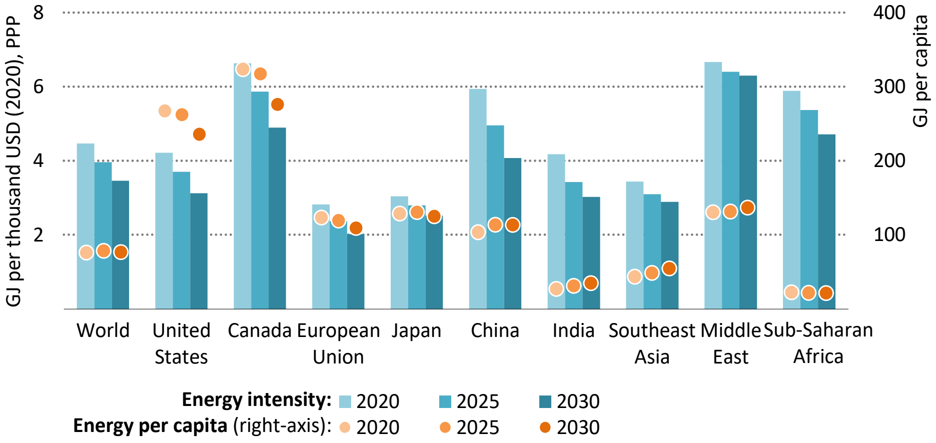
Pledges accelerate the uptake of low-carbon energy sources in the APS relative to the STEPS, but the speed and scale of the transition are well short of what is required in the NZE

Trends by fuel show more marked differences between the scenarios (Figure 4.12) (see Chapter 5). In the STEPS, coal demand rises slightly to 2025, but declines to below 2020 levels by 2030, while demand for oil and gas increases: demand growth is split roughly equally between fossil fuels and renewables, and the share of fossil fuels in the global energy mix declines only slightly from 79% today to 75% in 2030. In the APS, coal demand declines by 10% to 2030, demand for oil and gas grows at only half the rate in the STEPS, and almost 85% of demand growth is met by renewables, as a result of which the share of nuclear and renewables increases from 17% to 24% in 2030 and the share of unabated fossil fuels declines to 72% of the global energy mix.

Regional trends

In **advanced economies**, energy demand increases by 0.1% annually in the STEPS to 2030. Pledges in most major advanced economies mean energy demand in 2030 in the APS is 7% lower than in the STEPS. In the NZE it falls to almost 10% below the level in the APS. Improvements over the STEPS could come about as a result of policies to improve energy efficiency. Measures may include more stringent fuel-economy standards, building codes for new construction, deep retrofits for existing buildings, and the adoption of energy management systems in industry and buildings along with policies to accelerate the electrification of transport and heat, including through bans on new fossil fuel boilers and new ICE cars. On average, the energy intensity of gross domestic product (GDP) in advanced economies improves by 2.1% a year through to 2030 in the STEPS, by 2.8% in the APS and by around 4% in the NZE (Figure 4.13).

Figure 4.13 ▷ Energy intensity and energy demand per capita in selected regions in the Announced Pledges Scenario, 2020-2030



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Despite some significant changes in the APS over the next decade, there remain wide differences in per capita energy use among countries in 2030

Notes: GJ = gigajoules. Energy intensity is defined as the ratio of total energy supply to GDP in PPP terms. Energy per capita corresponds to the ratio of total energy supply to population.

The picture is varied in many **emerging market and developing economies**, where limited emissions reduction pledges to date mean no major implementation gap emerges to 2030: energy demand increases by almost 2% annually through to 2030 in both the STEPS and the APS. Nevertheless, the energy intensity of GDP improves by 2.8% annually in both scenarios, faster than the global average in the STEPS or the APS. Increasing the ambition of energy efficiency and electrification policies would further accelerate this improvement in energy intensity: in the NZE, the annual improvement rate to 2030 rises to 4.8%.

In many developing economies, energy demand per capita continues to increase through to 2030 in order to increase services for the billions of people who want to improve their quality of life, for example by buying refrigerators and air conditioners, motorbikes and cars, and to provide energy services to those who lack access today. This growth of energy services implies higher consumption of industrial products and increased energy demand for their production. Efficiency and/or electrification policies have an important part to play in tempering energy demand growth and helping to keep goods and services affordable (Box 4.2).

In advanced economies, most households already have access to appliances, thermal comfort and transportation, as reflected in high levels of per capita energy demand today. Therefore the focus is on tapping the energy efficiency potential of these goods and services to reduce demand, especially in the NZE. Many advanced economies are already moving in this direction. For example, as part of its Renovation Wave strategy and the Energy Performance of Buildings Directive, the European Union aims to increase retrofit rates and implementing stringent standards for new constructions.

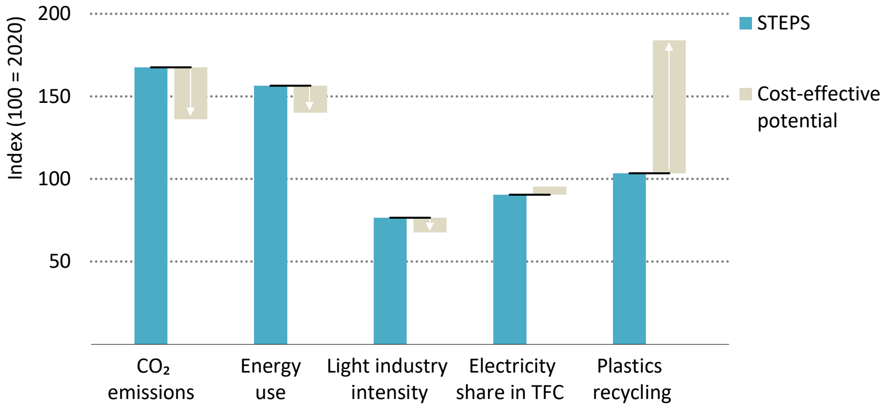
In each scenario, emerging market and developing economies increase their share of global energy demand. This shift is accentuated in the APS: many advanced economies have made pledges which involve curbing demand growth, while few emerging market and developing economies have done so.

Box 4.2 ▷ Make in India, Make Efficient

The "Make in India" programme was launched in 2014 and aims to attract foreign direct investment in industry by improving the ease of doing business, investing in infrastructure and offering fiscal incentives to manufacturers. Make in India targeted an increase in the contribution to GDP from the manufacturing sector to at least 25% by 2022. In May 2020 the announcement of the Atmanirbhar Bharat Scheme provided a further boost to the sector by setting a target for India to achieve industrial self-reliance.

Policies under the Make in India banner cover the light industry sub-sector, whose value added is set to double in the next ten years, and the chemicals sub-sector, where production is set to increase by 55% to 2030. This expected growth points to a rise of almost 70% in CO_2 emissions from light industries and of 60% from chemicals this decade. Tempering the energy demand growth linked to expanding domestic manufacturing in India would have multiple benefits: reducing energy bills for manufacturers (which have been affected by a recent removal of energy subsidies), curbing industrial electricity demand growth (which approaches 770 terawatt-hours [TWh] in the STEPS, up from 540 TWh today) and reducing emissions (Figure 4.14).

Figure 4.14 ⊳ Key indicators for the chemicals and light industry sub-sectors in India in the Stated Policies Scenario in 2030 and cost-effective energy and materials efficiency potential



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Promoting cost-effective efficiency and electrification alongside "Make in India" could reduce associated energy demand by 10% and direct CO_2 emissions by 20%

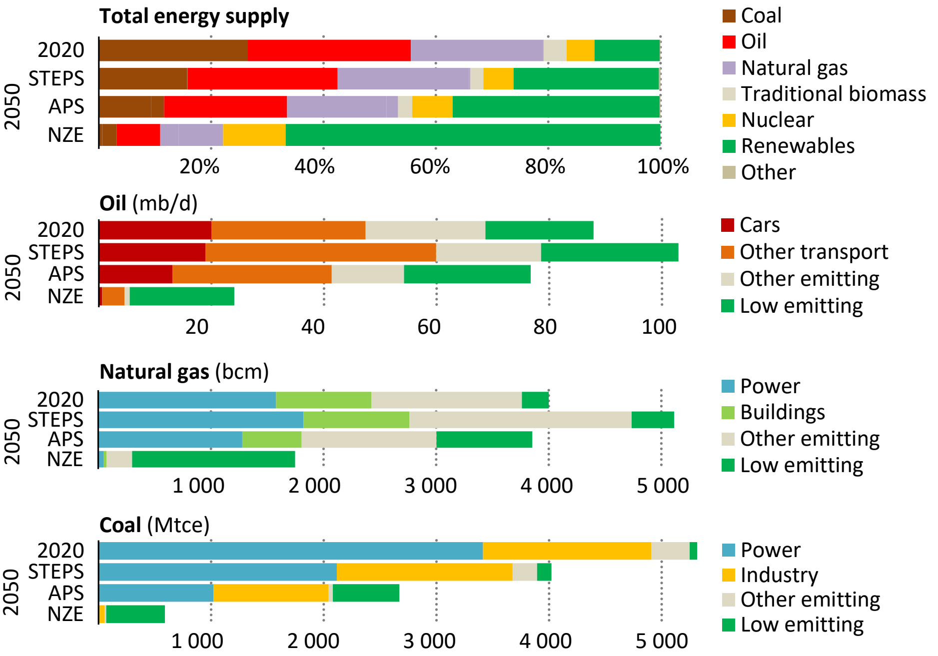
Notes: TFC = total final consumption. Energy and emissions indices are calculated for the chemicals and light industries sub-sectors.

