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2024

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Energy Agency

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The world is facing perilous times. Escalating conflict in the Middle East and Russia's continued war in Ukraine have global attention sharply focused on some of the world's most important energy-producing regions. While some of the acute impacts of the global energy crisis have receded, geopolitical uncertainty is exposing the underlying fragilities of the global energy system, regardless of technology or geography. Energy infrastructure is also facing increasing risks from extreme weather events that are becoming an all too common aspect of life for people around the world.

Too often, the worst impacts of these crises are reserved for the poorest in societies, especially in emerging and developing economies. Today, the greatest energy injustice is the hundreds of millions of people, mostly in Africa, who still lack access to basic energy services such as electricity or safe stoves for cooking.

With all these issues front of mind, energy security is again a major theme of this year's *World Energy Outlook* (WEO). In our fast-changing world, the concept of energy security goes well beyond safeguarding against traditional risks to oil and natural gas supplies, as important as that remains for the global economy. It also means ensuring access to affordable energy supplies; anticipating emerging risks in the electricity sector; shoring up supply chains for clean energy technologies and the critical minerals required to make them; and tackling the rising threats that extreme weather events pose to energy systems.

All these areas are key priorities for the IEA's day-to-day work. To advance the global discussion on these issues, the IEA is convening a major International Summit on the Future of Energy Security in the second quarter of 2025, hosted in London by the UK Government, to build a common understanding of the importance of energy security and what it takes to truly deliver it in the context of clean energy transitions.

The analysis in this year's Outlook reinforces my long-held conviction that energy security and climate action go hand-in-hand: the world does not need to choose between ensuring reliable energy supplies and addressing the climate crisis. This is because deploying cost-competitive clean energy technologies represents a lasting solution not only for bringing down emissions, but also for reducing reliance on fuels that have been prone to volatility and disruption.

The latest Outlook also confirms that the contours of a new, more electrified energy system are becoming increasingly evident, with major implications on how we meet rising demand for energy services. Clean electricity is the future, and one of the striking findings of this Outlook is how fast demand for electricity is set to rise, with the equivalent of the electricity use of the world's ten largest cities being added to global demand each year.

This WEO highlights, once again, the choices that can move the energy system in a safer and more sustainable direction. I urge decision makers around the world to use this analysis to understand how the energy landscape is changing, and how to accelerate this clean energy transformation in ways that benefit people's lives and future prosperity.

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Annexes

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Geopolitical tensions and fragmentation are major risks for energy security and for coordinated action on reducing emissions

Escalating conflict in the Middle East and Russia's ongoing war in Ukraine underscore the continued energy security risks that the world faces. Some of the immediate effects of the global energy crisis had started to recede in 2023, but the risk of further disruptions is now very high. The experience of the last few years shows how quickly dependencies can turn into vulnerabilities; a lesson that applies also to clean energy supply chains that have high levels of market concentration. Markets for traditional fuels and for clean technologies are becoming more fragmented: since 2020, almost 200 trade measures affecting clean energy technologies – most of them restrictive – have been introduced around the world, compared with 40 in the preceding five-year period.

Fragility in today's energy markets is a reminder of the abiding importance of energy security – the foundational and central mission of the International Energy Agency (IEA) – and the ways that more efficient, cleaner energy systems can reduce energy security risks. The increasingly visible impacts of climate change, the momentum behind clean energy transitions, and the characteristics of clean energy technologies are all changing what it means to have secure energy systems. A comprehensive approach to energy security therefore needs to extend beyond traditional fuels to cover the secure transformation of the electricity sector and the resilience of clean energy supply chains. Energy security and climate action are inextricably linked: extreme weather events, intensified by decades of high emissions, are already posing profound energy security risks.

Clean energy transitions have accelerated sharply in recent years, shaped by government policies and industrial strategies, but there is more near-term uncertainty than usual over how these policies and strategies will evolve. Countries representing half of global energy demand are holding elections in 2024, and energy and climate issues have been prominent themes for voters that have been buffeted by high fuel and electricity prices, and by floods and heatwaves. Yet energy policies and climate targets, influential though they are, are not the only forces behind the continued rise of clean energy. There are strong cost drivers, as well as intense competition for leadership in clean energy sectors that are major sources of innovation, economic growth and employment. More than ever, the energy outlook is complex, multifaceted and defies a single view on how the future might unfold.

Robust, independent analysis and data-driven insights are vital to navigate today's energy uncertainties

Reflecting today's uncertainties, our three main scenarios are complemented by sensitivity cases for renewables, electric mobility, liquefied natural gas (LNG) and how heatwaves, efficiency policies and the rise of artificial intelligence (AI) might affect electricity demand. The scenarios and sensitivity cases illustrate different pathways that the energy sector could follow, the levers that decision-makers can use to reach them, and their implications for energy markets, security and emissions, and for people's lives and livelihoods. The Stated Policies Scenario (STEPS) provides a sense of the energy sector's direction of travel today, based on the latest market data, technology costs and in-depth analysis of the prevailing

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policy settings in countries around the world. The STEPS also provides the backdrop for the upside and downside sensitivity cases. The Announced Pledges Scenario (APS) examines what would happen if all national energy and climate targets made by governments, including net zero goals, are met in full and on time. The Net Zero Emissions by 2050 (NZE) Scenario maps out an increasingly narrow path to reach net zero emissions by mid-century in a way that limits global warming to 1.5 °C.

Geopolitical risks abound but underlying market balances are easing, setting the stage for intense competition between different fuels and technologies

The next phase in the journey to a safer and more sustainable energy system is set to take place in a new energy market context, marked by continued geopolitical hazards but also by relatively abundant supply of multiple fuels and technologies. Our detailed analysis of market balances and supply chains brings an overhang of oil and LNG supply into view during the second half of the 2020s, alongside a large surfeit of manufacturing capacity for some key clean energy technologies, notably for solar PV and batteries. These provide something of a buffer against further market disruptions, but also imply downward pressure on prices and a period of increased competition among suppliers. The rapid rise in clean energy deployment in recent years came during a period of price volatility for fossil fuels. Clean technology costs are coming down, but maintaining and accelerating momentum behind their deployment in a lower fuel-price world is a different proposition. How consumer choices and government policies play out will have huge consequences for the future of the energy sector, and for tackling climate change.

How fast will clean energy transitions unfold?

Clean energy is entering the energy system at an unprecedented rate, including more than 560 gigawatts (GW) of new renewables capacity added in 2023, but deployment is far from uniform across technologies and countries. Investment flows to clean energy projects are approaching USD 2 trillion each year, almost double the combined amount spent on new oil, gas and coal supply – and costs for most clean technologies are resuming a downward trend after rising in the aftermath of the Covid-19 pandemic. This helps renewable power generation capacity rise from 4 250 GW today to nearly 10 000 GW in 2030 in the STEPS, short of the tripling target set at COP28 but more than enough, in aggregate, to cover the growth in global electricity demand, and to push coal-fired generation into decline. Together with nuclear power, which is the subject of renewed interest in many countries, low-emissions sources are set to generate more than half of the world’s electricity before 2030.

China stands out: it accounted for 60% of the new renewable capacity added worldwide in 2023 – and China’s solar PV generation alone is on course to exceed, by the early 2030s, the total electricity demand of the United States today. There are open questions, in China and elsewhere, about how quickly and efficiently new renewable capacity can be integrated into power systems, and whether grid expansions and permitting times keep pace. Policy uncertainty and a high cost of capital are holding back clean energy projects in many developing economies. Recent clean energy trends in advanced economies present a mixed picture, with accelerations in some areas accompanied by slowdowns in others, including a

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large fall in heat pump sales in Europe in the first half of 2024. Progress on the other headline commitments from COP28 is lagging: the goal of doubling the global rate of energy efficiency improvements could provide larger emissions reductions by 2030 than anything else, but looks far out of reach under today's policy settings. Tried and tested policies and technologies are likewise available to deliver a major reduction in methane emissions from fossil fuel operations, but abatement efforts have been patchy and uneven.

Clean energy momentum remains strong enough to bring a peak in demand for each of the fossil fuels by 2030

Demand for energy services is rising rapidly, led by emerging and developing economies, but the continued progress of transitions means that, by the end of the decade, the global economy can continue to grow without using additional amounts of oil, natural gas or coal. This has not been the case in recent years: despite record clean energy deployment, two-thirds of the increase in global energy demand in 2023 was met by fossil fuels, pushing energy-related CO_2 emissions to another record high. In the STEPS, the largest sources of rising demand for energy are, in descending order, India, Southeast Asia, the Middle East and Africa. But growth in clean energy and structural changes in the global economy, particularly in China, are starting to temper overall energy demand growth, not least because a more electrified, renewables-rich system is inherently more efficient than one dominated by fossil fuel combustion (in which a lot of the energy generated is lost as waste heat). Outcomes in individual years can vary in practice depending on broader economic or weather conditions, or in hydropower output, but the direction of travel under today's policy settings is clear. Continued growth in global energy demand post-2030 can be met solely with clean energy.

The world has the need and the capacity to go much faster

Ample clean energy manufacturing capacity creates scope for faster transitions that move towards alignment with national and global net zero goals, but this means addressing imbalances in today's investment flows and clean energy supply chains. Over the past five years, annual solar capacity additions quadrupled to 425 GW, but annual manufacturing capacity is set for a sixfold increase to more than 1 100 GW, a level that – if deployed in full – would be very close to the amounts needed in the NZE Scenario. There is a similar story of plentiful manufacturing capacity for lithium-ion batteries. Bringing these technologies at scale to developing economies would be transformative for the global outlook, helping rising demand to be met in a sustainable way and allowing global emissions not only to peak in the coming years, as they do in the STEPS, but also to enter a meaningful decline, which they do not do in the STEPS. This requires concerted efforts to facilitate investment in developing economies by addressing risks that push up the cost of capital. Periods of ample supply make life difficult for new entrants, but improving the resilience and diversity of the supply chains for clean energy technologies and for critical minerals remains an essential task. For the moment, these supply chains are heavily concentrated in China.

Demand for electricity is taking off, but how high will it go?

The contours of a new, more electrified energy system are coming into focus as global electricity demand soars. Electricity use has grown at twice the pace of overall energy

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demand over the last decade, with two-thirds of the global increase in electricity demand over the last ten years coming from China. Electricity demand growth is set to accelerate further in the years ahead, adding the equivalent of Japanese demand to global electricity use each year in the STEPS, and rising even more quickly in scenarios that meet national and global net zero goals. The projections for global electricity demand in STEPS are 6%, or 2 200 terawatt-hours (TWh), higher in 2035 than in last year's *Outlook*, driven by light industrial consumption, electric mobility, cooling, and data centres and AI.

Rising data centre electricity use, linked in part to growing use of AI, is already having some strong local impacts, but the potential implications of AI for energy are broader and include improved systems coordination in the power sector and shorter innovation cycles. There are more than 11 000 data centres registered worldwide and they are often spatially concentrated, so local effects on electricity markets can be substantial. However, at a global level, data centres account for a relatively small share of overall electricity demand growth to 2030. More frequent and intense heatwaves than we assume in the STEPS, or higher performance standards applied to new appliances – notably air conditioners – both produce significantly greater variations in projected electricity demand than an upside case for data centres. The combination of rising incomes and increasing global temperatures generate more than 1 200 TWh of extra global demand for cooling by 2035 in the STEPS, an amount greater than the entire Middle East's electricity use today.

The rise of electric mobility, led by China, is wrong-footing oil producers

The slowdown in oil demand growth in the STEPS puts major resource owners in a bind as they face a significant overhang of supply. China has been the engine of oil market growth in recent decades, but that engine is now switching over to electricity: the country's oil use for road transport is projected to decline in the STEPS, although offset by a large increase in oil use as a petrochemical feedstock. India becomes the main source of oil demand growth, adding almost 2 million barrels per day (mb/d) to 2035. Cost-competitive EVs – many of them from Chinese manufacturers – are making inroads in a range of markets, although there is uncertainty over how fast their share will grow. EVs currently have a share of around 20% in new car sales worldwide, and this rises towards 50% by 2030 in the STEPS (a level already being achieved in China this year), by which time EVs displace around 6 mb/d of oil demand. If the market share of electric cars were to rise more slowly, remaining below 40% by the end of the decade, this would add 1.2 mb/d to projected oil demand in 2030, but there would still be a visible flattening in the global trajectory. Additional near-term oil supply is coming mainly from the Americas – the United States, Brazil, Guyana and Canada – and this is putting pressure on the market management strategies of the OPEC+ grouping. The STEPS sees prices around USD 75-80 per barrel, but this implies further production restraint and an increase in spare capacity, which is already at record levels of around 6 mb/d.

Who will ride the wave of new LNG?

An increase of nearly 50% in global LNG export capacity is on the horizon, led by the United States and Qatar, but the prices that many suppliers need to recover their investments may not entice developing economies to switch to natural gas at scale: something has to give.

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Around 270 billion cubic metres (bcm) of annualised new LNG capacity has been approved and, if delivered according to announced schedules, is set to enter into operation over the period to 2030, a huge addition to global supply. In the STEPS, LNG demand grows by more than 2.5% per year to 2035, an upward revision from last year's outlook and faster than the rise in overall gas demand. Europe and China have the import infrastructure to absorb significantly more gas, but their scope to clear the market is constrained by their investments in clean energy. Gas-importing emerging and developing economies would generally need prices at around USD 3-5/MBtu to make gas attractive as a large-scale alternative to renewables and coal, but delivered costs for most new export projects need to average around USD 8/MBtu to cover their investments and operation. If gas markets are to absorb all the prospective new LNG supply and to continue to grow past 2030, this would require some combination of even lower clearing prices, higher electricity demand and slower energy transitions – with less wind and solar, lower rates of building efficiency improvements, and fewer heat pumps – than projected in the STEPS. However, any acceleration of global energy transitions towards the outcomes projected in the APS or NZE Scenario, or a wild card for supply like a large new Russia-China gas supply deal (which we do not include in the STEPS), would exacerbate the LNG glut.