Energy efficiency is the key to tempering demand growth and unlocking these multiple benefits. Current and announced policies would only lead to annual efficiency improvements of 2%, but pushing efficiency towards its full economic potential – including through switching to heat pumps for low-temperature process heat needs – could increase the rate of improvement to 3%. Further to energy efficiency, materials efficiency can play an important role in tempering growth. Improving plastics recycling rates reduces energy demand for chemicals by 4%. Doing so would require the implementation of more stringent and wide-ranging efficiency policies, and measures to link the policies to the Make in India programme and related benefits.

4.3.2 Energy demand trends after 2030

In the STEPS, energy demand continues to climb after 2030, while in the APS it plateaus as a result of net zero pledges that require increased energy efficiency and further electrification across all sectors, ending up almost 10% lower in 2050 than in the STEPS. Even so, the APS lags well behind what is required in the NZE, where energy demand in 2050 is an additional 20% lower than in the APS (Figure 4.15).

Figure 4.15 ▷ Energy supply and demand by fuel and sector, 2020 and 2050



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Announced pledges drive the share of unabated fossil fuels in the APS 17 percentage points lower than the STEPS in 2050; demand for all fossil fuels declines relative to today

Notes: mb/d = million barrels per day; bcm = billion cubic metres; Mtce = million tonnes of coal equivalent. Traditional biomass = traditional use of biomass; other = non-renewable municipal waste and other non-specified; power = electricity and heat; low emitting includes fossil fuels combusted in plants equipped with CCUS and non-combustion use of fossil fuels which includes use for non-emitting, non-energy purposes such as petrochemical feedstocks, lubricants and asphalt.

Changes in energy demand are underpinned by shifts in the equipment and fuels used to meet energy demand. Announced pledges in the APS reduce the share of unabated fossil fuels in the global energy mix to just below 50% in 2050. Demand for coal and oil declines the most, with their respective shares in the energy mix falling 15 percentage points and seven percentage points from 2020 levels by 2050. Failure to fully implement the pledges in the APS would slow the transition away from fossil fuels. In the STEPS, unabated fossil fuels still account for two-thirds of the global energy mix in 2050 underlining the need for more support policies to achieve the objectives of the APS. Both scenarios fall very far short of what is needed to deliver the NZE, where the share of unabated fossil fuels drops to around 10%, a share that falls below 5% when non-combustion uses of energy are excluded.

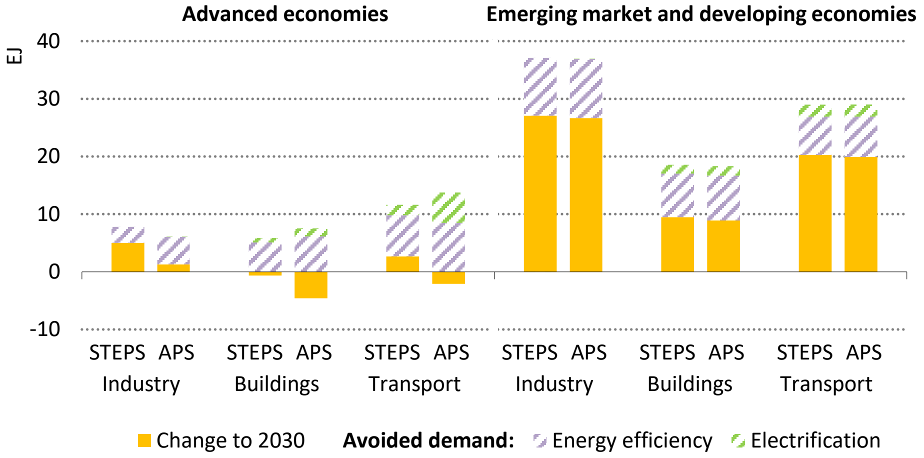
In the APS, oil demand in 2050 is more than 25 million barrels per day (mb/d) below the STEPS levels. Lower oil demand in the APS relative to the STEPS reflects reduced oil use in uses such as road passenger transport, petrochemicals, heavy trucks, aviation and shipping, but the reductions in the APS pale by comparison with what is needed in the NZE. Coal demand is affected in particular by trends in the electricity and heat sector, especially in major emerging markets such as China. China's pledge to reach net zero emissions by 2060 is realised in the APS and drives a structural decline in coal use for electricity and heat generation and industry, but the lack of targets in other major emerging market and developing economies means that coal demand in the APS is far above the levels in the NZE.

4.4 Transitions in final energy consumption

Total final consumption of energy increases by an average 1.7% per year from 2020 to 2030 in the STEPS, and by 1.4% per year in the APS. By 2030, final consumption in the APS is 3% lower than in the STEPS (it is much lower still in the NZE – 17% below the level in the APS). The differences between the STEPS and the APS are largely accounted for by energy efficiency and electrification.

Energy efficiency improvements relative to today reduce overall demand by 8% in the STEPS and 9% in the APS by 2030. Improvements in the APS are sufficient to slow final energy demand growth to 1.4% and a decline of almost 10% in demand in advanced economies. Without energy efficiency improvements in the APS global demand would grow by around 2.3% per year, resulting in a 75% increase in demand growth by 2030 in the APS (Figure 4.16). The impact is greatest in advanced economies, where both existing energy efficiency policies and emissions reductions pledges are most prevalent.

Figure 4.16 ▷ Change in energy demand to 2030 and demand avoided due to energy efficiency and electrification in the Stated Policies and Announced Pledges scenarios



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Pledges in the APS accelerate energy efficiency and electrification, but are insufficient to offset growth in emerging market and developing economies

Electrification also contributes to lowering energy demand because many electric technologies are significantly more efficient than their fossil fuel counterparts. For example, today's electric cars use on average 70% less energy to travel one kilometre than a conventional ICE car and electric heat pumps can be three- to four-times more efficient than conventional boilers. In the APS, electrification reduces energy demand in 2030 by 10 EJ equivalent to 2.5% of today's demand, compared with 1.5% in the STEPS.

4.4.1 Energy efficiency improvements

In the STEPS, energy efficiency improvements through to 2030 offset 30% of the increase in CO_2 emissions linked to expanding demand for energy services. In the APS, this rises to almost 40%. Actions to unlock direct emissions savings include renovating buildings, introducing stringent energy efficiency codes to reduce the use of fossil fuels in buildings, upgrading the efficiency of industrial processes, and improving engine performance in transport (Table 4.2). Efficiency measures that indirectly reduce emissions by reducing electricity demand or slowing growth are also important. Actions to unlock indirect emissions savings include shifting sales of appliances to more efficient models and to 100% light-emitting diodes (LEDs) in lighting sales, implementing standards to require the uptake of the most efficient electric motors and deploying building energy management systems.

In **buildings**, energy efficiency avoids 10% more demand in the APS than in the STEPS to 2030. Almost 85% of this energy efficiency implementation gap is in advanced economies where current policy frameworks are not stringent enough to deliver on announced emissions reduction pledges. In the United States, there is significant untapped potential for energy efficiency improvements in buildings, though policies that would enable emissions reductions ambitions to be realised have yet to be announced. As a result, there is an efficiency implementation gap of almost 0.7 EJ, or 3.5% of demand from the buildings sector, in the United States. The European Union Energy Performance of Buildings Directive is promoting ambitious improvements in the energy efficiency of both new and existing buildings (Box 4.3).

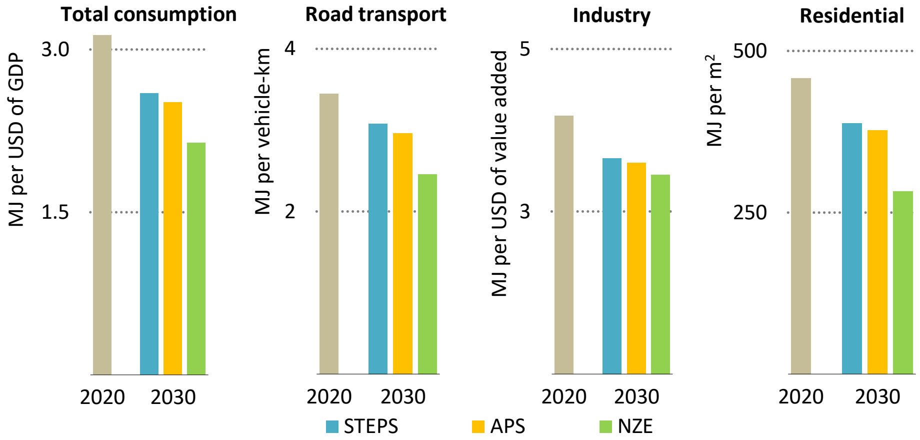
The **transport** sector sees major energy efficiency improvements in the STEPS as the efficiency of ICE vehicles improves and older vehicles are retired (Figure 4.17). Closing the gap with the NZE would require a major step up in efficiency standards as well as a shift away from ICE vehicles to EVs and fuel cell electric vehicles, and further advances in more efficient batteries, fuel cells and low-carbon fuels. The combined effect of electrification and technical efficiency gains is 50% larger in the APS than in the STEPS in advanced economies. Strict fuel economy targets, as deployed in the European Union, have a central part to play in achieving the transport outcome in the APS. The US Department of Transportation recently announced that it will propose a major tightening of corporate average fuel economy (CAFE) standards, targeting 8% fuel economy improvements annually for passenger cars and light trucks manufactured in model years 2024-26, and the APS reflects this upward revision from the previous rules as well as a 50% market share target for zero emissions car sales by 2030.

Table 4.2 ⊳ Selected energy efficiency policies in industry and buildings

Country / region	Policy / action	Description
Canada	Energy Efficiency Regulations	Industrial energy-consuming products (e.g. electric furnaces, heat pumps) need to meet federal standards to be imported, or sold or leased across provinces.
	Canada Greener Homes	Grants and interest-free loans programme to finance deep home retrofits. Dedicated funding stream available for low-income homeowners
Chile	Law on Energy Efficiency	Mandatory reporting of energy efficiency ratings for all new buildings.
European Union	A Renovation Wave for Europe	Double the annual rate of building retrofits in the European Union by 2030.
France	Multi-annual energy plan	+27% improvement of energy efficiency by 2030. Investment support for building retrofits Industry final consumption target of 269 TWh by 2028.
India	New Energy Performance Standards for Air Conditioners	Mandate a default set point temperature of 24 °C for all room air conditioners. Improve minimum performance standards.
Japan	Strategic Energy Plan	Net zero emissions on average from new buildings (residential and services) by 2030.
Korea	Green New Deal	Funding for retrofits of public service and residential buildings.
United Kingdom	Industrial Energy Transformation Fund	Support investment in energy efficiency and the use of low-carbon technologies in energy-intensive industries.
	Future Homes Standard	Fossil fuel heating systems banned from new homes by 2025.
United States	Better Plants program	Energy management plans and energy performance tracking.

Efficiency improvements in **industry** under current and announced policies lag what is required to meet announced pledges by 15%. Industry is the end-use sector with the biggest implementation gap, reflecting the current lack of policies and measures to support efficiency improvements, and almost 90% of this implementation gap is in advanced economies. The introduction of more stringent standards for boilers that provide process heat and for electric motor systems and other industrial equipment is critical to closing the gap. Electrifying industrial processes could also bring efficiency gains, for example by providing low-temperature heat through heat pumps. Increased use of less energy-intensive materials, such as wood instead of concrete for construction, could also help drive down energy intensity. In advanced economies, closing the gap between the STEPS and the APS cuts demand growth from industry by a factor of four.

Figure 4.17 ▷ **Energy intensity by sector and scenario**



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Energy intensity improves by more than 10% to 2030 in all sectors in the STEPS, but there remains an energy efficiency implementation gap between the STEPS and the APS

Note: MJ = megajoules.

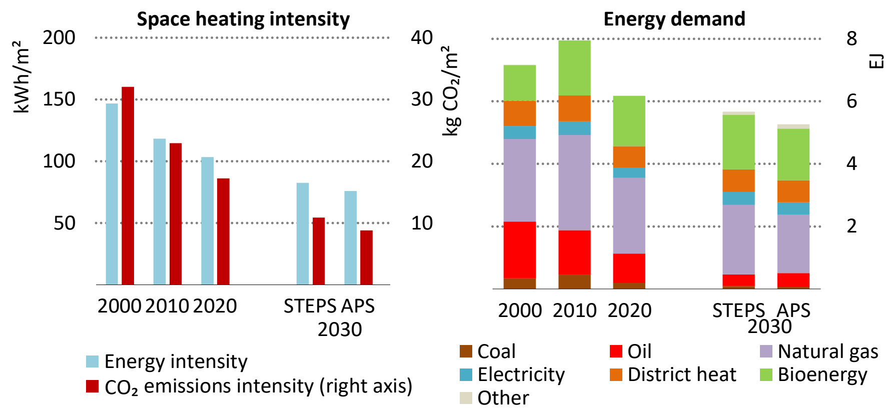
Box 4.3 ▷ Space heating in the European Union: Act now to keep the 2050 target in reach

Space heating in the European Union accounts for 60% of energy demand and 80% of direct CO_2 emissions in the buildings sector. Reducing emissions from space heating is a central pillar of its climate policy and critical to the achievement of the European Union target of net zero emissions by 2050. Progress towards this objective in the buildings sector is supported by a suite of complementary policy measures and targets, notably the Energy Performance of Buildings Directive (EPBD), Renovation Wave for Europe strategy, Energy Efficiency Directive, Renewable Energy Directive, equipment energy performance standards and national long-term renovation strategies. The EPBD requires all new buildings to be nearly zero energy buildings, which means that they must have a very high level of energy performance and meet the majority of energy demand from renewable sources. This requirement came into force at the end of 2018 for public buildings and at the end of 2020 for all other new buildings.

Decarbonisation of space heating hinges on addressing emissions from existing buildings, with the vast majority of existing buildings in the European Union expected to still be in use in 2050. The EPBD aims to support the renovation of existing buildings to achieve a highly energy efficient and decarbonised building stock by 2050. More than 90% of the existing EU building stock needs to be retrofitted to achieve this target, but current retrofit rates are far from sufficient, averaging between 0.5% and 1% of the building stock annually in recent years, and even less for deep renovations. The Renovation Wave for Europe strategy aims to kick-start progress by doubling annual renovation rates in the next ten years, while the Fit for 55 package sets the goal of retrofitting 3% of all public buildings annually. Many Member States are directing funding from the EU recovery and resilience plan toward national building retrofit programmes in an effort to accelerate action.

So far, not all EU Member States have transposed the EPBD into national building energy codes and policies that establish quantified targets in line with the EPBD, and a number of other recently announced targets and strategies have yet to be underpinned by policies and measures. In the STEPS, which reflects current legislation and concrete policy announcements, the energy intensity of residential space heating in the European Union declines from an average of just over 100 kilowatt-hours per square metre (kWh/m^2) in 2020 to 80 kWh/m^2 by 2030 (Figure 4.18), and total space heating demand declines by less than 10%.

Figure 4.18 ▷ Residential space heating energy intensity and energy demand in the European Union in the Stated Policies and Announced Pledges scenarios



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Space heating demand falls 15% to 2030 with full implementation of EU policies and targets. Delay in increasing retrofit rates to 2% puts building sector targets out of reach.

Note: kg CO_2/m^2 = kilogrammes of carbon dioxide per square metre.

Full implementation of the suite of policies and targets in the European Union and its member states, as assumed in the APS, would see residential space heating energy demand intensity fall to 75 kWh/m^2, with total space heating demand declining by 15% between 2020 and 2030, and CO_2 emissions falling by 35%. Annual building retrofit rates would need to ramp up to at least 2% by 2030 and 20% of the EU building stock would need to undergo retrofitting by 2030. This is a tall order, but delaying policy action to accelerate retrofit rates by even five years risks pushing the EU climate neutrality goal out of reach.

Reducing space heating emissions in line with the EU climate objectives also depends on a switch to low-carbon heating technologies such as heat pumps or renewables together with the use of building-related digital and connected technologies for energy management and of more efficient appliances. One important milestone on the path to a decarbonised building stock is the phase-out of sales of oil and/or gas boilers for new and/or existing buildings, and several member states are already taking action on this front.

4.4.2 Electrification

Electrification options are cost-effective and commercially available in most end-use sectors today. They become an important driver of emissions reductions in each of the three scenarios.

In **buildings**, electric heat pumps offer the biggest opportunity for displacing fossil fuel boilers for heating. Electric heat pumps are an increasingly attractive technology to meet heating needs in buildings, and installations in the STEPS rise from the current 1.5 million per month to around 3 million by 2030, leading sales for new construction in many regions. In the APS, heat pump installations reach 3.5 million per month by 2030, while in the NZE they reach 5 million a month.

Thanks to significant cost declines in the last decade, heat pumps are becoming more and more competitive as the technology and market mature. They are especially attractive for the one-third of the global population living in regions requiring both space heating and cooling, since reversible heat pumps are able to deliver both services (IEA, 2020a). However, non-economic barriers commonly hinder customer adoption. For example, heating equipment is usually only replaced when the existing equipment fails, and switching to a different kind of heating system may take time and involve substantial extra work. This is compounded by split incentives in rental properties: the savings from lower utility bills often accrue to renters, while building owners pay the higher upfront costs. Some governments have created financing programmes to overcome these upfront cost barriers or have introduced bans on new fossil fuel boilers.

In **industry**, electricity is increasingly used for heat below 200 °C in the STEPS, mainly in the food, textile and chemical industries. In the APS, the switch from fossil fuel boilers to heat pumps and electric boilers is faster, and electric heat provides almost 10% more low- and medium-temperature heat by 2030 than in the STEPS. In the NZE, electric heat also makes inroads into the provision of high-temperature heat demand by 2030, for example in electric furnaces for glass production.

In **transport**, a few countries have announced and started to implement policies to end the sale of new ICE vehicles, usually focusing on passenger cars (Table 4.3). Battery electric cars typically can cost from USD 8 000 to USD 18 000 more than ICE models,[9] dissuading many customers from switching (see examples in Box 4.4). However, future cost reductions and improvements in battery performance are expected to make EVs cost competitive in the 2020s (See Chapter 3, section 3.5.2). EV sales proved to be resilient during the pandemic: around 3 million electric cars were sold in 2020, accounting for 4.6% of car sales worldwide. Sales of all types of EVs continue to accelerate in the STEPS, and there are some 135 million electric cars in the global fleet in 2030. In the APS, this figure increases to over 190 million, and EVs account for over 3% of global electricity demand in 2030. In the NZE there are over 300 million electric cars on the road in 2030, accounting for 20% of the global car fleet, and the world is on track to end the sale of new ICE cars by 2035.