Lower fuel prices ease concerns about affordability and industrial competitiveness in fuel-importing economies

The new market context may provide some breathing space for fuel-importing countries and regions – such as Europe, and South and Southeast Asia – that have been hit hard by higher prices for fossil fuels and electricity in recent years. Consumers around the world spent nearly USD 10 trillion on energy in 2022 during the global energy crisis, around half of which ended up as record revenues for oil and gas producers. An easing of price levels promises some welcome relief, particularly in fuel-importing countries. Lower natural gas prices should lift some of Europe's gloom about its industrial competitiveness, although Europe still faces a sizeable structural energy price disadvantage compared with the United States and China. The breathing space from fuel price pressures can provide policymakers with room to focus on stepping up investment in renewables, grids, storage and efficiency; facilitating the removal of inefficient fossil fuel subsidies; and allowing developing economies to regain the momentum that was lost in recent years behind the provision of access to electricity and clean cooking fuels. However, cheaper natural gas can also slow structural changes by diminishing the economic case for consumers to switch to cleaner technologies, and by making it more difficult to close the cost gap with alternatives like biomethane and low-emissions hydrogen.

A sustainable energy system needs to be people-centred and resilient

A new energy system needs to be built to last: this means prioritising security, resilience and flexibility, and ensuring that the benefits of the new energy economy are shared. The STEPS does not see traditional energy security concerns diminishing, particularly for importers in Asia that face a long-term rise in their dependence on oil and gas imports to nearly 90% for oil and around 60% for gas by 2050. At the same time, faster clean energy transitions put the spotlight on electricity security, as growing electricity demand and more

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variable generation increase the operational need for flexibility in power systems, both for short-term and seasonal needs. This also requires a rebalancing of power sector investment towards grids and battery storage, as proposed by the IEA in advance of the COP29[1] climate conference in Baku, Azerbaijan. At the moment, for every dollar spent on renewable power, 60 cents are spent on grids and storage. By the 2040s, this reaches parity in all scenarios. Many power systems are vulnerable to an increase in extreme weather events and cyberattacks, putting a premium on adequate investments in resilience and digital security.

Dividing lines are emerging on energy and climate, which can only be bridged if there is more help provided to poorer countries, communities and households to manage the upfront costs of change, including much greater international support. High financing costs and project risks are limiting the spread of cost-competitive clean energy technologies to where they are needed most, especially in developing economies where they can deliver the biggest returns for sustainable development and affordability. Lack of access to modern energy is the most fundamental inequity in today's energy system, with 750 million people – predominantly in sub-Saharan Africa – remaining without access to electricity and more than 2 billion without clean cooking fuels. The outlook for access projects is improving thanks to cheaper technologies, new policies, the growing availability of digital payment options and pay-as-you-go business models, but more is needed, including a stronger focus on electrifying productive uses, which can improve project bankability. The climate finance discussions at COP29 and at the G20 will be a barometer of the prospects for scaling up clean energy investment in developing economies, which will also require strengthened national policy visions, policies and institutions, and a willingness to engage with the private sector.

Choices and consequences

Despite gathering momentum behind transitions, the world is still a long way from a trajectory aligned with its climate goals. Decisions by governments, investors and consumers too often entrench the flaws in today's energy system, rather than pushing it towards a cleaner and safer path. There are some positive developments in the STEPS, but today's policy settings still put the world on course for a rise of 2.4 °C in global average temperatures by 2100, entailing ever more severe risks from a changing climate. Our scenario analysis highlights the prospect of buyers and consumers having the edge in energy markets for a time, with suppliers competing for their attention as they make fuel and technology choices that have widely different implications for the energy sector and for its emissions. All parties need to recognise that locking in fossil fuel use has consequences. There may be downward pressure on fuel prices for a while, but energy history tells us that one day the cycle will be reversed, and prices will rise. And the costs of climate inaction, meanwhile, grow higher by the day as emissions accumulate in the atmosphere and extreme weather imposes its own unpredictable price. By contrast, clean technologies that are increasingly cost-effective today are set to remain so, with greatly reduced exposure to the vagaries of commodity markets and lasting benefits for people and planet.

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[1] See IEA (2024) From Taking Stock to Taking Action: How to implement the COP28 energy goals.

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Overview and key findings

Where do we go from here?

SUMMARY

- There are three overarching and inter-related themes for this year's *Outlook*. The first is energy security, corresponding to the longstanding core of the IEA's mandate as well as the imperatives of the present given escalating risks in the Middle East. The second relates to the prospects for clean energy transitions, which have accelerated rapidly in recent years, but which need to move much faster to meet climate goals. A third theme is uncertainty, an ever-present factor in any forward-looking analysis but particularly visible this year: our *Outlook* includes several sensitivity cases on key factors affecting oil, gas and electricity demand in the Stated Policies Scenario (STEPS).
- The potential for near-term disruption to oil and gas supply is high due to conflict in the Middle East. Around 20% of today's global oil and liquefied natural gas (LNG) supplies flow through the Strait of Hormuz, a maritime chokepoint in the region. However, while geopolitical risks remain elevated, an easing in underlying market balances and prices is on the horizon as slowing oil demand growth in the STEPS sees spare crude oil production capacity rise to 8 million barrels per day by 2030. A wave of new LNG projects is set to add almost 50% to available export capacity by 2030.
- In all our scenarios, growth in global energy demand slows thanks to efficiency gains, electrification and a rapid buildout of renewables. In the STEPS by 2030, nearly every other car sold in the world is electric, although delays in the roll-out of charging infrastructure or in policy implementation could lead to slower growth.
- Clean energy meets virtually all growth in energy demand in aggregate in the STEPS between 2023 and 2035, leading to an overall peak in demand for all three fossil fuels before 2030, although trends vary widely across countries at different stages of economic and energy development.
- Electricity demand grows much faster than overall energy demand, thanks to existing uses, notably cooling, and new ones such as electric mobility and data centres. Renewables lead the expansion in electricity generation, with sufficient speed to meet in aggregate all the increases in demand. There is scope to go even faster: today's solar manufacturing capacity hovers around 1 100 GW per year, potentially allowing for deployment almost three-times higher than in 2023.
- The share of clean energy investment in emerging market and developing economies outside of China remains stuck at 15% of the total, even though these economies account for two-thirds of the global population and one-third of global GDP. A range of new business models and a policy push in some countries ensure that an additional 550 million people gain access to clean cooking and nearly 200 million to electricity in the STEPS between 2023 and 2030. This still falls well short of universal access goals.

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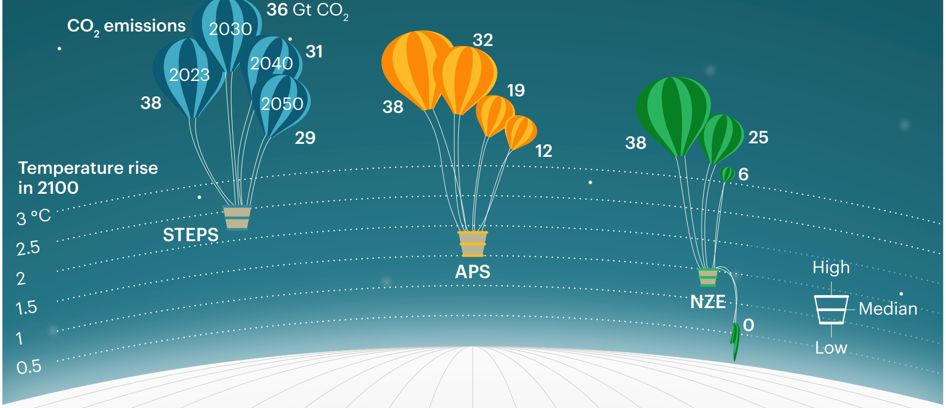
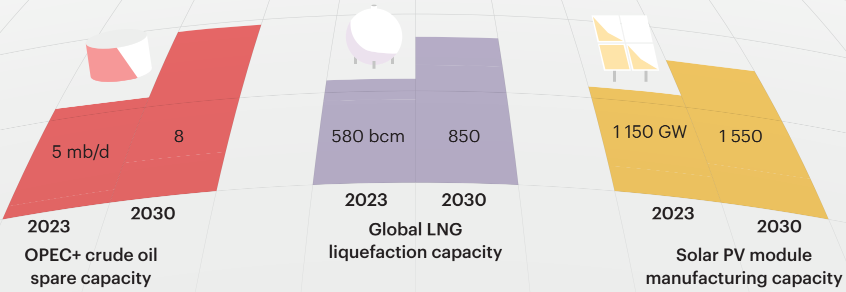
Emissions need to fall fast

Emissions are set to peak soon, but have to decline rapidly: how consumer choices and government policies play out will have huge consequences for energy markets & for our planet.



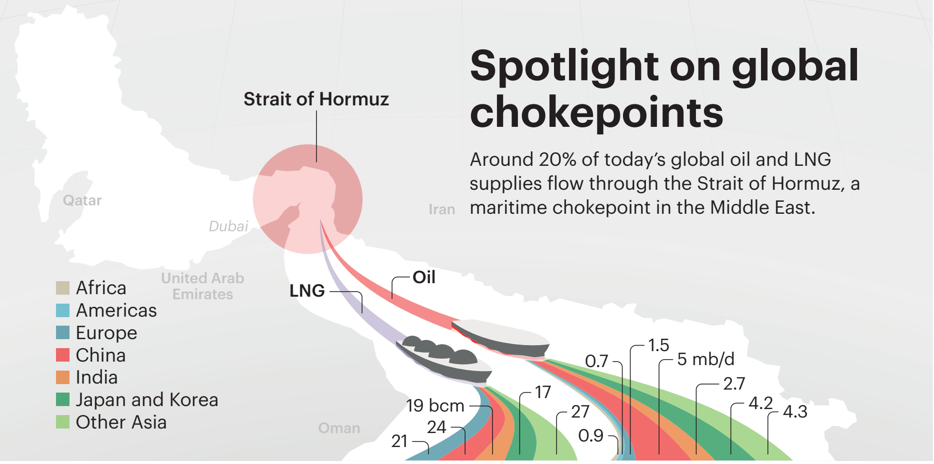
A new market context

Geopolitical risks are set to remain high but underlying market balances for many fuels and technologies are easing, signalling a shift towards a buyers' market.



Spotlight on global chokepoints

Around 20% of today's global oil and LNG supplies flow through the Strait of Hormuz, a maritime chokepoint in the Middle East.



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Introduction

After a period of extreme turbulence caused first by the Covid-19 pandemic and then the global energy crisis that was intensified by the full-scale invasion of Ukraine by the Russian Federation (herein after Russia) in 2022, this edition of the *World Energy Outlook* again unfolds against a backdrop of acute geopolitical tensions. Russia's war in Ukraine continues alongside the clear risk of escalating conflict in the Middle East. The range of possible outcomes and the risk of near-term oil price rises is large. As ever, energy security is a major theme of this year's analysis.

A second theme for this *Outlook* is the momentum behind clean energy transitions amid rising evidence of the risks to the global climate posed by emissions. Structural changes in energy production and consumption have gained speed over recent years, especially in advanced economies and the People's Republic of China (herein after China), raising hopes that the world can soon put global energy-related emissions into decline and accelerate the journey towards a net zero emissions system. We examine the state-of-play in detail, the implications for fossil fuels, and what it would take to align the trajectory with national and global energy and climate goals.

A third theme is uncertainty. Voters in countries accounting for half of global energy demand went to the polls in 2024 in national or regional elections, with energy and climate issues prominent in many campaigns. The speed at which clean technologies make their way into the market is likewise subject to uncertainty, as is the frequency and intensity of extreme weather events. This edition of the *Outlook* therefore includes a number of sensitivity cases, against the backdrop of the Stated Policies Scenario (STEPS), alongside the scenario modelling of trajectories that meet national and global net zero emissions targets.

After a brief overview of the main scenario results, the bulk of this chapter explores these themes through a series of questions, covering the following issues:

- Against a backdrop of heightened international tensions, what do today's fractured geopolitics mean for the future of energy?
- What do market data and our projections tell us about the prospects for electric mobility: are electric vehicle sales hitting speed limits?
- Electricity demand growth is accelerating, but which factors – including data centres and artificial intelligence – will determine how fast it grows?
- Given the rise in electricity demand, can clean power generation expand fast enough to bring down emissions in the power sector?
- There is a wave of new liquefied natural gas coming to market: where will it go and what will be the implications for gas demand and prices?
- With hundreds of millions of people remaining without access to electricity and clean cooking fuels, what will it take to achieve access goals by 2030?
- How to correct the large imbalance and scale up clean energy investment in emerging market and developing economies?

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1.1 Scenario overview

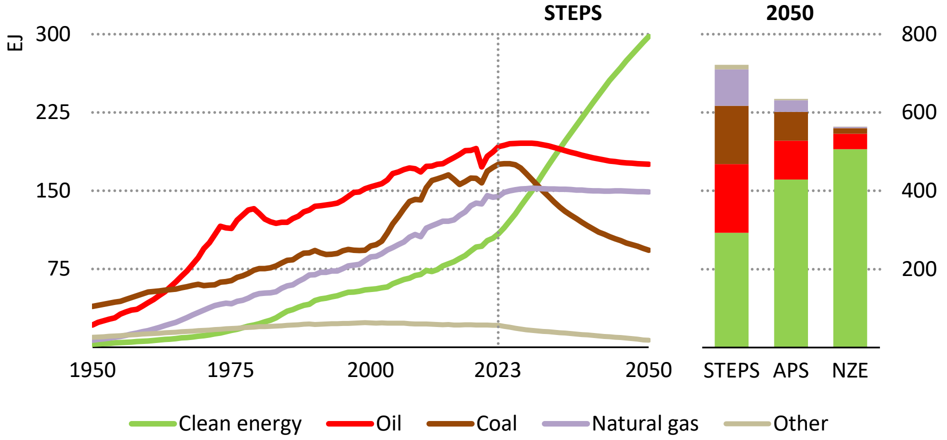
1.1.1 Energy demand

The last decade has seen the share of fossil fuels in the global energy mix gradually come down from 82% in 2013 to 80% in 2023. Demand for energy has increased by 15% over this period and 40% of this growth has been met by clean energy, i.e. renewables in the power and end-use sectors, nuclear, and low-emissions fuels, including carbon capture, utilisation and storage (CCUS).

In advanced economies, overall energy demand declined on average by 0.5% per year over the past decade. Oil demand peaked in this grouping in 2005, coal has been in structural decline since 2008 while natural gas, in aggregate, has ceased to grow. Nuclear has fallen around one-half percentage point per year, while renewables have increased by 3% per year since 2013.

In emerging market and developing economies – a grouping that includes almost 85% of the world's population – energy demand increased at around 2.6% per year over the last decade. The underlying drivers are a rise in the population of more than 720 million people, a 50% rise in the size of the economy and a 40% increase in industrial output. Floorspace in buildings has increased by 40 000 square kilometres, enough to cover the entirety of the Netherlands. With this rapid rate of development, clean energy has to work harder to displace oil, gas and coal in emerging market and developing economies than in advanced economies.