Table 4.3 ⊳ Selected policies and targets to phase out sales of ICE passenger vehicles by country and automaker

Year	Countries/states	Type of vehicles
2025	Norway	Light-duty vehicles
2030	Austria, Slovenia	Light-duty vehicles
	Iceland, Ireland, Netherlands, Singapore	Passenger cars
2035	Canada, United Kingdom, California and New York (United States)	Light-duty vehicles
	Cape Verde, Denmark	Passenger cars
2040	France, Spain	Light-duty vehicles
2050	Costa Rica, Germany*, Connecticut, Maryland, Massachusetts, New Jersey, Oregon, Rhode Island, Vermont, Washington (United States)*	Passenger cars
Year	**Automaker**	**Announcement** (passenger cars)
2025	Jaguar	100% EV sales
2027	Alfa Romeo	100% EV sales
2028	Opel	100% EV sales in Europe
2030	Bentley, Fiat, Mini, Volvo	100% EV sales
	Ford	100% EV sales in Europe
2033	Audi	100% EV sales
2035	General Motors	100% ZEV sales
	Hyundai	100% EV sales in Europe
	Volkswagen	End ICE vehicle sales in Europe
2040	Honda	End ICE vehicle sales

*Country/state included based on membership of the International Zero-Emission Vehicle Alliance.

Notes: This table includes those countries and states with legislation, a target or stated ambition in place to phase out the sales of ICE passenger vehicles. Announcements with only proposals to phase out the sales of ICE vehicles such as the EU under the draft legislation in the Fit for 55 package are not included in this table.

Source: IEA analysis and ICCT (2021).

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[9] The additional upfront purchase cost of an electric car relative to an ICE depends on the size and performance of the battery, among other variables. Smaller car models have lower additional costs and in certain regions the additional cost of electric models relative to ICE vehicles is less than USD 4 000.

EVs also face non-economic barriers that are not completely overcome in the STEPS or in the APS. For instance, emerging market and developing economies rely heavily on second-hand vehicle markets where EVs will only become available with a time lag. Governments in these countries could consider instituting environmental regulations to encourage earlier uptake of EVs. Without policies of this kind, car fleets in some emerging market and developing economies may lag advanced economy efficiency and emissions standards. This is the case of Africa today, where only a few countries have emissions standards in place. Standards in countries like Nigeria or South Africa are at or below Euro 3, a level superseded by more stringent standards almost two decades ago in Europe (IEA, 2019a). Another potential barrier is that EV adoption may not be viable in regions with weak or unreliable grids. Targeted distribution grid enhancements and smart charging of EVs are likely to be the best way to address this issue. The widespread deployment of public charging infrastructure could also boost adoption, especially for electric heavy trucks.

Box 4.4 ▹ Rolling out zero emissions vehicles in North America

Road transportation currently accounts for 1.5 Gt CO_2 emissions in North America, about 30% of total emissions. With SUVs and pick-up trucks accounting for around three-quarters of all passenger light duty vehicle sales in the United States and Canada in 2019, the transition towards zero emissions will require targeted government policies and a further evolution in the strategies of traditional automakers.

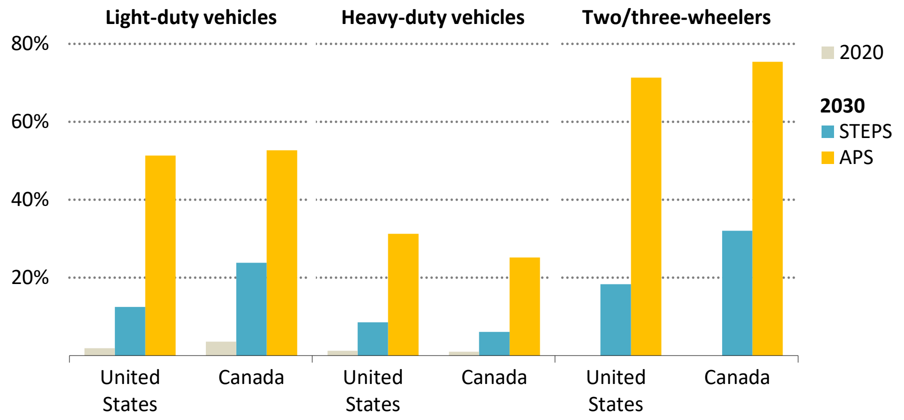
In Canada, co-ordinated, comprehensive zero emissions vehicle policy programmes are beginning to shift the market, and the share of EVs in light-duty vehicles sales reaches almost 25% by 2030 in the STEPS. In the United States, company- and state-level commitments succeed in increasing the share of EVs in light-duty vehicle sales to more than 10% by 2030 in the STEPS.

The Government of Canada has committed to ensure that all new passenger cars and light commercial vehicles are zero emissions vehicles (ZEVs) by 2035, and some provinces have translated this target into law. This target, met in full in the APS, is supported by upfront subsidies for ZEVs and public investment in charging infrastructure. The government is now creating partnerships with auto manufacturers to re-tool and produce ZEVs in Canada and to re-train current workers in the industry to work on EVs. Reflecting Canada's target, sales of ZEVs in the APS are double the level of the STEPS in 2030 (Figure 4.19).

In the United States, an executive order announced in August 2021 sets a target for 50% of all new passenger cars and light trucks to be zero emissions vehicles by 2030. The announcement came with a call to improve fuel efficiency standards (CAFE standards), and the US Department of Transportation has set a fleet-wide goal of 52 miles per gallon by 2026 for passenger cars and light trucks. At the state level, California is leading the way. It aims for 100% of passenger car and light commercial vehicle sales to be ZEVs by 2035, and for 100% of medium- and heavy-duty vehicles sales to be ZEVs by 2045.

General Motors, which accounts for over 15% of total car sales in the United States, has budgeted USD 35 billion through to 2025 to invest in both EVs and autonomous driving. The Ford Motor Company, which accounts for around 15% of total car sales in the United States, is set to spend USD 22 billion in the period to 2025 to further develop its EVs capabilities. Full implementation of the recently announced targets as modelled in the APS would increase the number of electric cars in the United States to 32 million by 2030, compared with 11 million in the STEPS.

Figure 4.19 ▷ Share of zero emissions vehicles sales in Canada and the United States in the Stated Policies and Announced Pledges scenarios, 2020 and 2030



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Policies in Canada are bringing the country closer to meet its 2035 target of 100% ZEV sales

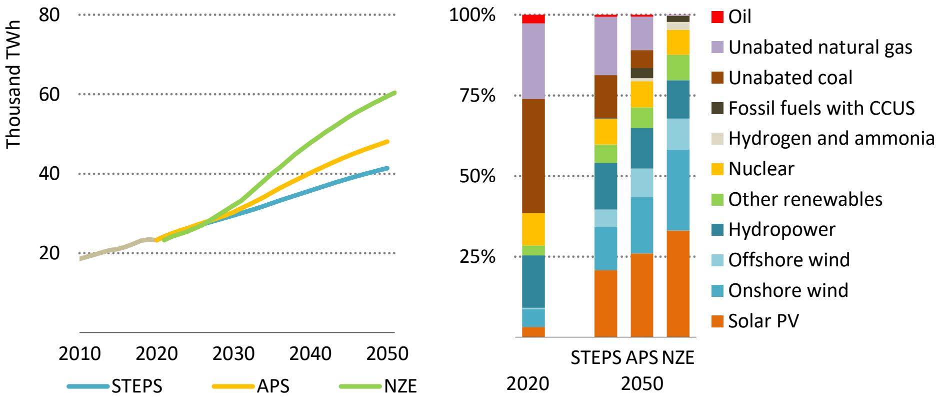
Note: Light-duty vehicles include passenger cars and light trucks; heavy-duty vehicles include medium and heavy freight trucks, and buses; ZEVs include battery electric, plug-in hybrid and fuel cell vehicles.

4.5 Electricity

The electricity sector has the potential to reshape global energy demand and supply through the electrification of end-uses and a shift towards renewables and other low emissions sources of electricity. Whether it does so, and at what speed, depends to a large extent on decisions by policy makers. Long-term visions and plans are needed to align electricity demand and supply developments, with electricity networks included as an integral part of the system, and to put in place the necessary policy and regulatory environments to achieve them.

Electricity demand increases steadily in the STEPS (Figure 4.20). There is a modest shift away from coal, and renewables rise from below 30% of generation in 2020 to over 40% in 2030. Delivery in full of announced pledges would lead to an additional 40% growth in electricity demand to 2050: it would also accelerate the move away from coal in the generation mix and increase the share of renewables to around 45% by 2030. The higher level of ambition in the NZE would double electricity demand growth compared with in the STEPS, cut coal-fired generation faster and lift the share of renewable energy to 60% by 2030.

Figure 4.20 ▷ Global electricity demand and generation mix by scenario



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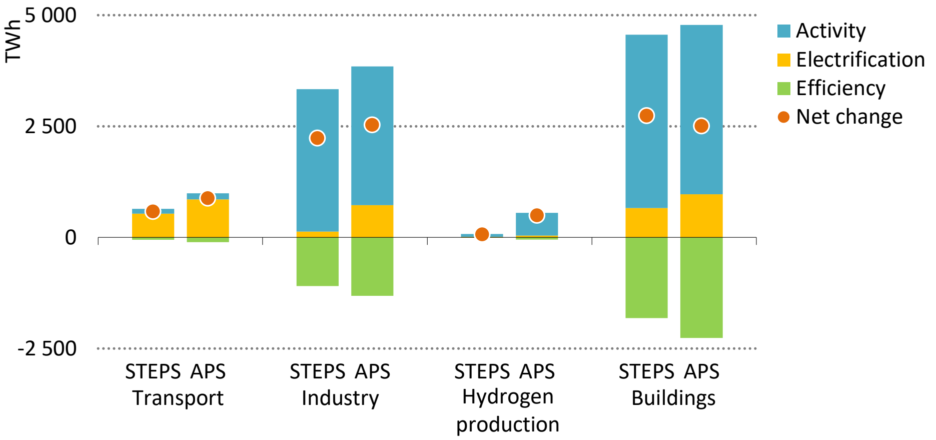
More electrification and clean electricity transitions lie ahead, and policy makers have the power to accelerate the pace of progress

4.5.1 Electricity demand

The Covid-19 crisis was a shock for the global energy system, but electricity proved to be more resilient than other energy sources. Global demand for electricity fell by only 1% in 2020. It is expected to rebound above 2019 levels in 2021 and continue to grow in 2022, as economies recover, boosted by stimulus spending.

In the years ahead, current and announced policies push electricity demand in the STEPS up by almost 30% from 23 300 TWh in 2020 to almost 30 000 TWh by 2030. Demand is projected to approach 42 000 TWh by 2050, almost 80% above today's level. Closing the implementation gap between the STEPS and APS would result in an acceleration of the average rate of annual electricity demand growth to 2030 from 2.4% in the STEPS to 2.7% in the APS, and would require an acceleration of efforts to electrify road transport, heating in buildings, and industrial processes (Figure 4.21). It would also need effective action in parallel to temper demand growth by increasing energy efficiency (see section 4.4.1).

Figure 4.21 ▷ Drivers of change in electricity demand in the Stated Policies and Announced Pledges scenarios, 2020 to 2030



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Meeting announced pledges requires new policies to accelerate efficiency improvements, electrification and the ramp up of hydrogen production

Note: Activity includes the impact of materials efficiency that reduces demand for industrial products as well as higher recycling rates.

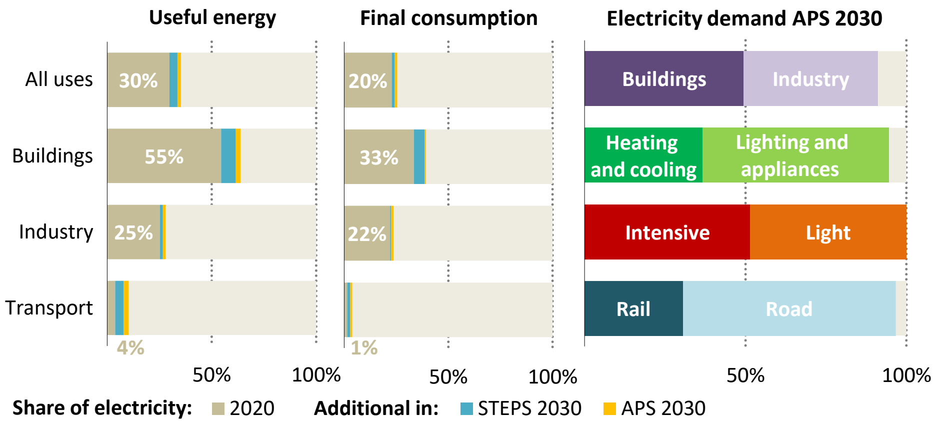
The vast majority of the increase in electricity demand between the STEPS and the APS is concentrated in **advanced economies**. They are responsible for most of the net zero and other emissions reduction pledges which have been made, and those pledges lead to faster electrification of end-uses in the APS. Electricity demand in advanced economies increases by almost 2% per year in the APS compared to only 1.2% in the STEPS to 2030, and demand is 7% higher in the APS than in the STEPS by 2030. The biggest drivers of the additional 7% of demand are faster growth in electrolytic hydrogen production and more rapid electrification of transport in the APS.

Emerging market and developing economies, led by economies in developing Asia, account for over 80% of electricity demand growth in the STEPS to 2030. However, their limited pledges mean that there is little difference in the level of their electrification between the APS and STEPS, and therefore not much of an implementation gap.

Improving the **efficiency** of electricity use is critical to tempering demand growth as economic activity increases and energy use is increasingly electrified. It decreases the overall amount of capacity needed, reduces costs and facilitates the transition to low-carbon generation. The biggest efficiency savings to 2030 in the STEPS are in the buildings sector, where demand is reduced by more than 1 800 TWh (largely due to efficiency improvements in appliances and lighting), and in the industry sector, where demand is reduced by 1 000 TWh (largely due to greater uptake of more efficient motor systems and heat pumps for low-temperature process heating). The APS sees further efficiency gains from buildings and a 20% increase of efficiency savings in industry.

At an economy-wide level, increased **electrification** offsets almost 50% of the demand savings from energy efficiency improvements in the STEPS to 2030, and more than 70% of the demand savings in the APS, which sees a faster shift to electric technologies than the STEPS. The electrification of transport alone increases demand by almost 900 TWh in the APS. Although the share of electricity in final energy demand increases to 22% in the APS by 2030 compared to 20% today, looking at the share of electricity in meeting demand for energy services provides a more accurate picture of its growing role because its high conversion efficiency means that one unit of electricity can provide more energy services, or useful energy[10], than fossil fuels in almost all cases. To take one example, electric cars are more efficient than their fossil fuel-powered counterparts, and the result is that, while electricity accounts for around 3% of passenger car energy demand in 2030, it accounts for over 10% of kilometres travelled. Electricity meets an average 30% of useful energy demand today across all sectors, and this increases to 34% in the STEPS and 35% in the APS by 2030 (Figure 4.22).

Figure 4.22 ▹ Share of electricity in useful energy demand and final consumption by sector and scenario



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Electricity is more efficient than fossil fuels in providing energy services, so its share of final consumption understates its contribution to the supply of useful energy

Notes: All uses refers to all end-use sectors, i.e. industry, transport, buildings, agriculture and non-energy use. Percentage values shown are for 2020.

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[10] Useful energy is that available to end-users to satisfy their need for energy services. It is also referred to as energy service demand. As a result of transformation losses at the point of use, the amount of useful energy is lower than the corresponding final energy demand for most technologies. Equipment using electricity often has higher conversion efficiency than equipment using other fuels, meaning that for a unit of energy consumed, electricity can provide more energy services.

4.5.2 Electricity supply

Record amounts of solar photovoltaics (PV) and wind capacity were added to global electricity supply in 2020, while demand fell slightly related to the pandemic. As a result, the share of fossil fuels in electricity generation fell to a 20-year low, and coal-fired generation dropped to its lowest share in the past 50 years. Recovery plans unveiled in recent months have committed huge funds to spur economic growth, but the amounts directed towards clean energy and electricity networks fall well short of the levels suggested in the Sustainable Recovery Plan (IEA, 2020b), and the continued expansion in renewables has not been sufficient to offset the increase of fossil fuels to meet electricity demand growth: the upshot is that CO_2 emissions from electricity generation are set to rebound in 2021.

Over the next decade, the strong growth of **renewables** is set to continue in all scenarios. Solar PV and wind power lead the way with capacity increases that far outstrip those for other sources of electricity (Figure 4.23). This reflects policy support in over 130 countries and the success of solar PV and wind in becoming established as the cheapest and most competitive sources of new electricity in most markets.[11] Current policies lead to an increase in combined capacity additions from a record 248 GW in 2020 to 310 GW in 2030 in the STEPS. Additional implementation measures (such as securing more capacity through auction schemes, streamlining permitting and approval processes, raising minimum share requirements, bolstering tax credits or strengthening carbon pricing) are needed to expand deployment to almost 470 GW in 2030 in the APS. The increase needs to be achieved mostly outside of China – today's largest market for solar PV and wind – as it faces a relatively small implementation gap. China's current policies are consistent with announced targets to 2030. The implementation gap is largest in advanced economies, including the United States, Canada, Australia and the European Union. The net zero pathway set out in the NZE requires wind and solar PV capacity additions in 2030 of over 1 000 GW. Ambitions would need to be raised significantly in emerging market and developing economies in particular to make this happen.

Solar PV and wind alone meet three-quarters of electricity demand growth to 2030 in the STEPS and 90% in the APS: they easily exceed demand growth in the NZE. This means that the share of solar PV and wind in electricity supply in 2030 rises from under 10% in 2020 to 23% in the STEPS, 27% in the APS and 40% in the NZE. Hydropower, bioenergy, geothermal and concentrating solar power see much smaller increases to 2030 across the scenarios, as they often have longer project lead times and require favourable site conditions and resources, but they match the pace of electricity demand growth and continue to provide about 20% of electricity generation worldwide.

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[11] Competitiveness of power generation technologies is evaluated in the IEA World Energy Model by combining technology costs and system value through the value-adjusted levelised cost of electricity (IEA, 2018). It does not include grid-related integration costs.