Figure 1.1 ▹ Global energy mix by scenario to 2050



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STEPS, a scenario based on current policy settings, sees clean energy poised for huge growth, while coal, oil and natural gas each reach a peak by 2030 and then start to decline

Notes: EJ = exajoules; STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario; NZE = Net Zero Emissions by 2050 Scenario. Oil, coal and natural gas refer to unabated uses as well as non-energy use. Clean energy includes renewables, modern bioenergy, nuclear, abated fossil fuels, low-emissions hydrogen and hydrogen-based fuels. Other includes traditional use of biomass and non-renewable waste.

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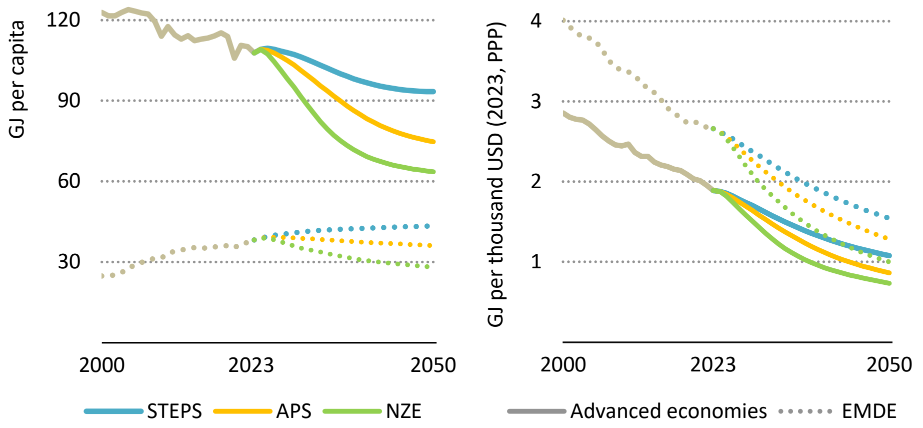
In the Stated Policies Scenario (STEPS), clean energy deployment accelerates as the pace of overall energy demand growth slows, leading to a peak in all three fossil fuels before 2030 (Figure 1.1). Increasing reductions in coal demand means it is overtaken by natural gas in the global energy mix by 2030. Clean energy grows more than total energy demand between 2023 and 2035. Led by surging solar photovoltaic (PV) and wind power, clean energy becomes the largest source of energy in the mid-2030s.

Although the STEPS sees a threefold increase in renewables that brings fossil fuel use down from 80% of total energy demand in 2023 to 58% in 2050, this falls far short of the step change that occurs in the Announced Pledges Scenario (APS) and the Net Zero Emissions by 2050 (NZE) Scenario, especially the latter. In both these scenarios, renewables begin to rapidly eat into the fossil fuel market share. By 2035, clean energy meets 40% of global energy demand in the APS, and this rises to nearly three-quarters by 2050. In the NZE Scenario, clean energy meets 90% of global energy demand in 2050. Around one-third of the remaining fossil fuel demand in the NZE Scenario is fully abated, around half is used as a feedstock or in other non-energy use, and the remainder is offset by direct air capture, negative emissions from bioenergy or other forms of carbon removal.

1.1.2 Total final consumption

The energy intensity of the global economy has been falling due to technological progress, efficiency improvements and changes in the structure of the global economy (Figure 1.2). Growth in renewables and increasing electrification of end-uses both play an important part to increase the efficiency of energy systems.

Figure 1.2 ⊳ Total final consumption per capita and per unit of GDP by scenario, 2000-2050



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Falling energy use per unit of GDP has accompanied rising per capita energy use in developing economies, though this remains well below the level in advanced economies

Note: GDP = gross domestic product; GJ = gigajoule; PPP = purchasing power parity; EMDE = emerging market and developing economies.

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Historically, the expansion of gross domestic product (GDP) growth has been faster than the rate of energy demand growth, reflecting improvements in the energy intensity of GDP. These improvements in energy intensity continue and even accelerate in our scenarios: global GDP continues to expand, but it takes steadily less energy to fuel this growth (Box 1.1). Electric technologies such as heat pumps and electric vehicles deliver energy services more efficiently than those reliant on the direct combustion of fossil fuels, and efficiency gains and electrification also arrest further growth in per capita energy consumption in emerging market and developing economies, despite higher levels of ownership of vehicles and appliances such as air conditioners.

Box 1.1 ▹ What factors explain slowing growth in global energy demand?

Over the past decade, global energy demand increased at an annual average rate of 1.4%. In the STEPS, this slows to around 0.5% per year on average between 2023 and 2035, three-times slower than in the past. This is not a result of slower economic growth: global GDP growth is expected to average 3% annually between 2023-2035, similar to the previous decade. Underlying energy services demand, such as for lighting, cooling and mobility, is projected to continue to rise at least as fast as in the past, even though there is a distinct slowdown in global population growth: between 2023 and 2035, annual population growth is around 85% of the average level seen between 2013 and 2023.

The slowdown in global energy demand in our scenarios is driven by a combination of three main factors.

The first factor is improvements in the technical efficiency of energy use, via more efficient processes or equipment. These kinds of improvements and technological innovations are a longstanding feature of the global energy system and are heavily influenced by policies that incentivise efficiency gains, like minimum energy performance standards or other forms of regulation. There is an uptick in the projected pace of technical efficiency improvements in our scenarios, but this is much more visible in the APS and in the NZE Scenario than in the STEPS.

The second explanatory factor relates to changes in the structure of the global economy towards the provision of services, which require less energy, and away from energy-intensive sectors. Here we see an evolution in future trends compared with the past, as growth rates for energy-intensive materials such as steel and aluminium are projected to moderate compared with the rates seen in the last decade. This is due in part to structural changes in China’s economy.

The third factor, which is increasingly influential in our scenarios, relates to the effect on energy demand of introducing more renewables and more electrified end-uses into the energy system, as these are inherently more efficient than processes based on fossil fuel combustion (which generates a lot of waste heat, also known as conversion losses). Unlike fossil fuels, most renewables are considered 100% efficient, i.e. conversion losses are not measured because the resources are directly harnessed from naturally occurring

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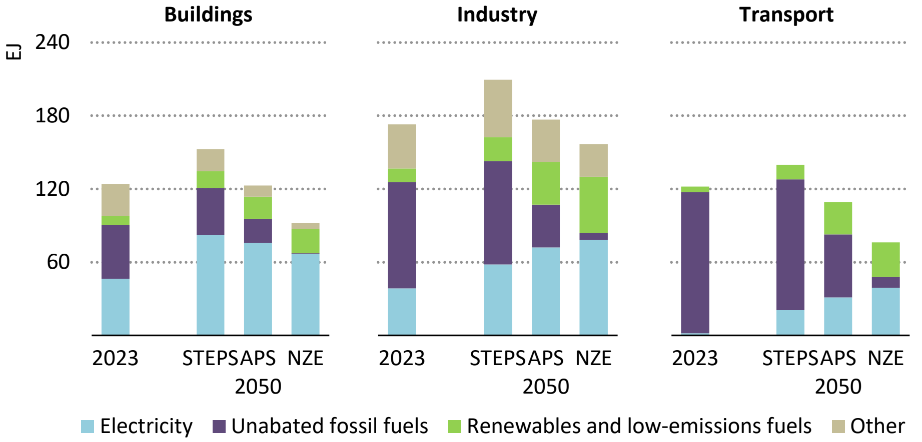
sources of energy, such as sunlight, wind and water, without the need for extraction or combustion processes. As renewables take a larger share of electricity generation, the total amount of primary energy inputs required to meet electricity demand from households, businesses and public services decreases. The rising share of electricity in total final consumption also has a dampening effect on energy demand growth because it displaces the direct use of gas, coal and oil, all of which typically involve energy conversion losses.

Global final energy consumption currently stands at 445 exajoules (EJ). In the STEPS, this rises steadily to over 530 EJ by 2050. In the APS and NZE Scenario, total final consumption starts to fall back (Figure 1.3). It is 3% lower than current levels of demand by 2035 in the APS, and 15% lower in the NZE Scenario. In the APS, energy efficiency gains limit growth in consumption even as living standards continue to rise, thanks to additional retrofit targets, broader electrification, more stringent fuel economy standards in transport, and more rapid efficiency gains in industry. In the NZE Scenario, year-on-year energy intensity improvements more than double by 2035: this reflects both faster electrification and a more rapid phase out of traditional use of biomass, which is largely replaced by more efficient sources such as electricity and liquefied petroleum gas (LPG). Behavioural changes also play a role.

Figure 1.3 ▹ Total final consumption by energy source in selected sectors by scenario, 2023 and 2050



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Electricity increases its share of TFC in all sectors, while additional efficiency measures in the APS and NZE Scenario hold down overall demand growth, and in some cases reverse it

Notes: EJ = exajoules. Other in buildings includes district heat, traditional use of biomass and non-renewable waste. Other in industry includes district heat, fossil fuel non-energy use and non-renewable waste. Low-emissions fuels include modern bioenergy, fossil fuels with CCUS in industry, hydrogen and hydrogen-based fuels.

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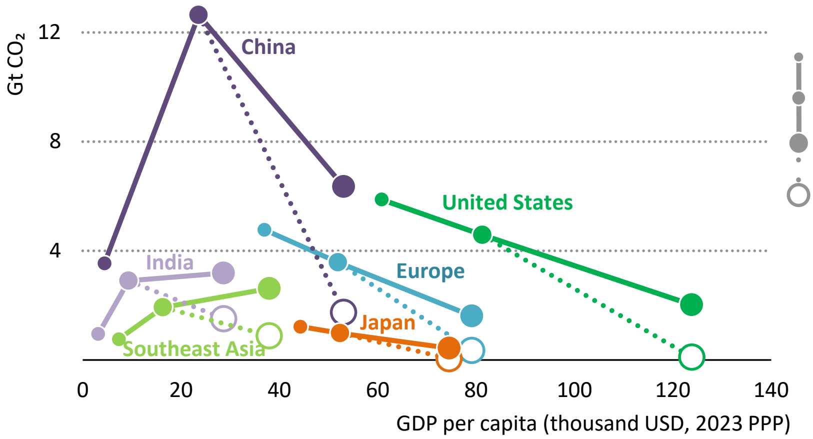
Electrification accelerates across all scenarios and in all sectors, providing heating, cooling and mobility, powering motors and appliances, and producing onsite electrolytic hydrogen for heavy industry. By 2050, the share of electricity in total final consumption increases by half in the STEPS, doubles in the APS and nearly triples in the NZE Scenario, where unabated fossil fuels are swiftly replaced by electricity generated by clean sources. Along with the direct use of renewables, including modern bioenergy, solar thermal and geothermal, and low-emissions hydrogen and hydrogen-based fuels, the share of unabated fossil fuels by 2050 declines from today's level by 30% in the STEPS, over 65% in the APS and 95% in the NZE Scenario. In hard-to-abate sectors such as aviation and shipping, biofuels and low-emissions fuels displace around 50 EJ of fossil fuels by 2050 in the NZE Scenario.

1.1.3 CO_2 emissions

CO_2 emissions peak in all scenarios before 2030, but the subsequent rate of decline varies considerably. In the STEPS, emissions fall 1% per year between 2030 and 2050, led by a 3% annual decline in emissions in China, where they end up at half of the current level by 2050 (Figure 1.4). In the APS, global emissions fall by 4% per year, and in the NZE Scenario they fall by 15% per year, three-times faster than the drop recorded in 2020 after the onset of the Covid-19 pandemic. The STEPS trajectory implies an average temperature increase of 2.4 degrees Celsius (°C) by 2100. In the APS, the increase is 1.7 °C, while this *World Energy Outlook-2024 (WEO-2024)* updated NZE Scenario shows an increasingly narrow but still achievable pathway to limiting the temperature rise to below 1.5 °C.

Figure 1.4 ▷ CO_2 emissions and GDP per capita in selected countries/regions in the STEPS and APS



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Global CO_2 emissions peak and gradually decline to 2050, led by sharp drops in China as well as in advanced economies

Note: Gt CO_2= gigatonnes of carbon dioxide.

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An increasing number of emerging market and developing countries have announced targets or goals to achieve net zero CO_2 or greenhouse gas (GHG) emissions. They include eight-out-of-ten Southeast Asian countries, plus India, which is targeting net zero emissions by 2070. These targets are achieved in full in the APS, driving innovation and providing incentives for consumers and private sector actors to reduce emissions. As a result, CO_2 emissions from India and Southeast Asia fall by half in the APS, dropping below 2010 levels by 2050.

1.2 What do fractured geopolitics mean for the future of energy?

1.2.1 Fossil fuels

The global energy crisis triggered by the Russian invasion of Ukraine highlighted the vulnerability of the current energy system to geopolitical events and underlined how much of an impact energy price rises can have on consumers. The immediate price shocks from the energy crisis have abated, but escalating hostilities in the Middle East and attacks on shipping in the Red Sea serve as reminders of the potential for wider world events to cause shocks to energy markets.

Existing and planned fossil fuel infrastructure expansions set to come online over the next ten years should provide some buffer against potential outages, and imply downward pressure on prices (Box 1.2). Global spare crude oil production capacity, excluding Iran and Russia, which averaged less than 3 million barrels per day (mb/d) in 2019, stands today at around 6 mb/d. If announced capacity additions by members of the Organization of the Petroleum Exporting Countries (OPEC) proceed, the level of demand growth in the STEPS would mean spare capacity rising to 8 mb/d to 2030. For natural gas, a large new wave of LNG liquefaction projects is set to come online that is set to produce a surplus of LNG supply over demand until 2040 (section 1.6).

Ample spare crude oil capacity and new LNG supplies provide buffers against the risk of sharp price shocks, but the security of fuel supplies is far from guaranteed, not least because the effectiveness of this capacity to address any shortfalls that may arise hinges on the ability of alternative sources of supply to reach an affected country or region quickly. Moreover, a general trend of increased supply concentration and rising import dependence means supply shocks – if they occur – have the potential to be more disruptive. Asia has become the focal point for global oil and gas trade: it now imports more than twice as much oil as Europe, the next-largest importing region, and it eclipsed Europe as the largest market for imported natural gas in 2022 (Figure 1.5). In the STEPS, these trends continue. China – the world's largest importer – sees its dependence on oil imports rise from around 75% today to more than 80% by 2050. Similar trends are projected for India, where natural gas dependence rises from 50% today to nearly 75%. Meanwhile, Southeast Asia, which is currently a net exporter of natural gas, becomes a net importer before 2030.