Figure 4.23 ▷ Change in electricity generation by source and scenario, 2020 to 2030

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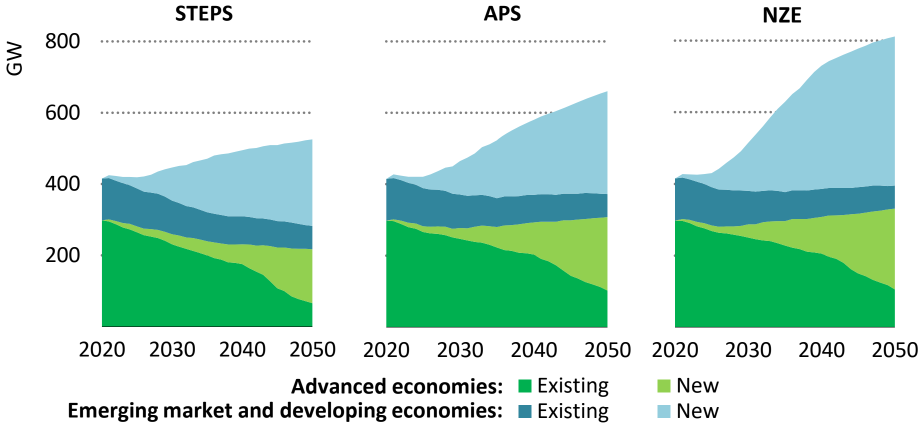
Solar PV and wind take the lead in each scenario by 2030, but their strong growth at the expense of coal in the APS falls short of what is needed for net zero emissions by 2050

The outlook for **nuclear power** depends on decisions yet to be made about both existing reactors and new construction. Over the next decade, the expansion of nuclear power is largely determined by the nearly 60 GW of capacity under construction in 19 countries at the start of 2021. China, Russia and Korea have successfully constructed many recent projects in five to seven years both at home and abroad, so it is possible that some additional reactors that start construction before 2025 could be completed by 2030. Beyond 2030, there are over 100 GW of planned projects that have not yet broken ground and several times that proposed individually or through policy targets. There is more uncertainty about the pace of retirements for existing reactors, with many ageing reactors in the United States, Europe and Japan in need of additional investment (and new regulatory approvals in some cases) to extend their operational lifetimes. Lifetime extension decisions also face challenging market conditions, rigorous safety checks and social acceptance issues.

In the STEPS, over 65 GW (23%) of the existing nuclear fleet in advanced economies is retired by 2030, compared with 50 GW in the APS (Figure 4.24). Even though lifetime extensions offer a cost-effective way of providing more low emissions electricity over the next decade, there is a risk that reactors in advanced economies could be retired at an even faster pace, eroding the low-carbon foundation for electricity supply provided by nuclear power (IEA, 2019b). By 2040, about three-quarters of the current nuclear fleet in advanced economies will exceed 50 years of operations, and currently this looks very likely to lead to a wave of retirements in each of the scenarios. Innovative nuclear power technologies, such as small modular reactors, could offer shorter construction and approval times for new capacity, as well as expanding opportunities for nuclear power beyond electricity, for example for heat and hydrogen production, but innovation efforts need to be accelerated to improve their prospects.

Figure 4.24 ▷ Nuclear power capacity by scenario, 2020-2050



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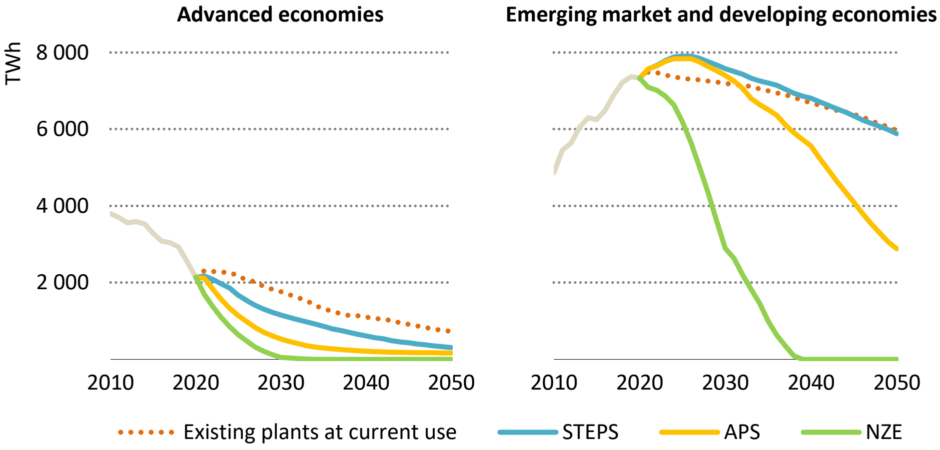
Nuclear power can help clean energy transitions through lifetime extensions for existing reactors where safe, and the acceleration of new construction where acceptable

The technologies needed to equip **power plants with carbon capture technologies or to co-fire ammonia and hydrogen** in high shares in coal- or natural gas-fired power plants are currently at pre-commercial stages of development. Concerted efforts need to be made to drive down their costs if they are to make inroads by 2030. These technologies are important because they can provide a low emissions source of generation and flexibility, and because they help to extend the use of existing assets. They are not deployed on a significant scale in the STEPS at any stage through to 2050. Meeting announced pledges in the APS calls for some development of these technologies, while the path to net zero emissions in the NZE calls for several projects using these technologies to be completed by 2030 and for many more to be under development at that point, putting them on course to make a larger contribution between 2030 and 2050.

The outlook to 2030 for **coal** varies widely across the three scenarios. It was the leading source of electricity in 2020, but it was also responsible for three-quarters of total CO_2 emissions from electricity generation. In advanced economies, coal continues its recent decline in all scenarios, but emerging market and developing economies face the challenge of slowing and stopping its growth before it can begin a long-term decline. Underscoring this challenge is the 140 GW of coal-fired capacity currently under construction and the over 430 GW at the planning stage. Financing coal has become increasingly difficult in some regions, including Southeast Asia, developing Asia and Africa, as international pressures related to climate change mount and erode the expected profitability of new coal plants.

The implementation gap for unabated coal is sizeable in advanced economies, where generation falls by almost 50% in the STEPS from 2020 to 2030 but by 75% in the APS (Figure 4.25), underlining the case for accelerating renewables growth. In emerging market and developing economies, unabated coal peaks in 2025 in both the STEPS and the APS (and is higher at that point than in 2020) before declining rapidly, whereas the NZE calls for immediate reductions and 60% reductions of unabated coal-fired generation by 2030. Over the next 30 years, pledges announced in China and elsewhere close only one-quarter of the gap between the STEPS and the NZE in terms of cumulative unabated coal-fired generation and related CO_2 emissions.

Figure 4.25 ▹ Unabated coal-fired electricity generation by scenario, 2010-2050



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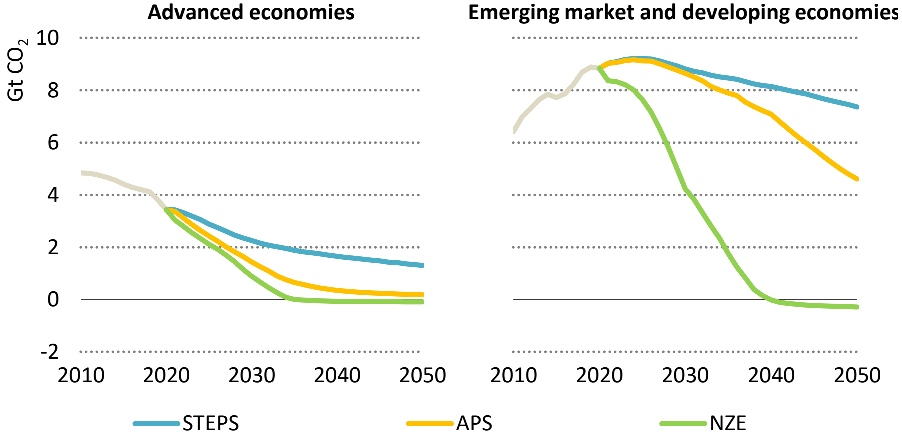
Unabated coal is set to decline, but even in the APS it continues to be used widely: this puts the world off track to reach net zero emissions by 2050

Existing coal-fired power plants present a significant challenge. If they were to continue recent operations for the remainder of their technically viable lives, it is very hard to see how net zero emissions could be reached by 2050. Efforts to tackle these emissions, including those from the large fleet of young coal plants in emerging market and developing economies, are therefore essential. In many cases, coal-fired plants were traditionally the cornerstone of power systems, providing electricity along with stability, flexibility and other grid services. Phasing down and ultimately replacing coal in these systems in a secure and affordable manner requires a number of regulatory and operational changes, including actions to tap a wider set of smaller and more distributed sources for grid services, in systems that often face financial difficulties. International collaboration and knowledge sharing of past experiences and best practices are important ingredients to build the confidence needed to raise ambitions.

Natural gas use in the electricity sector worldwide increases between 5% and 15% to 2030 in the STEPS and the APS, though its share of generation declines. It also provides essential system flexibility and grid services in both these scenarios. Natural gas is the largest source of electricity in advanced economies and its level of use remains broadly stable in those economies over the next decade, while it increases by about one-third in the emerging market and developing economies, helping to moderate the use of coal. In the NZE, natural gas provides a bridge to deeper CO_2 emissions reductions by displacing the need for coal-fired power, but it then begins a long-term decline before 2030.

Beyond 2030, electricity sector transitions continue to shift away from coal and towards renewables. Unabated coal-fired generation declines after 2030 in each scenario, but it remains a major source of electricity in the STEPS through to 2050, whereas its use falls by 60% from 2030 to 2050 in the APS, and it is phased out entirely by 2040 on the net zero pathway set out in the NZE. The share of renewables in electricity generation reaches 60% by 2050 in the STEPS, 70% in the APS and nearly 90% in the NZE. Wind and solar PV continue to lead, with hydropower and other renewables accounting for about 20% of generation in 2050 in each scenario, while nuclear power, fossil fuel plants equipped with CCUS, and hydrogen and ammonia combined contribute about another 10% of generation. The additional demand for electricity embodied in the APS, and still more in the NZE, means that substantially more growth is required to keep pace with electricity demand in these scenarios. Unabated natural gas for electricity generation varies most between 2030 and 2050 across the scenarios: in the STEPS, it grows almost 20%; in the APS, it declines by almost 15%; and in the NZE it declines by over 95%.

Figure 4.26 ▷ Electricity sector CO_2 emissions by scenario, 2010-2050



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In the APS, CO_2 emissions from electricity decline steadily to 2030 in advanced economies but rise until a peak in the mid-2020s in emerging market and developing economies

The electricity sector is the largest source of global **CO_2 emissions** today and these emissions are set to decline in each scenario over the coming decades. However, the reductions by 2030 are 10% in the STEPS and nearly 20% in the APS compared with close to 60% in the NZE where electricity leads the way and enables reductions in other sectors through electrification (Figure 4.26). The difference between the APS and the NZE highlights the large ambition gap in the electricity sector. In advanced economies, the announced pledges that are incorporated in the APS close about 70% of the gap between the STEPS and the NZE in terms of cumulative emissions savings to 2050. In emerging market and developing economies, the pledges in the APS reduce electricity sector CO_2 emissions starting in the mid-2020s and close about 15% of the gap between the STEPS and the NZE.

4.5.3 Electricity system flexibility

Electricity system flexibility is becoming increasingly central to electricity security, and systems are going to need greater flexibility from minute-to-minute, hour-to-hour and season-to-season over the coming decades.[12] In India, the emphasis on scaling up solar PV and other renewables drives the largest increase in hour-to-hour flexibility needs over the next decade (Figure 4.27). In the United States, the European Union and China, average flexibility needs rise by over 40% in the STEPS from 2020 to 2030. Some countries in Europe and some states in the United States, Australia and India already have high shares of variable renewables (NITI Aayog and IEA, 2021), and others may find it useful to draw on their experiences.

By 2050, global average flexibility needs triple in STEPS, increase 3.5-times in the APS and quadruple in the NZE. The growth in flexibility needs outpaces electricity demand growth in each scenario. In the United States, for example, hour-to-hour flexibility needs double over the next decade in the APS.

The main drivers of increasing short-term flexibility needs are the rising shares of variable wind and solar PV in electricity generation and the changing nature of electricity demand patterns. (See Box 4.5 and the wider flexibility and electricity security discussion in Chapter 6). Solar PV and wind are set to more than double their combined current share of electricity generation (nearly 10%) over the next decade in the STEPS and APS, and to quadruple it in the NZE. The non-dispatchable and variable nature of these renewable energy technologies requires additional system flexibility to continuously balance electricity supply and demand and maintain grid stability. To date, dispatchable thermal generators like coal and gas plants have been the main sources of electricity, but this is rapidly changing as their market share declines.

Beyond 2030, the amount of flexibility needed by scenario continues to widen based primarily on the contributions of wind and solar PV. At the same time, increased

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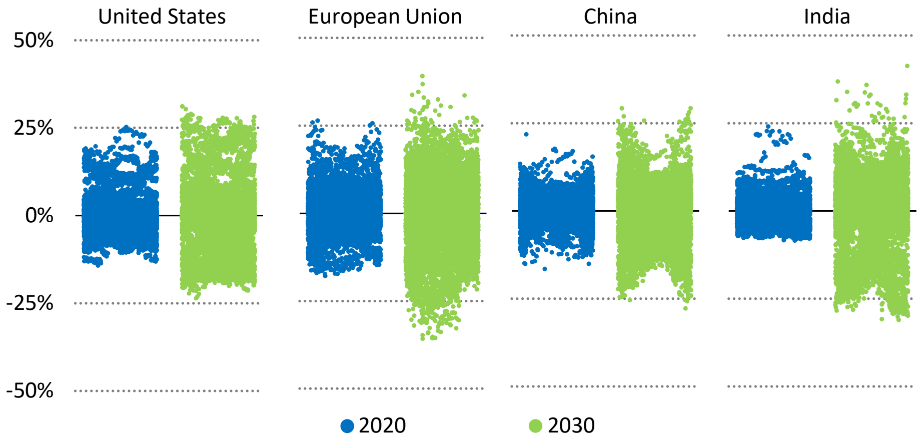
[12] Flexibility is defined as the ability of a power system to reliably and cost-effectively manage the variability and uncertainty of demand and supply across all relevant timescales, from ensuring instantaneous stability of the power system to supporting long-term security of supply.

electrification (including road transport, heating in buildings and industrial processes) and an expansion of electrolytic hydrogen production together reshape electricity demand, raising peaks and increasing variability throughout the day and as a result pushing up overall electricity system flexibility needs.

Figure 4.27 ▹ **Hour-to-hour flexibility needs in the United States, European Union, China and India in the Stated Policies Scenario, 2020 and 2030**



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Even with the relatively modest clean electricity transitions in the STEPS, electricity system flexibility needs to rise by two-thirds over the next decade

Note: Flexibility needs are represented by the hour-to-hour ramping requirements after removing wind and solar production from electricity demand, divided by the average for the year.

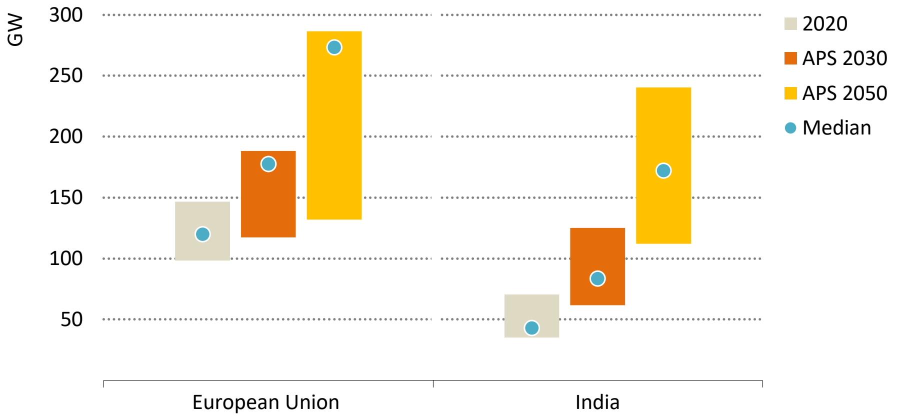
Box 4.5 ▹ Changing shape of electricity demand

The electrification of road transport, heating in buildings, industrial processes and the emergence of electrolytic hydrogen production have the potential to reshape electricity load curves and compound the challenges for electricity systems in transition. By 2030 these emerging end-uses are set to increase their share of electricity demand to 14% in the STEPS, 16% in the APS and 25% in the NZE.

Electricity demand peaks are influenced by annual variations in demand for certain end-uses, such as heating and cooling, and daily variations in demand corresponding to patterns of activity. For this *World Energy Outlook*, the IEA has added further detail to its modelling of hourly heating, cooling and lighting electricity demand across the year, using deep learning algorithms, in order to provide detailed insights into the contributions of these end-uses to peak demand today and in the future.

Recent cold snaps and heat waves have underlined the impact that weather can have on electricity demand variation and the importance of understanding and preparing for these impacts. The rapidly increasing deployment of heat pumps and air conditioners will increase the temperature sensitivity of demand, while uncontrolled charging of the EV fleet presents an additional risk of rapid variations in demand. Daily electricity demand today varies by around 120 GW in the European Union and 40 GW in India, or more than 40% and 30% of annual average demand respectively. Without effective planning and deployment of demand-side response, the daily variation of demand is expected to increase to as much as 270 GW in the European Union and some 170 GW in India by 2050 in the APS (Figure 4.28).

Figure 4.28 ▷ Range of maximum variation in daily electricity demand in the European Union and India in the Announced Pledges Scenario, 2020, 2030 and 2050



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Daily demand becomes more changeable as demand for EV charging, digital appliances, heating and cooling and other highly variable end-uses increases

Note: The range of variations in daily demand is based on the difference in the minimum and maximum hourly demand for each day of the year.

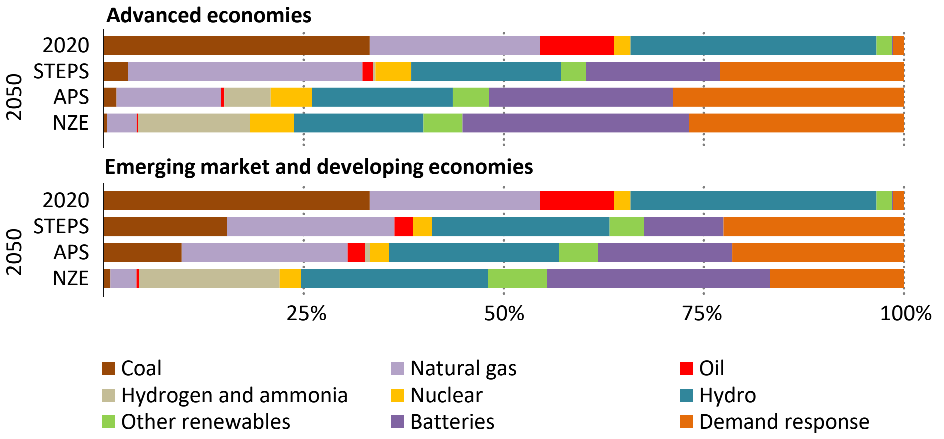
These changes are happening in parallel with a rapid increase in the share of electricity being generated from variable renewables in each of the scenarios. Additional flexibility resources need to be deployed in order to successfully integrate these increasing shares of variable renewables and maintain security of supply. With the right control technology and incentives, around 15% of electricity demand could be shifted in time to some extent by 2030 so as to provide flexibility in the APS, increasing to 40% by 2050. For example, electric cars could be smart charged and used in a vehicle-to-grid configuration, grid-connected hydrogen electrolysers could be switched on and off in line with system needs, and well insulated homes and some appliances could shift heating and cooling demand in line with system needs.