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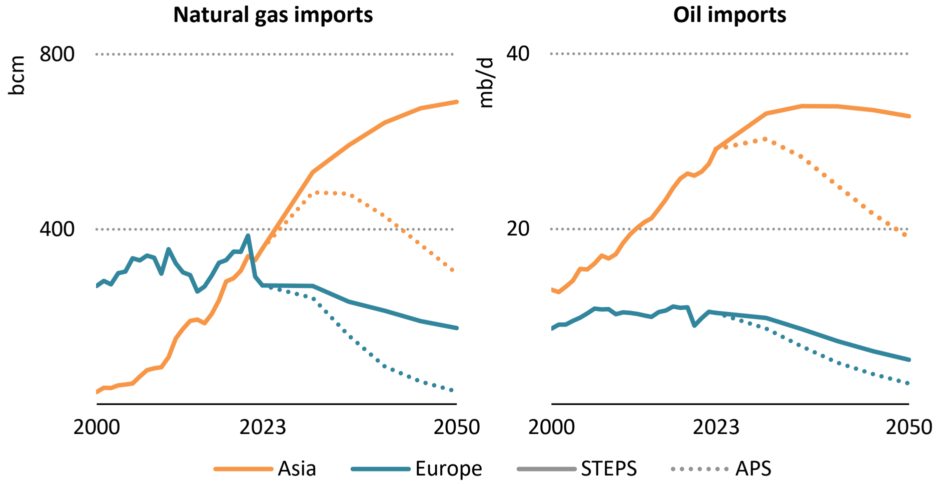
Figure 1.5 ▹ **Natural gas and crude oil imports to Asia and Europe in the STEPS and APS**



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Import dependence increases in both scenarios, especially in Asia, which accounts for 60-70% of global oil and gas imports by 2050

Notes: bcm = billion cubic metres; mb/d = million barrels per day. Asia includes Japan, Korea and developing Asia.

Key maritime trade routes remain vital to the well-being of global oil and gas markets. This includes the safe passage of ships through passages such as the Strait of Malacca and Strait of Hormuz. The Strait of Malacca is particularly important to oil and gas trade, and is set to become even more so in the future, with oil volumes increasing from 24 mb/d today (55% of global oil trade) to 28 mb/d in the STEPS, and LNG flows increasing from 70 billion cubic metres (bcm) in 2023 (12% of global LNG trade) to 140 bcm in 2050. Around 20% of global oil and LNG supplies also flow through the Strait of Hormuz today, a share that remains broadly constant in the STEPS. Any disruption in either of these straits could lead to supply shortages and price volatility. A complete closure of the Strait of Hormuz, while unlikely, would be particularly damaging because there are limited alternative routes to market and because it would block off the vast majority of OPEC spare capacity.

Box 1.2 ▹ Are oil and natural gas prices set to fall and what would this mean for producers?

Oil and natural gas prices act as intermediaries between supply and demand in our scenarios to ensure that sources of supply meet changes in demand and hold the system in equilibrium. This balancing act means that prices in our scenarios follow a relatively smooth trajectory; we do not attempt to anticipate the fluctuations or price cycles that

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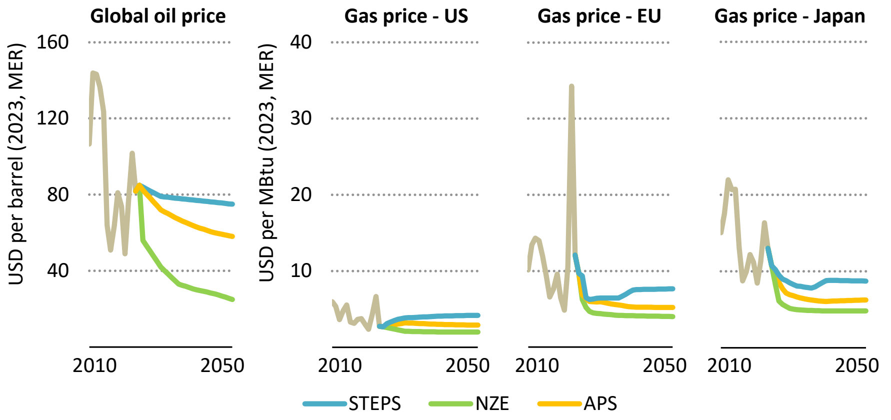
characterise commodity markets. Oil prices are contingent on continued efforts by major oil producers to manage oil markets; there is no analogous arrangement for natural gas, but the increasing importance of global LNG trade means benchmark prices in different regional markets become increasingly interdependent. In practice, the potential for oil and gas price volatility is ever present, especially given the profound changes that are needed in today's energy system to meet the world's climate goals.

Figure 1.6 ⊳ Oil and natural gas price by scenario, 2010-2050



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Relatively smooth trajectories for oil and gas prices belie historical volatility; the major variations arise between scenarios with different degrees of climate ambition

Notes: MER = market exchange rate; MBtu = million British thermal units; US = United States, EU = European Union.

The oil price in the STEPS remains broadly similar over the projection period to what it was in 2023 (Figure 1.6), with technological improvements, continued efforts by the oil and gas industry to keep a lid on costs and downward pressure from a slight decline in demand more or less offset by the need to tap into more remote and difficult-to-access resources. This trajectory rests on the assumption that market management efforts by major producers are pursued and are effective in putting a floor under prices; this cannot be taken for granted. In the APS, lower demand levels mean that prices fall to much lower levels then they are at today. In the NZE Scenario, the oil price drops to the operating costs of the marginal project required to meet falling demand. In both of these scenarios, policies need to be designed to ensure that lower prices do not result in a rebound in oil demand which would undercut overall emissions reduction efforts.

For natural gas, the overhang in LNG capacity looks set to create a very competitive market at least until this is worked off, with prices in key importing regions averaging USD 6.5-8 million British thermal units (MBtu) to 2035. The lowest cost existing LNG

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projects – those that have paid off their initial invested capital and/or that benefit from low cost feedgas and low operating costs – can make a profit at prices of USD 3-5/MBtu, but many under construction projects have break even costs above USD 8/MBtu. This poses major risks for the sponsors of these LNG projects or the offtakers, as some of the value of their assets might end up having to be written off. In the STEPS, the LNG overhang is worked off in the 2030s and prices paid by importers then rise. In the APS and NZE Scenario, demand for LNG remains well below the supply that is available and so prices around the world are much lower. Lower prices could stimulate additional demand for natural gas and LNG (a prospect further explored in Chapter 4); however, policy settings favouring renewables and energy efficiency may constrain a robust demand response.

In the STEPS, net income to oil and gas producers remains largely flat at around USD 2 400 billion to 2035. It falls to USD 1 750 billion in the APS by 2035, or 30% less than the average levels over the past five years, and to USD 680 billion in the NZE Scenario by 2035, 70% lower than recent levels. Many oil and gas producers would struggle to withstand the strains on their fiscal balances from lower income in this scenario.

1.2.2 Clean energy supply chains and critical minerals

New energy security hazards are emerging as the world moves towards a more electrified and renewables-rich energy system, highlighting the need for policy makers to continually adjust and assess their approach to energy security. One issue of particular concern for many policy makers today is the concentration in a small number of countries of clean energy supply chains for manufacturing capacity and critical mineral mining and processing. China has a very large proportion of existing manufacturing capacity for key clean energy technologies. This includes 85-95% of global manufacturing capacity for battery cathode and anode materials, more than 80% of global solar PV manufacturing capacity, and more than 75-90% of the global processing capacity for cobalt, graphite and rare earth elements.

A wide range of countries are looking to bolster domestic clean energy manufacturing. Both the US Inflation Reduction Act and the EU Net Zero Industry Act include major incentives for domestic manufacturing, and around 10% of the USD 2 trillion clean energy investment earmarked by governments around the world since 2020 comes with conditions that require local content. Some countries are also taking steps in their trade policies to address concerns about aspects of current trade in clean energy manufacturing through tariff adjustments, antidumping duties and countervailing measures.

There are some signs of success in efforts to diversify supply chains. In battery cell manufacturing, for example, announced capacity additions in Europe and the United States should be sufficient to meet the 2030 domestic deployment needs associated with their climate goals, provided that all planned projects come online as scheduled. In many other clean energy supply chains, however, a large portion of planned projects are being developed

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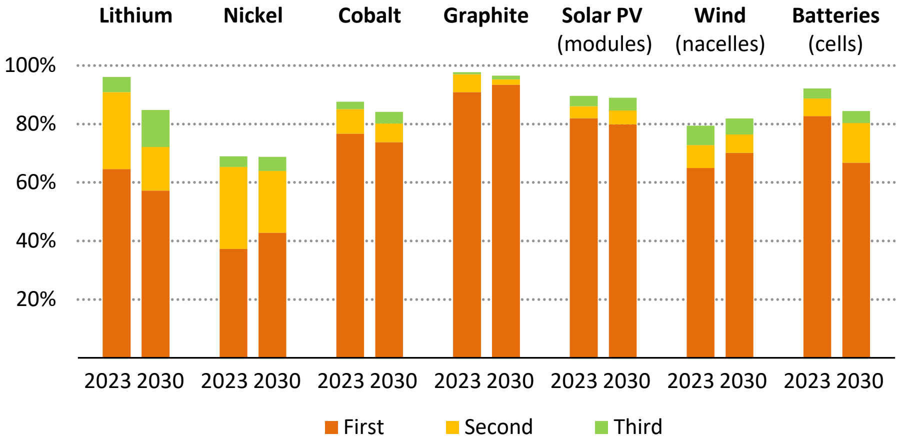
in precisely the regions where most capacity is already located (Figure 1.7). For example, some 50-95% of supply growth between 2023 and 2035 for refined copper, lithium, nickel and cobalt is projected to take place in today's largest producer, such as China or Indonesia.

Figure 1.7 ▷ Share of top-three suppliers of selected critical minerals and clean technologies based on announced projects, 2023 and 2030



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Announced projects indicate that the geographic concentration of critical minerals and clean energy technology manufacturing is set to remain high through to 2030

Note: Critical minerals data are refined material production.

Another concern is the level of critical mineral supplies that are available. For a number of critical minerals, supply growth from the pipeline of confirmed and announced projects is set to be slower than expected growth in demand. The situation is most pressing for copper and lithium, highlighting some new risks to supply security and clean energy transitions. Market signals should lead to the development of new projects, although new mining projects tend to have very long lead times. On the demand side, changes in battery chemistries or enhanced efforts for recycling may succeed in reducing demand.

Policy makers need to be alert to the new energy security risks that are emerging in clean energy and look for ways to mitigate them. However, there are some important differences between the risks for consumers associated with clean energy and those that arise from traditional fuels. With traditional fuels, a shortage in supply means that consumers immediately face higher prices to continue operating existing equipment such as cars and boilers. With clean energy, a shortage in supplies would tend to increase the cost of new equipment but would have little immediate effect on the cost of using existing equipment.

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1.3 Are EV sales hitting speed limits?

Electric vehicles provide the main mechanism to decarbonise the road transport sector. Their prospects in recent years have been bolstered by ambitious plans from governments and the EV and battery industries (Table 1.1). However, the transition to mass market adoption is unlikely to be linear, and additional efforts are required to achieve the right balance of incentives for broader consumer uptake, to ensure that adequate charging infrastructure is in place and to reinforce electricity grids.

Over 7 million electric cars were sold in the first-half of 2024, which represents an increase of close to 25% compared to the same period a year ago. The share of EVs in the total global car fleet is likely to approach around 5% by the end of 2024. China accounts for nearly 80% of the increase, with sales rising from more than 3 million in the first-half of 2023 to over 4 million in the first-half of 2024. Even if China is set to one side, however, the overall percentage rise in sales elsewhere in the global market is over 10%. While sales in the European Union remained flat, with a decline in Germany offsetting a rise elsewhere of around 3% on average, the United Kingdom saw a 15% rise, and the United States recorded an increase of nearly 10%. Large jumps in year-on-year sales also occurred in nascent EV markets such as Brazil, Indonesia, Mexico, the Caspian region and the Middle East.

One important trend is the rising share of plug-in hybrid electric vehicle (PHEV) sales, which accounted for over 35% of total EV sales in the first-half of 2024. In China, the PHEV sales increase was largely driven by range-extended electric vehicles (REEVs) which have longer driving ranges due to larger batteries. This provides an average electric range of around 130 kilometres (km), compared with 80 km for a standard PHEV (BNEF, 2024a). Sales of PHEVs, including REEVs, surged by 70% in China, while sales of battery electric vehicles (BEVs) rose by only 15%. Similarly, in the United States PHEV sales increased by 25%, compared to just 5% for BEVs. This highlights the need for an expansion of recharging infrastructure to ease range anxiety.

EV sales are anticipated to be robust over the rest of 2024, with around 17 million electric cars being sold over the course of the year. China is expected to continue dominating global growth, with electric car sales topping over 10 million during 2024. It is worth noting in this context that the EV market in China has maintained strong momentum through August, with monthly sales exceeding 1 million units (EV Volumes, 2024). The continuing rise in EV sales is well above what was predicted by some analysts in 2022 when battery costs increased by 7%. In fact, this increase prompted the battery industry to adopt different chemistries that require less cobalt and nickel, and this – together with further developments in battery technology – has led battery cell prices to drop below USD 80 per kilowatt-hour (kWh) during the first nine months of 2024.

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Table 1.1 ▷ Selected support policies for electric vehicles

Country/region	Policy type	Description	Year
Australia	Target	- National Electric Vehicle Strategy includes details of state-level targets and incentives.	2023
Canada	Policy	- Electric Vehicle Availability Standard regulates annual zero emissions light-duty vehicle sales targets beginning in 2026 and reaching 100% in 2035.	2023
China	Policy	- Trade-in subsidies for replacing mainly used fossil fuel-powered vehicle with new energy or fuel-efficient vehicles.	2024
European Union	Policy	- 100% CO_2 emissions reduction for new cars and vans by 2035.	2023
India	Policy	- Electric Mobility Promotion Scheme (April to September 2024) and the PM E-DRIVE to incentivise and subsidise the uptake of electric two/three-wheelers, buses and freight vehicles.	2024
Indonesia	Target	- Target to have 2 million EVs in passenger light-duty vehicle stock and 13 million electric motorcycles in the fleet by 2030.	2023
Japan	Target	- 100% sales of EVs, fuel cell vehicles and hybrids for passenger cars by 2035 and for light commercial vehicles by 2040.	2021
Korea	Target	- 51% of new light-duty vehicles to be electric, fuel cell or hybrid by 2025 and 83% by 2030.	2021
Mexico	Target	- 100% of passenger car, two/three-wheeler and bus sales to be electric and plug-in hybrids by 2040.	2023
New Zealand	Target	- 100% of new cars and van sales to be zero emissions by 2035. - 100% of urban bus sales to be zero emissions vehicles by 2025 and 100% of stock by 2035. Increase zero emissions vehicles to 30% of the light-duty vehicle fleet by 2035.	2021
Pakistan	Target	- 30% of passenger light-duty vehicle sales to be electric by 2030. - 90% of truck sales to be electric by 2040; 90% of urban bus sales to be electric by 2040; and 50% of electric two/three-wheeler sales to be electric by 2030.	2019
United Kingdom	Policy	- 80% of new cars and 70% of new vans to be zero emissions vehicles by 2030, increasing to 100% by 2035.	2024
United States	Policy	- Infrastructure Investment and Jobs Act provides funding for EV charging infrastructure, battery-related projects and alternative fuels infrastructure. - EPA Phase 3 GHG emissions standards target a nearly 50% emissions reduction for light-duty vehicles for model year 2032 compared to 2026, a 44% reduction for medium-duty vehicles and roughly 30-60% reductions for heavy-duty vehicles.	2021 2024
Viet Nam	Target	- Net zero GHG emissions in the transport sector by 2050, with a goal of 100% of road transport using electricity and green energy.	2022

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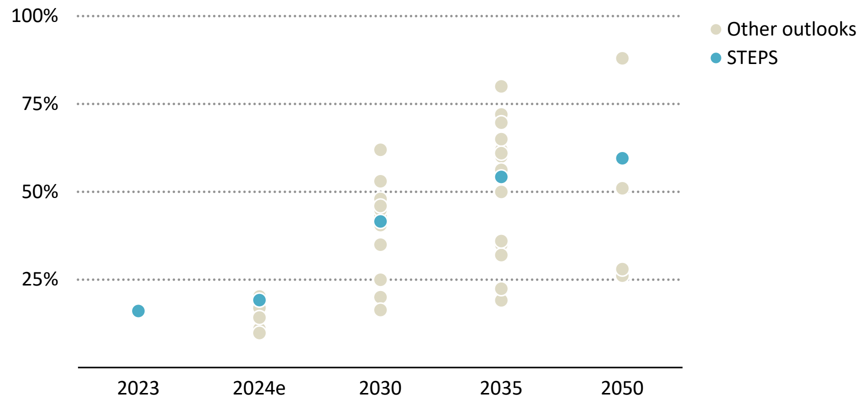
Box 1.3 ⊳ Future landscape for electric vehicles

Around 30 countries have set zero emissions vehicle goals or timelines to phase out internal combustion engine vehicles. In the STEPS, electric car sales reach more than 40 million globally by 2030, which means that nearly one-in-two cars sold that year will be either a battery electric or a plug-in hybrid vehicle.

The number of electric car sales in the STEPS is aligned with the plans of the automotive industry. Although some automakers have recently scaled back short-term EV production plans, their longer-term EV plans still point to the production of well over 40 million electric cars per year by 2030. The projections in the STEPS are also in line with those of other outlooks (Figure 1.8).

Figure 1.8 ⊳ Global electric light-duty vehicle sales in the STEPS compared with other EV outlooks, 2023-2050



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Projected sales of electric light-duty vehicles in the STEPS are broadly in the middle of the range of other outlooks

Note: 2024e = estimated values for 2024.

Sources: IEA analysis based on data from Barclays, Boston Consulting Group, BloombergNEF, DNV, Energy Information Administration, EV Volumes, ExxonMobil, Goldman Sachs, McKinsey, Morgan Stanley, OPEC, Rocky Mountain Institute and Shell.

As there are inevitably uncertainties surrounding the future level of EV sales, we explore a range of potential shifts in EV trends. In our sensitivity analysis, the share of electric cars in new registrations ranges from less than 40% to 50% by 2030, with key differentiators being the scale of consumer adoption, the level of government support for EVs and the rate of expansion of charging infrastructure. Depending on the pace of EV uptake and the utilisation of the electric mode of PHEVs, global oil demand could vary from 101 mb/d to 103 mb/d by 2030. Similarly, global electricity demand could differ between the high and low case by around 350 terawatt-hours (TWh), highlighting the far-reaching changes that EVs could bring across the whole energy sector (See Chapter 4).

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1.3.1 Trends in the EV market

Challenges and uncertainties are inevitable, but there are strong underlying reasons why EV sales are likely to continue to expand rapidly. One of the most important is that battery prices are continuing to fall, prompting automakers to reduce EV sticker prices. Key automakers in the United States have reduced the price of their main models by more than USD 10 000, for example (IEA, 2024a). Chinese automakers have also made price reductions of around USD 1 600 compared to 2022 (BNEF, 2024b). European automakers are meanwhile planning to launch seven new models in 2025 priced at under USD 28 000 (T&E, 2024). While some automakers have adjusted their short-term targets and made slight changes to their longer term 2030 projections, their commitment to EVs remains robust across the board. The same is true for the battery industry globally, which is currently experiencing consolidation rather than a reduction in plans.

Although some incentive schemes have been revised, governments remain active in supporting EV uptake in a variety of ways (Table 1.1). China recently launched a new trade-in policy to encourage drivers to scrap less efficient vehicles and replace them with either electric or more efficient ones, and is looking at ways to speed development of charging infrastructure. In the European Union, stringent CO_2 standards are prompting automakers to expand EV production. The United States aims to increase EV uptake by providing subsidies under the Inflation Reduction Act and to support the development of charging infrastructure under the Infrastructure Investment and Jobs Act.

But there is much still to do, and delays in the roll-out of charging infrastructure or in policy implementation could lead to the market share of electric cars in 2030 being about ten percentage points lower than projected in the STEPS, though this would still mean a big increase in EV shares from current levels (see Chapter 4).

1.3.2 Implications of the transition to EVs for the energy sector

In energy terms, the adoption of EVs means a shift from a fossil fuel-based mobility system to one that relies much more on critical minerals, and a linking of the transport and power sectors. There are clear synergies between manufacturing batteries for EVs and for energy storage, and processes from one industry can benefit the other. For example, EV batteries could be repurposed for storage applications. They could also support grid flexibility through smart charging, helping to optimise grid load, and through bi-directional charging, supplying power to buildings or the grid (IEA, 2024b).

In the STEPS, electricity demand from EVs rises from 115 TWh today to around 1 000 TWh by 2030 – an amount equivalent to today's electricity demand in Japan. This increase accounts for around 15% of total global electricity demand growth. Significant as this is, the impact of EVs on the oil market is even more significant (Figure 1.9). Over the past decade, road transport has increased oil demand by 4.2 mb/d, accounting for more than 45% of global oil demand growth. However, oil demand for passenger cars declines by 1 mb/d from today's levels by 2030, and this is largely responsible for global oil demand reaching a peak by the

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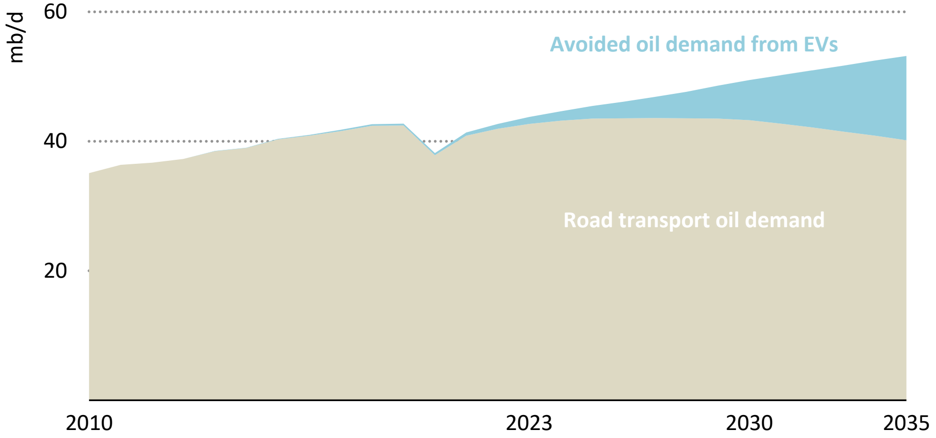
end of this decade in the STEPS. With renewables providing an ever-increasing share of power generation, electro-mobility helps to drive the world towards its climate commitments, and EVs displace nearly 10 billion barrels of oil from 2020 to 2030, avoiding a total of over 4 gigatonnes of carbon dioxide (Gt CO_2) emissions in the process.

Figure 1.9 ▹ Oil demand in road transport in the STEPS and savings from EVs, 2010-2035



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Without EVs, projected oil demand would be 13 mb/d higher in 2035

1.3.3 Key enablers to achieve net zero emissions milestones for EVs

In the STEPS, nearly one-in-two cars sold are electric by 2030. In the NZE Scenario, electric cars account for over two-thirds of sales by 2030. Achieving this level requires further movement in a number of areas. One of the most pressing is cost differentials. Despite recent price reductions, on average an electric car is USD 10 000-15 000 more expensive than a comparable conventional internal combustion engine vehicle, though this is much less of an issue in China, where over 60% of electric cars are priced below their conventional counterparts (IEA, 2024a). Another critical issue is the need for extensive charging infrastructure. To achieve a two-thirds market share of electric cars, investment of nearly USD 1000 billion will be required from now until 2030, which represents a 45% increase over levels in the STEPS. A third issue is meeting the demand for batteries. Annual EV battery demand reaches around 5.5 TWh by 2030 in the NZE Scenario, up from 0.8 TWh in 2023. However, the battery industry seems well-positioned to meet this escalating demand, with recent announcements and developments indicating a robust capacity to scale up production and develop technology.

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1.4 How fast might demand for electricity increase?

The global energy economy is increasingly electrifying. Since 2010, electricity demand has increased on average by 2.7% per year, while overall energy demand has risen by 1.4% per year. Electricity is increasingly being used in place of fossil fuels to provide heat, mobility and industrial energy demand. Innovations such as smart grids and advances in the efficiency of electric motors and appliances have also boosted the appeal of electricity.

The share of electricity in total final consumption rises more rapidly than in the past in all three scenarios and across nearly all regions. This trend is a consequence of increased electrification in households and commercial buildings as well as in transport and industry. Most of this demand growth is from emerging market and developing economies. China dominates, but other countries make a significant contribution, especially after 2030. However, the pace of demand growth – and the uncertainties surrounding it – also pose challenges for ensuring a secure, affordable and sustainable electricity supply.

1.4.1 Emerging market and developing economies lead demand growth in the STEPS

In the STEPS, global electricity demand nearly doubles by 2050, rising to 50 000 TWh from 26 000 TWh in 2023. From 2023 to 2035 alone, growth averages nearly 1 000 TWh per year, equivalent to adding another Japan to global electricity consumption each year.

Trends vary by sector. The transport sector has the lowest current rate of electrification in final consumption, but it also sees the fastest rate of projected demand growth as EVs account for a rising share of vehicle sales (section 1.3). Increased space cooling and appliance ownership drive electricity demand growth in the buildings sector, underpinned by economic expansion. Electrification in industry is also a significant factor.

Emerging market and developing economies are projected to contribute nearly 80% of growth in electricity demand to 2030 in the STEPS, with China alone making up over 45% of the global growth total (Figure 1.10). China's energy sector has electrified particularly fast, with electricity rising from 11% of final consumption in 2000 to 26% in 2023: a major cause was surging electricity use in the buildings sector, with growing incomes leading to rapid increases in appliances and demand for space cooling, while space heating has also increasingly been electrified. China's demand rises further in the coming decades, with the rapid uptake of EVs being a key driver. The story in India is similar, though starting from a lower base: the share of electricity in final consumption rose in India from 11% in 2000 to 18% in 2023, and half of the electricity demand growth to 2050 is projected in the STEPS to come in the buildings sector.

After a period of slower growth, trends in advanced economies are changing. In the United States, the share of electricity in final consumption was static from 2010 to 2023 at under 22%, but it rises to nearly 40% by 2050 in the STEPS, with an expanding EV fleet accounting for 65% of overall demand growth. After falling in recent years, electricity demand in the

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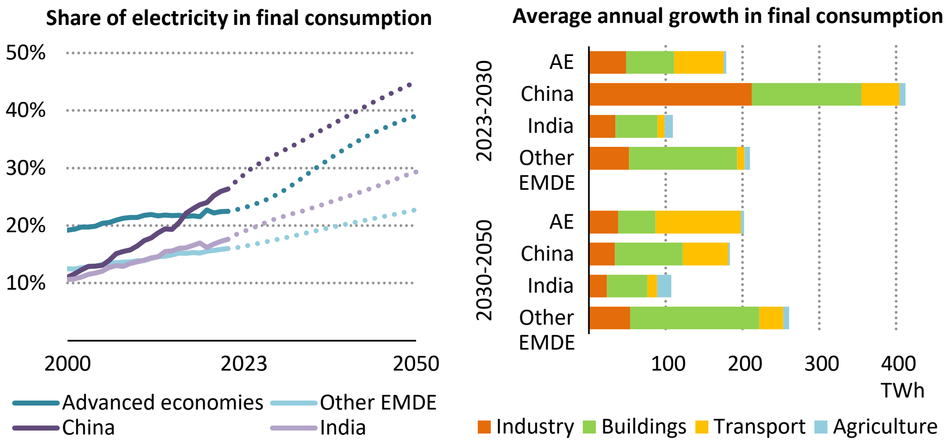
European Union is also shifting back to growth, and the share of electricity in final consumption today more than doubles to 45% in 2050 in the STEPS. Rising demand from EVs is again one of the main causes, along with more electrification of space heating in the buildings sector.

Figure 1.10 ▷ Electricity in total final consumption and demand growth in the STEPS to 2050



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Emerging market and developing economies, especially China, dominate the growth story in all sectors, while advanced economies see demand increase as transport electrifies

Notes: TWh = terawatt-hours; AE = advanced economies; Other EMDE = emerging market and developing economies other than China and India.

1.4.2 Exploring uncertainties in the STEPS

Electricity demand is subject to major uncertainties, and could be higher or lower than projected. One key uncertainty revolves around possible variations in the outlook for the building sector, which in the STEPS is set to deliver nearly 45% of electricity demand growth in final consumption by 2035, mostly from increased cooling and appliance use.