Policy action is required to ensure that demand-side response resources can participate in flexibility markets and that incentives to shift demand are available to consumers through models such as time-of-use and dynamic electricity pricing. The right frameworks and incentives could do much to help maximise the system utility of emerging end-uses such as EV charging and electrolytic hydrogen production, encourage consumer behavioural change and support the innovations needed to integrate ever higher shares of variable renewables.

A transition is also underway in electricity system flexibility. There are four main sources that contribute to ensure the balance of electricity demand and supply at all times: power plants, energy storage, demand-side response and electricity networks.

Power plants have always played an important role in providing flexibility, but that role changes in the future, with the extent of change varying by scenario. In the STEPS, transitions are limited in most regions, with unabated coal and natural gas playing an important role through to 2050, and the changes needed in the way systems are managed are similarly limited. With more vigorous action to phase out coal in the APS and the NZE, dispatchable low emissions sources – including hydropower, bioenergy and nuclear power – become more central to system flexibility, although natural gas-fired power plants continue to be a primary source of flexibility to 2050 in all but the NZE (Figure 4.29).

Figure 4.29 ▷ Electricity system flexibility by source and scenario, 2020 and 2050



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Coal and natural gas remain cornerstones of electricity flexibility in the STEPS, but the mix of flexibility sources shifts dramatically on the path to net zero emissions by 2050

Storage technologies are set to play a much larger role in system flexibility in all scenarios. Battery storage systems have become an attractive option to address flexibility needs measured in seconds up to hours because they are capable of near-instantaneous charging or discharging to suit system needs. Although batteries are usually designed to store limited amounts of energy, other energy storage technologies are better suited to address longer duration flexibility needs, even across seasons: they include pumped hydro, which looks set for strong growth over the next decade (IEA, 2021c), as well as compressed air energy storage, gravity storage, hydrogen and ammonia.

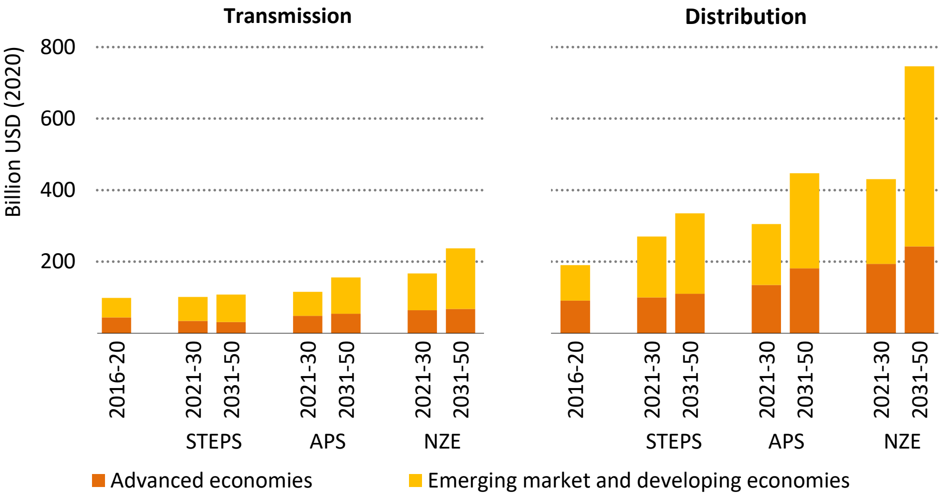
Demand-side response has the potential to play a large role in system flexibility, but its ability to do so hinges critically on the regulations and digital infrastructure in place. By shifting the times when energy is consumed, demand-side response helps to align demand with available supply, thereby lowering stress on the system. In each scenario, there are rapid increases in electricity demand from air conditioners, heat pumps, EVs and other potentially flexible sources of demand. Price signals are a powerful means of determining when and where flexibility is needed, and are best applied equally to all sources of flexibility, whether they are large or small and whether they come from the supply side or demand side.

Electricity networks pool the potential of flexibility sources and bolster overall system flexibility. Large transmission lines assist the balancing of electricity demand and supply within and between regions, for example by linking into hydro-rich systems to help manage the integration of wind and solar PV, thereby increasing system resiliency. Strengthened distribution lines connect decentralised sources, including distributed solar PV and battery systems, enabling more localised electricity usage and decreasing demand on a main network. Smart grids add further resiliency by dispatching energy more accurately and rapidly relaying data on optimised load balancing.

4.5.4 Networks

Electricity networks are the foundation of reliable and affordable electricity systems, making them critical infrastructure in all modern economies. There are around 80 million kilometres of networks in the world today. Over the next decade, investment in these networks needs to increase substantially in order to maintain and improve grid reliability, support clean energy transitions and provide access to electricity to all. In the STEPS, investment in transmission and distribution grids climbs from less than USD 300 billion on average per year over the past five years to over USD 370 billion on average over the next decade, with most of the increase going to distribution (Figure 4.30). The APS calls for only marginally higher grid investment to 2030, but the level of investment needed rises significantly after 2030 in line with the pace of overall decarbonisation. In the NZE, grid investment to 2030 averages USD 630 billion per year, a major increase in an area where new projects often span a decade or more.

Figure 4.30 ⊳ Average annual electricity network investment by scenario, 2016-2050



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Grid investment needs to scale up as electricity demand and variable renewables increase, making long-term visions for grids essential for energy transitions

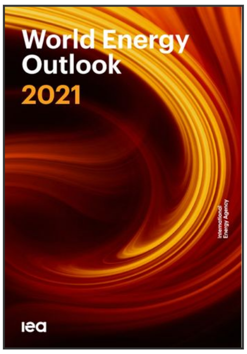
The main catalyst for investment to reinforce and extend electricity networks is electricity demand growth. By 2030, electricity demand rises by about 30% in both the STEPS and APS, while it increases by almost 45% in the NZE. However, network expansion and modernisation also play a crucial role in decarbonisation, paving the way for rising shares of renewables and universal access to electricity, and this needs to be supported by investment too. Modernising and extending electricity network infrastructure – from transmission and distribution lines to substations and other equipment – constitutes a major challenge for owners and operators. New transmission lines are needed to connect utility-scale wind and solar PV to demand centres, sometimes over long distances; new distribution lines are needed to handle distributed solar PV capacity, which globally grows nearly fourfold by 2030 in the APS and nearly sixfold in the NZE; and new offshore substations and dynamic cabling are needed to connect offshore wind to the mainland. In addition to new and replacement sections of networks, investment is needed in smart grids and digitalisation components, not least to help ensure that expanding volumes of solar PV and wind can be accommodated in a way that ensures network stability and reliability. Cities all over the world have a particular opportunity to accelerate progress towards net zero emissions by taking advantage of the new opportunities presented by digitalisation (IEA, 2021d). Early action is essential to keep pace with transitions: grid projects generally take years longer than most renewable energy projects, and inadequate progress has the potential to create bottlenecks in the uptake of renewables.

In all scenarios, at least 60% of investments to 2050 are in emerging market and developing economies, where millions of new customers continue to be connected to the network and end-uses are increasingly electrified. In advanced economies, investments are largely focused on ensuring network reliability throughout the transition to a decarbonised power sector facing higher demand. Interconnections have a part to play in all regions in meeting rising flexibility needs, maximising the use of available resources and ensuring overall system reliability.

Policy makers have a crucial role to play in setting long-term visions and plans for electricity aimed at ensuring that electricity network expansion and modernisation keep pace with expanding renewables deployment and new sources of demand. Clear visions and plans will limit uncertainty for regulators, investors and project developers in terms of system needs and market conditions, and in so doing will help to minimise the costs of transitions.

Regulators have the important task of ensuring electricity network development while maintaining system stability and adequacy. With the rapid growth of grid-connected variable renewables and storage, avoiding grid congestion and modernising ageing equipment are likely to be primary concerns, and these are likely to be easier to manage where network planning provides timely signals to invest in new sources of electricity. Greater integration of renewables also increases the complexity of grid operations, not least in terms of grid-forming capabilities for maintaining power quality, and may give rise to new questions about asset ownership and the allocation of responsibilities. Regulators need to examine whether electricity market designs are still fit for purpose, which will involve reviewing cost allocation frameworks and ensuring fair remuneration to system operators and investors. They also need to ensure the resilience of power systems in the face of growing cybersecurity and climate risks (IEA, 2021e).

With all these considerations, network-wide oversight can help to ensure that the grids of tomorrow will be able to meet the needs of accelerated clean energy transitions. This includes coordinating long-term grid planning and, where necessary, clarifying the roles and responsibilities of regulators, transmission system operators (TSOs) and distribution system operators (DSOs). The importance of network-wide co-ordination has already been recognised in countries such as Australia and Japan, and steps to enhance the role of TSOs and DSOs to support this are being considered in the United States and the European Union. Given lead times of a decade or more to build new lines, it would be helpful to have entities responsible for co-ordination that are able to take an overall view of retirements of conventional generators, new renewable energy projects, opportunities for demand-side response and cross-border trade, and the state of domestic grids. Long-term planning and co-ordination could also help address other potential bottlenecks, including land availability.



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