Demand for space cooling in buildings rises at an average annual rate of 3.7% to 2035 in the STEPS. Over 90% of this growth takes place in emerging market and developing economies, where economic growth and rising incomes drive air conditioner ownership, while a warming global climate boosts demand and leads to air conditioners having to work harder to provide cooling (see Chapter 3, section 3.3.2). As well as raising overall demand, cooling is projected to lead to higher peaks in demand, putting additional strain on power grids.

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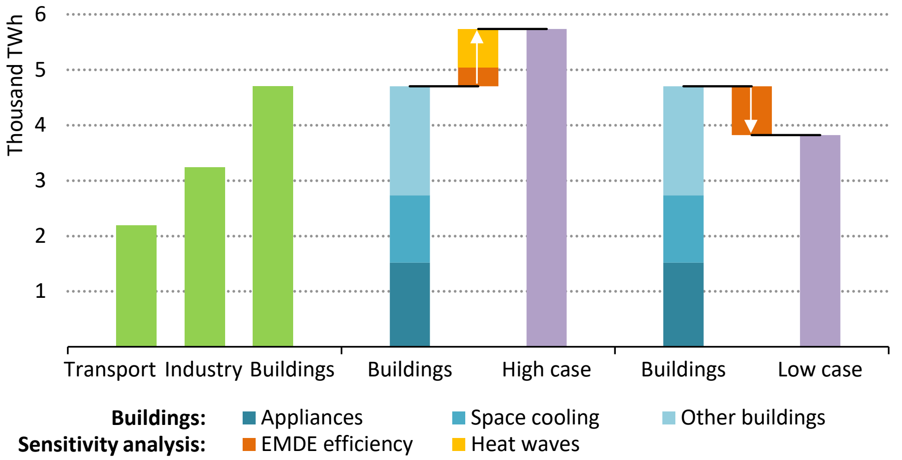
Demand growth from cooling could be even stronger than projected in the STEPS. Heat waves trigger increased demand for air conditioning, as seen in the prolonged recent heat wave in India, which reportedly doubled sales of cooling units (BBC, 2024). A sensitivity analysis exploring the impact of more frequent, intense and lengthy heat waves on air conditioner ownership and usage finds that they could increase electricity demand for cooling in 2035 by as much as 700 TWh (20%) more than projected in the STEPS (see section 4.6.2). About 80% of this additional increase occurs in emerging market and developing economies, mostly in developing Asia (Figure 1.11).

Figure 1.11 ▻ Electricity demand growth by sector in the STEPS and selected buildings sector sensitivity analysis, 2023-2035



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In absolute terms, the buildings sector is set to see the most growth in electricity demand to 2035 in the STEPS; sensitivity analysis shows that this could increase further

Note: EMDE = emerging market and developing economies.

Energy efficiency improvements, supported by strong policy measures, are key to moderating the fast growth projected in appliance ownership, floorspace and overall living standards. But current trends indicate limited progress on efficiency in key markets, and highlight the risk that weak, disparate efficiency standards could lock in additional demand in fast-growing regions. A sensitivity analysis indicates that lower efficiencies could cause electricity demand for appliances and cooling in emerging market and developing economies to be around 340 TWh (5%) higher than in the STEPS by 2035. By contrast, faster adoption of effective efficiency standards could result in electricity demand being almost 900 TWh lower in 2035 in these end-uses than in the STEPS, highlighting the value of action in these areas to temper future demand growth (see Chapter 4, section 4.6.3).

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Box 1.4 ▹ Data centre and artificial intelligence energy demand is set to expand

Nascent sectors or trends add to uncertainties in projections. One example is data centres: not a new source of electricity demand, but now in a new phase of growth arising from both the increasing digitalisation of the economy and advances in technology, including artificial intelligence (AI).

With established technology companies and AI start-ups making major investments, a sharp rise in electricity consumption by data centres looks inevitable, but the relatively early stage of this new phase of growth and sparse data availability mean that any projections are bound to be tentative. Among other things, the pace of growth may be restricted by supply chain bottlenecks, particularly for the chips that handle AI and other compute-intensive workloads. Challenges in building local grids and generation capacity may also constrain growth.

Our assessment of uncertainties indicates that demand growth to 2030 could vary from the STEPS by as much as 170 TWh. It also suggests that, while data centre electricity demand will grow, it is likely to account for a relatively small share of total global electricity demand growth to 2030, although the sector will be more significant at the national or regional level in major data centre markets (see Chapter 4, section 4.6.1).

1.4.3 Clean energy transitions are driving rapid electricity demand growth

Clean energy transitions are a primary cause of fast-rising global electricity demand (Figure 1.12). Faster electrification of end-uses and the decarbonisation of power grids together play a vital role to improve efficiency and reduce emissions, as reflected in the APS and NZE Scenario. In 2050, total electricity demand reaches 60 000 TWh in the APS and 66 000 TWh in the NZE Scenario – as much as a third higher than the 50 000 TWh projected in the STEPS.

The pace and scale of the electrification of transport is a key differentiator of electricity demand across the three *World Energy Outlook (WEO)* scenarios. The projected share of EV sales in total road vehicle sales reaches 70% in 2035 in the APS, compared with 55% in the STEPS, and this translates into a 465 TWh increase in electricity demand from road transport in the APS compared to the STEPS. In the NZE Scenario, near universal adoption of EVs by 2035 means a 1 500 TWh increase compared to the STEPS.

Faster uptake of heat pumps is central to efforts to boost energy efficiency and cut fossil fuel use in buildings. Although sales of heat pumps slowed in 2023 in some regions, and saw a major slowdown in Europe in the first half of 2024, their market share in space heating is still set to almost double by 2035 in the STEPS, and to reach approximately 30% in the APS and 40% in the NZE Scenario. Their high efficiency means the additional electricity demand from heat pumps is modest, adding only around 325 TWh by 2035 in the STEPS, 445 TWh in the APS and 425 TWh in the NZE Scenario.

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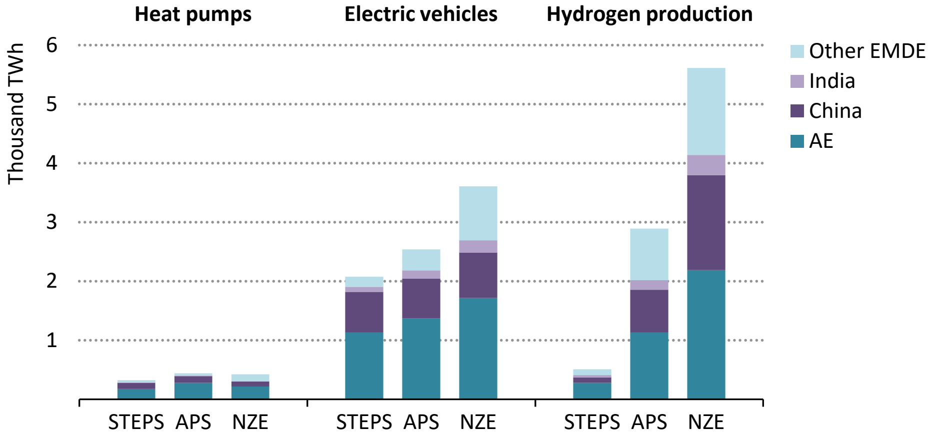
Figure 1.12 ▹ **Electricity demand growth from selected clean energy technologies by region and scenario, 2023-2035**



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Electrification of road transport and electrolytic hydrogen production to tackle emissions in hard-to-abate sectors significantly boosts electricity demand in transition scenarios

Notes: AE = advanced economies; Other EMDE= emerging market and developing economies other than China and India. Electricity demand for heat pumps represents space heating in buildings. Electricity demand for hydrogen production includes onsite production for industry and refineries.

The use of electricity to produce hydrogen, including onsite production for the steel, ammonia and refining industries, has the potential to increase demand for electricity very significantly. But the scale and timing are highly uncertain because they are contingent on how quickly different hydrogen production pathways and use develop. Electricity demand for hydrogen production increases from less than 5 TWh today to 9 000 TWh in the APS in 2050. In the NZE Scenario, electricity demand for hydrogen production reaches nearly 15 000 TWh in 2050, equivalent to over 55% of global electricity demand today.

As societies come to depend ever more on electricity, especially in rapid energy transitions, reliable supply becomes paramount (Box 1.5).

Box 1.5 ▹ Electricity is at the heart of energy security

Many of the new energy security challenges in a decarbonising world arise in the power sector as societies come to depend more on electricity for their energy needs. There are two core elements of electricity security: the ability to ensure sufficient capacity to meet peak demand (adequacy), and the ability to manage fluctuations in both demand and renewable energy supply (flexibility).

Peak demand is projected to rise faster than overall electricity demand in all scenarios, and up to 80% faster in emerging market and developing economies by 2035 in the STEPS (Figure 1.13). Efficiency measures like improved insulation and more efficient appliances

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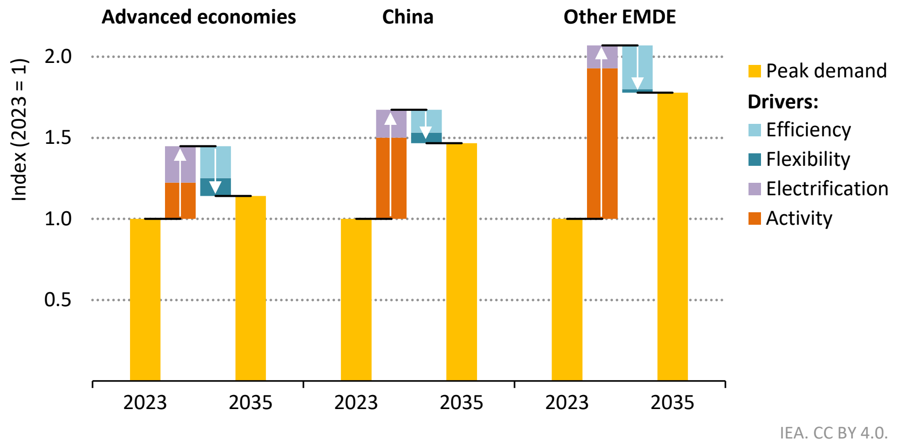
help avoid a bigger rise, along with measures that enable demand-side flexibility such as smart meters and dynamic tariffs. Batteries become essential for dispatchable capacity, and over 1 700 gigawatts (GW) of battery capacity are added in the STEPS by 2035. Natural gas and coal plants continue to play a role to provide dispatchable capacity in emerging market and developing economies, but the larger share of short-term flexibility is projected to be met by batteries and demand response, with seasonal needs met largely by hydropower and thermal plants.

Figure 1.13 ▹ Peak electricity demand by driver and region in the STEPS, 2023-2035



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Higher activity and end-use electrification are key drivers of peak demand growth, but efficiency gains and nascent demand-side flexibility mitigate some of the increase

Notes: Other EMDE = emerging market and developing economies other than China. Peak demand is the average level of demand for the 100 hours of the year with the highest demand.

A larger share of variable renewables raises the potential for imbalances between available supply and demand. A good deal of seasonal energy demand is also transferred onto the power system through the increasing use of electric heating and cooling equipment. Electricity storage, stronger grids, demand-side response and dispatchable low-emissions sources of power are essential to meet flexibility requirements in clean energy transitions, and the STEPS sees investment in grids increase by nearly 70% to 2030 to modernise and extend them, and investment in battery storage nearly triples.

Load patterns may also change as more end-uses become electric. This presents both a challenge and an opportunity. While the APS sees short-term flexibility requirements in 2050 increase up to seven times in some regions, it also sees half of those requirements met by maximising the scope for demand response, for example by shifting peak load to reflect when owners charge EVs or operate heat pumps. Measures of this kind would also help to keep household electricity bills down.

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1.5 Is clean power generation growing fast enough?

Rapidly scaling up low-emissions sources of electricity is a central part of any clean energy transition. While the electricity sector is the largest emitting energy sector today, a lot of action is in hand to reduce those emissions, driven by national and international commitments. For renewables, ambitious collective goals were set at COP28, including to triple global installed capacity of renewable energy by 2030, while over 150 countries have policies to expand the use of renewables in the power sector. For nuclear power, an initiative was established in December 2023 that targets a tripling of global nuclear capacity by 2050, and more than 30 countries have plans to expand their use of nuclear energy. There are additional initiatives to accelerate less mature technologies including carbon capture and low-emissions hydrogen. All the actions taking place are vital to efforts to decarbonise electricity and achieve the COP28 goal of transitioning away from fossil fuels in line with net zero emissions by 2050.

Many clean energy technologies are already mature. Solar PV and wind are now the cheapest electricity sources in most markets, and hydropower and bioenergy are well-established contributors. A new generation of large-scale nuclear reactors is being built in several countries with enhanced features, and small modular reactors are under development. In addition, the importance of a systems approach – including the need to expand and modernise electricity grids and accelerate the uptake of energy storage and demand response – is increasingly recognised as essential to deliver the most affordable and secure transitions (IEA, 2024c).

1.5.1 Clean power is not yet outrunning global electricity demand growth

One of the biggest success stories in clean energy transitions to date has been the rapid rise of solar PV and wind power. Between 2010 and 2023, global solar PV capacity increased 40-times and wind power six-times, with growth concentrated in China, European Union, United States and Japan. At the same time, more mature renewable energy technologies have also expanded, with bioenergy capacity increasing 2.5-times and hydropower 1.4-times. Nuclear power capacity has been broadly stable over the period.

Despite these gains, growth in clean power generation has not kept pace with global electricity demand. Global output from low-emissions sources of electricity, including all renewable energy technologies, nuclear, fossil fuels with carbon capture, hydrogen and ammonia, increased by 4 800 TWh from 2010 to 2023, but global electricity generation increased by nearly 8 400 TWh (Figure 1.14). Wind and solar PV together accounted for three-quarters of clean power growth over the period, and hydro, bioenergy, geothermal and nuclear power (in that order) accounted for the final quarter. To fill the gap, global coal-fired generation increased by almost 2 000 TWh (+23%) from 2010 to 2023 and gas-fired output increased by over 1 700 TWh (+36%). As a result, electricity sector CO_2 emissions increased by 20% over the period, rising from 11.4 gigatonnes (Gt) in 2010 to 13.7 Gt in 2023.

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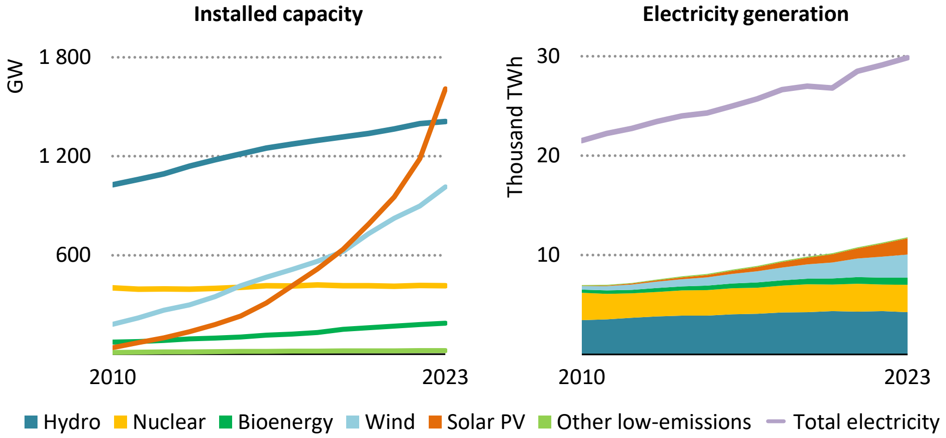
Figure 1.14 ▷ Global installed clean power capacity and electricity generation, 2010-2023



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Since 2010, installed capacity of solar PV expanded 40-fold, wind 6-fold, bioenergy 2.5-fold and hydro 1.4-fold, but electricity demand increased faster than clean power generation

Note: Other low-emissions includes geothermal, concentrated solar power, marine, fossil fuels with carbon capture and low-emissions hydrogen and ammonia.

In some regions, clean power has increased faster than electricity demand and reduced the need for unabated fossil fuels. Low-emissions sources of electricity grew by over 20% between 2018 and 2023 in countries including Australia, Korea, Japan, Argentina, South Africa, Brazil and Mexico: in all these countries, they outstripped any electricity demand growth, leading to reductions in the use of unabated fossil fuels (Figure 1.15). Low-emissions sources increased by around 10% or less in the European Union, United Kingdom and United States, but this was enough to outpace any demand growth and reduce the use of unabated fossil fuels in each case.

In several emerging market and developing economies, low-emissions sources were not able to keep pace with overall electricity demand growth between 2018 and 2023, leading to increased use of coal and natural gas to generate power. China is the global market leader in the deployment of clean power technologies, including solar PV, wind, hydro and nuclear power, but it has also seen coal-fired power increase by over 20% and natural gas by 40% over the last five years. Since its electricity demand is far larger than that of any other country, the speed at which China transitions to clean energy is of huge significance, and it will be a landmark day when clean power growth in China outstrips overall electricity demand. India and Indonesia have increased clean power by 40% and 50% respectively over the past five years, but from a low starting point, and the use of unabated fossil fuels in the power sector has also increased significantly. Given the high level of dependence on coal in both countries, their near-term plans for clean energy transitions and long-term commitments to reach net zero emissions are crucially important.

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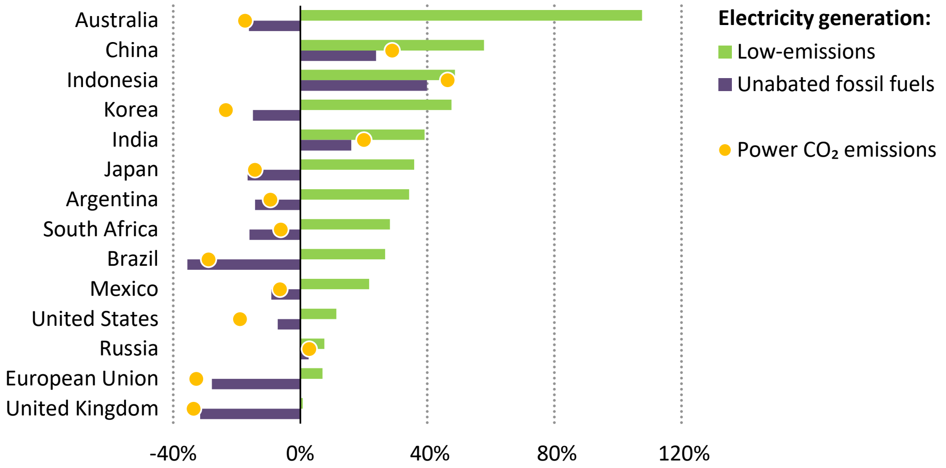
Figure 1.15 ▹ **Change in electricity generation by source and power sector CO_2 emissions in selected regions, 2018-2023**



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Over the past five years, low-emissions sources outpaced any electricity demand growth in many regions, driving down unabated fossil fuels and cutting power sector emissions

1.5.2 Clean power gets up to speed in most markets by 2030

From 2023 to 2030, growth of clean power sources outpaces electricity demand growth globally by 20% under current policy settings and market conditions. Renewables account for the vast majority of clean power growth to 2030, and renewables investment steps up from around USD 680 billion in 2023 to USD 850 billion in 2030, delivering annual average capacity additions of more than 600 GW of solar PV, about 160 GW of wind, around 30 GW of hydropower and 12 GW of other renewables. In total, renewables capacity worldwide increases 2.3-fold to 2030 in the STEPS. Nuclear power contributes to the growth of clean power sources reflecting efforts to maintain the existing fleet of nuclear reactors and construction of new reactors in around 30 countries. As a result, electricity generation from unabated fossil fuels declines to 2030, with falls of more than 10% in coal-fired power and 50% in oil-fired power more than offsetting about a 5% rise for natural gas. However, transitions away from fossil fuels must move faster to fulfil announced pledges, including the pledges to triple global renewables capacity by 2030 and to pursue net zero emissions by 2050.

In advanced economies, clean power increases twice as much as electricity demand to 2030, and both wind and solar PV individually nearly keep pace with electricity demand growth (Figure 1.16). Nuclear power increases due to a mix of lifetime extensions, new construction, return to operation of existing reactors in France and a progressive re-start of existing reactors in Japan. Electricity generation from fossil fuels declines by 30% to 2030: coal-fired power reduces by 50% and gas-fired power by 15%.

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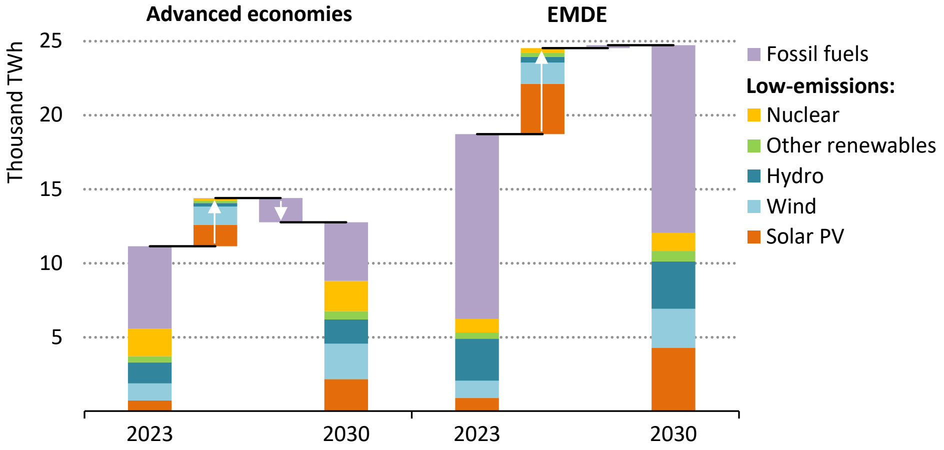
Figure 1.16 ⊳ Electricity generation by source in advanced economies and EMDE in the STEPS, 2023-2030



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Low-emissions sources outpace electricity demand growth in advanced economies to 2030, reducing fossil fuel use by 30%, and in share terms matches demand growth in EMDE

Note: EMDE = emerging market and developing economies.

In emerging market and developing economies, clean power growth starts to match strong electricity demand growth in the STEPS. Clean power expands by 5 800 TWh from 2023 to 2030, and electricity sector CO_2 emissions in emerging market and developing economies collectively peak in the mid-2020s. Solar PV dominates, providing over half of the increase in clean power between now and 2030 in the STEPS, with wind making the second-largest contribution and hydropower, other renewables and nuclear each also delivering a share of the increase. China alone accounts for almost 70% of emerging market and developing economies clean power growth, rising fast enough to keep pace with rising demand for electricity in China. Despite this progress in emerging market and developing economies, unabated fossil fuel use in 2030 remains nearly at current levels. Coal-fired power sees a slight decline over the years to 2030, while gas-fired generation rises.

1.5.3 Clean power needs to scale up faster to get on track for net zero emissions

While clean power is gaining momentum, today's policy settings and market conditions do not deliver fast enough growth to move onto a pathway to net zero emissions. In the NZE Scenario, which does move countries collectively onto such a pathway, global clean power generation increases twice as fast to 2035 as in the STEPS. To close the gap between the STEPS and the NZE Scenario through to 2035, clean power needs to expand 1.5-times faster in China, 1.9-times faster in advanced economies, and three-times faster in the other

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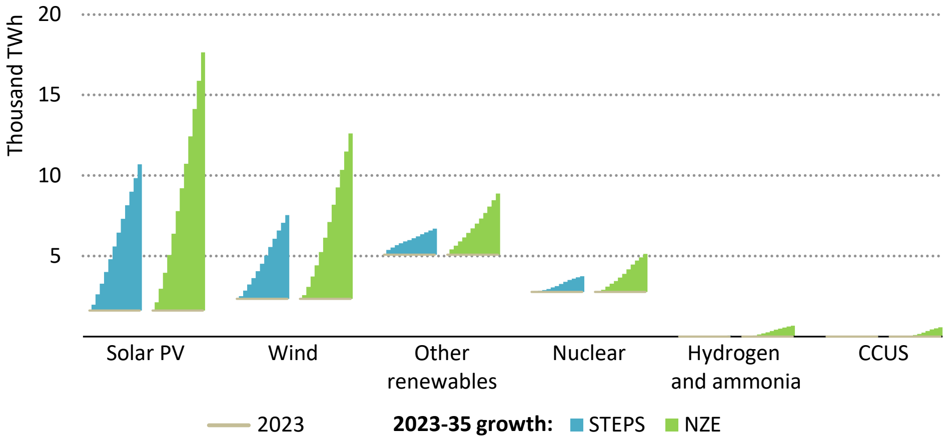
emerging market and developing economies. The faster uptake of clean power in the NZE Scenario leads to an 85% reduction in unabated coal-fired power and a 55% reduction in unabated gas-fired power by 2035, compared with a 35% reduction for coal-fired power and virtually no change for natural gas in the STEPS. To create the widest path possible to net zero emissions, all clean power technologies make a bigger contribution to reducing emissions than they do in the STEPS, though these contributions are differentiated by how mature and accessible the technologies are, by their respective costs, and by technology preferences in various economies, which are often expressed through differences in national policies.

Figure 1.17 ⊳ Global clean power generation increase by source in the STEPS and NZE Scenario, 2023-2035



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Solar PV and wind expand the most with current policy settings, and also make the biggest additional contribution in the NZE Scenario; other low-emissions sources also increase

Note: CCUS = carbon capture, utilisation and storage.

Despite their growth in the STEPS, solar PV and wind need to expand more than any other clean energy technologies to close the gap between the STEPS and the NZE Scenario, with the latter calling for an additional 7 000 TWh of solar PV and 5 000 TWh of wind by 2035 (Figure 1.17). The additional growth required in the NZE Scenario reflects the widespread availability of solar PV and wind, the strong policy support they enjoy in most countries and their cost advantages, since they are now the cheapest new sources of electricity in most markets. In the case of solar PV, it also reflects the excess manufacturing capacity that already exists, and which is anticipated to augment in the coming years (IEA, 2024d). A number of actions need to be taken to deliver the additional solar PV and wind called for in the NZE Scenario: these will vary from country to country but are likely in many cases to include taking immediate steps to address permitting and licensing issues, resolve grid

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connection delays and accelerate deployment of batteries and other energy storage technologies. Special efforts are needed to scale up financing for clean power in emerging market and developing economies outside China (section 1.8).

Vital as solar PV and wind are, the deployment of a wide set of dispatchable low-emissions sources, including hydropower, bioenergy and nuclear power, is essential for affordable and secure clean energy transitions. The NZE Scenario calls for about 1 000 TWh more hydro by 2035 than the STEPS does, and for about 650 TWh more bioenergy. While they are both mature technologies, their potential for growth is more limited than that of solar and wind, not least because of the limits on resource availability. There is also a gap of about 1 400 TWh between the NZE Scenario and the STEPS on nuclear power. This is significant, but much smaller than those for solar PV and wind: not all countries choose to use nuclear technology, and it involves relatively high initial costs and long construction times.

If the power sector is to lead the way to net zero emissions, new low-emissions options need to be brought to market by 2035. Small modular reactors are one of these technologies, and their development helps to accelerate the contribution of nuclear in the NZE Scenario. The deployment of carbon capture technologies and the use of low-emissions hydrogen and ammonia are also important, since they can be used to reduce emissions from existing coal-fired power plants which between them would use the entire remaining carbon budget to 1.5 °C if operated as they are today (IEA, 2022). By 2035, fossil fuels with CCUS and low-emissions hydrogen and ammonia start to make an impact in the NZE Scenario: together they deliver an additional 1 100 TWh over what is in the STEPS, setting them up to play an important part in decarbonising energy beyond 2035.

1.6 There is a wave of new LNG coming: where will it go?

There has been a major reorientation in natural gas trade routes since the cut in Russian pipeline exports to Europe. A large new wave of LNG export capacity is also set to come on line: if all projects that are under construction are completed on time, available liquefaction capacity is expected to rise globally from 580 bcm per year today to 850 bcm per year in 2030 (Figure 1.18).[1] This increase in export capacity is larger than projected LNG demand growth in all three scenarios; the result is an overhang of capacity which is set to depress international gas prices and set the stage for fierce competition between suppliers.

On average, the delivered cost of LNG is around USD 4.50/MBtu, but costs vary widely. The most cost-competitive sources of LNG are projects that have paid off their initial invested capital and that benefit from low cost feedgas and low operating costs, such as the Qatari LNG trains that started in the early 2000s. Around 40% of existing projects have yet to recover

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[1] Available liquefaction capacity differs from nameplate capacity and is calculated as the capacity available taking into account maintenance, downtime and upstream supply availability at existing plants, as well as projects under construction that are currently labelled as shelved, suspended or under force majeure. Globally, it is around 90% of nameplate capacity.

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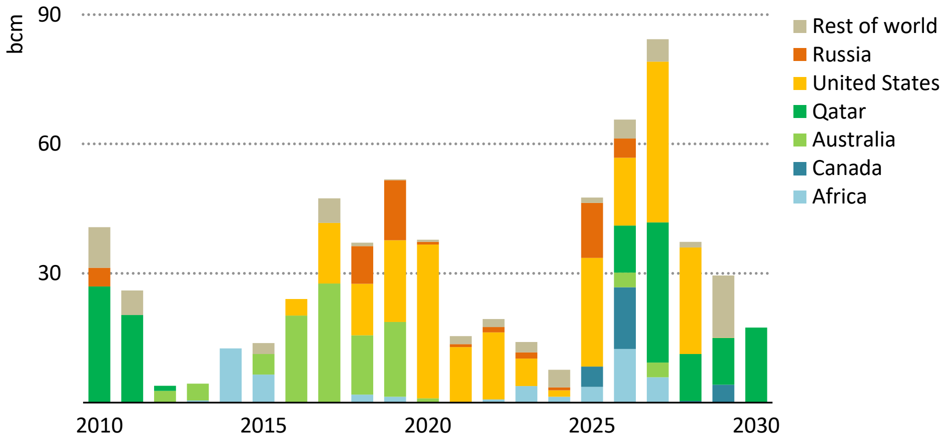
fully their invested capital, having been online for less than the typical ten-year period over which debt is recovered in project finance for large-scale LNG terminals. For projects under construction, average delivered costs are estimated to be around USD 8/MBtu, but there is a risk that this may increase due to mounting cost inflation amid a queue of projects. Indeed, delays or significant budget overruns have already affected around 20% of the projects that have made a final investment decision since 2019.

Figure 1.18 ▷ LNG export capacity additions by country to 2030



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An unprecedented volume of LNG is due to come online in the second-half of the 2020s, led by a near-doubling of export capacity in the United States and Qatar

In the STEPS, existing LNG export capacity and new capacity under construction are together sufficient to meet projected demand to 2040 (Figure 1.19). The utilisation rates of LNG plants average around 75% of nameplate capacity between 2025 and 2035 in the STEPS, which reflects very loose market conditions. After 2040, additional capacity is required as LNG demand continues to increase, and by 2050 the amount of additional capacity needed rises to around 180 bcm, most of which comes from the Middle East and North America.

Ample LNG supply in the second-half of the 2020s raises the question of whether demand might rise higher than projected in the STEPS. There is around 1 500 bcm of LNG import capacity around the world, and an additional 160 bcm is under construction. This suggests that there is sufficient infrastructure in place to handle additional LNG cargoes in most importing countries. As of mid-2024, around one-third of export capacity under construction is as yet uncontracted, meaning these additional volumes will be made available on the spot market to buyers, who are likely to be interested if prices look competitive against incumbent fuels or technologies. There are many price-sensitive markets in Asia, such as those for fertiliser in India or power generation in Pakistan, which in theory could ramp up LNG imports in response to lower prices.

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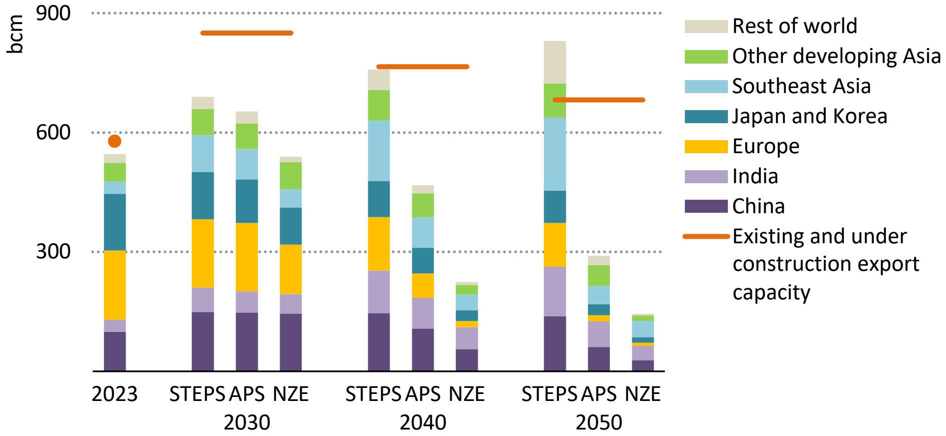
Figure 1.19 ▷ LNG demand by region and scenario relative to existing and under construction export capacity, 2023-2050



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LNG supply capacity outpaces demand in each scenario to 2030; only in the STEPS is there a need for new capacity beyond 2040

The problem for LNG suppliers is that, once all the costs of liquefaction, shipping and regasification are taken into account, it becomes a relatively expensive fuel, and a supplier could struggle to compete in emerging and developing markets while providing sufficient returns. For example, in countries such as India, imported gas prices would need to be around USD 3-5/MBtu to compete with coal, and prices in that range are likely to be below the delivered cost of LNG for many export projects around the world.

In the STEPS, the degree of demand response to the LNG surplus is constrained by the projected scale of renewables deployment, a gradual reduction in the potential for increased coal-to-gas switching as coal plants retire, and faster efficiency gains and electrification rates than in the past. Moreover, the markets with ample infrastructure in place to receive additional LNG, notably Europe and China, are also those that are making the most rapid progress with energy transitions, reducing the likelihood that they will absorb major additional volumes of LNG.

China in particular poses a conundrum: at around 8% in 2023, natural gas still accounts for a relatively small share of the overall energy mix, suggesting scope for expansion. But slowing economic growth sets the stage for intense competition in the domestic market, with coal being challenged by low-emissions sources that are an increasingly important source of economic growth and employment. In today's complicated geopolitical environment, with plenty of domestic coal and fast-growing clean energy sources, it is not obvious that Chinese conditions will allow for rapid expansion of an imported fuel. It is worth noting in this context that the possibility, albeit still a distant one, of China concluding an additional gas supply

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contract with Russia for the Power of Siberia-2 pipeline represents a major wild card for the LNG industry, as this would significantly increase the global glut of LNG.

Accelerated climate action – as seen in the APS and NZE Scenario – would also create an even larger surplus of LNG in the coming years. In the APS, LNG export plant utilisation rates fall to 70% in 2030, and existing LNG projects together with those under construction are able to fulfil LNG demand all the way through to 2050. In the NZE Scenario, utilisation rates fall to less than 60% in 2030 and LNG demand through to 2050 can be met entirely by projects existing today. In this latter scenario, we estimate that the sponsors of around 70% of LNG export projects currently under construction would struggle to recover their invested capital. Gas prices are higher in the APS, but there are still some 80 bcm of projects, or 30% of what is currently under construction, which would not fully recover their invested capital.

Nonetheless, markets typically find ways to clear, and it is therefore worth examining the conditions under which natural gas demand growth could be more robust. The 2010s – heralded by the IEA in a 2011 report as a potential "golden age for gas" – saw natural gas demand grow on average by around 2.7% per year, and it has in addition increased by 1.2% per year on average over the past five years (IEA, 2011). In the STEPS, natural gas demand peaks before 2030 and declines throughout the 2030s, mainly due to the rapid deployment of renewables, heat pumps and other efficiency measures. But clean energy technologies could be adopted at a slower pace and scale than seen in the STEPS, and alongside other factors, this could lead to natural gas demand continuing to rise throughout the 2030s and beyond (Box 1.6).

Box 1.6 ⊳ Could natural gas demand keep growing into the 2030s and beyond?

If natural gas were to keep growing at the pace seen over the past five years, demand would rise to around 5 200 bcm in 2040, or nearly 850 bcm higher than in the STEPS (Figure 1.20). The sorts of changes that, taken together, could enable natural gas demand to increase to this level by 2040 include:

Higher electricity demand: Global electricity demand increases by 2.9% on average each year between 2023 and 2040 in the STEPS. Failure to implement efficiency measures in buildings, appliances and industry at the scale projected in the STEPS could increase demand by an additional one-half percentage point per year. If gas-fired power plants were to meet the same share of electricity generation as they do today, this would mean an additional 100 bcm of gas demand in 2040.

Higher demand in industry: Energy demand in industry increases by 1% on average per year between 2023 and 2040 in the STEPS. A slowdown in efficiency and less electrification could mean total industry energy demand increases by an additional half percentage point, closer to average growth rates over the past five years. If natural gas were to meet the same share of industry demand as it does today, overall consumption would be around 90 bcm higher than in the STEPS by 2040.

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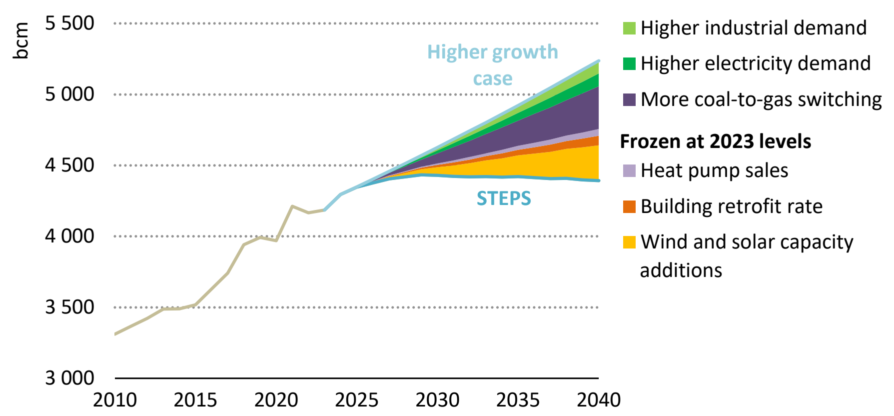
Coal-to-gas switching: The technical potential for coal-to-gas switching in the power sector is around 450 bcm today. In the STEPS, this potential progressively diminishes as coal plants retire and their output is replaced by clean electricity. If natural gas prices were to fall low enough, however, an additional 300 bcm above the level of the potential assumed in the STEPS would be opened to possible switching, primarily in China, India and Southeast Asia.

Wind and solar PV: Around 550 GW of solar PV and wind capacity were installed in 2023, and annual additions expand to over 800 GW in the STEPS by 2040. If capacity additions were to remain at current levels instead, this would imply 250 bcm of additional gas demand in 2040 above the level of the STEPS on the basis of the current power mix.

Building retrofit rates: Close to 20% of the building stock in advanced economies undergoes refurbishment in the STEPS to 2040. If retrofit rates were instead held at the 2023 level of around 1%, overall gas demand in 2040 would be around 60 bcm higher than in the STEPS.

Heat pumps: Around 110 GW of heat pumps were installed in 2023, and this increases to 300 GW by 2040 in the STEPS. If heat pump additions were to remain at 2023 levels, natural gas demand would be around 40 bcm higher in 2040 than in the STEPS.

Figure 1.20 ▷ Factors that could lead to continued natural gas demand growth above the levels of the STEPS to 2040



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Continued increase in gas demand cannot be ruled out, but it would take a major slowdown in clean technology deployment and efficiency improvements

Natural gas can also provide flexibility to integrate variable renewables, and this is often highlighted as a reason for its enduring role in transitions. But this role requires limited amounts of natural gas, and certainly much less than what is required by power plants in order to provide bulk electricity.

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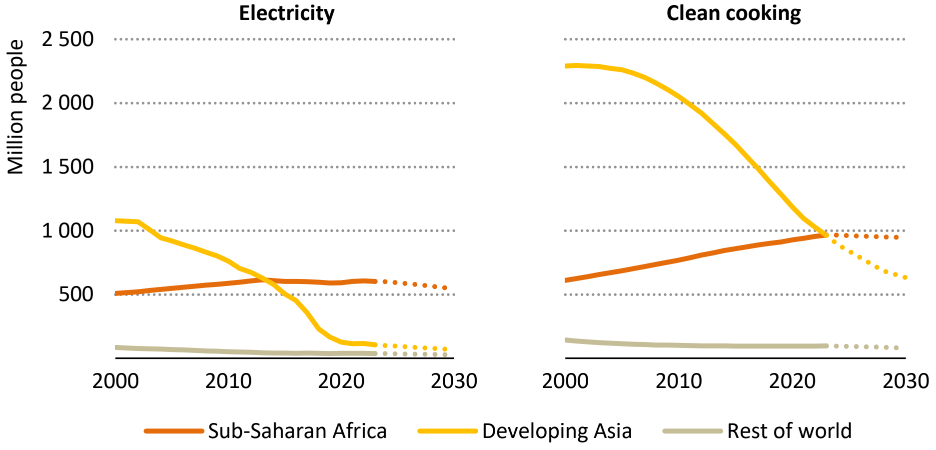
More favourable long-term circumstances for growth in natural gas demand cannot be ruled out, but they depend on a combination of policy settings, technology developments and market trends that lead to a major slowdown in the deployment of clean energy technologies and in the achievement of efficiency gains, and on LNG being priced for some years at levels that makes it difficult for exporters to recover their costs. Further sensitivities related to natural gas demand are explored in Chapter 4.

1.7 What will it take to achieve energy access goals by 2030?

Reaching universal access to electricity and clean cooking is central to a just, people-centred energy transition. The deployment of ever more innovative, efficient and sustainable solutions has widened the range of options now available to achieve that goal while improving the quality of life of millions and reducing the impact on the environment.

Since the early 2000s, many countries have made rapid progress to extend energy access, led by developing economies in Asia and parts of Latin America (Figure 1.21). Other countries, especially in sub-Saharan Africa, have struggled to keep up with population growth. As part of the United Nations Sustainable Development Agenda, UN members in 2015 agreed to the goal of providing affordable, reliable and modern energy to all by 2030 (SDG7.1) – a goal that is achieved in the NZE Scenario.

Figure 1.21 ⊳ Population without access to modern energy 2000-2023 and in the STEPS to 2030



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Major progress in energy access is evident in recent decades; while Asia has been leading the way, sub-Saharan Africa lagged behind

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IEA tracking shows that, even before the Covid-19 pandemic and the global energy crisis, a major boost in progress was needed to deliver this goal. Recent years have seen progress slow and even go into reverse in some cases, intensifying the pressure on countries that were already facing a difficult outlook. This raises the question of whether the 2030 goal is slipping out of reach.

Yet, there are reasons for guarded optimism. A range of innovative energy access solutions is renewing momentum and helping to bring about faster progress in some regions. In addition, a flurry of new policies and national plans have markedly improved the longer-term outlook. This section explores how energy access progresses under current policy settings, and where accelerated action is needed.

1.7.1 Access to electricity

Progress on electricity access has been remarkable in the past decades: since 2000, the world has reduced the number of people without electricity access by 925 million, and 40 countries have reached at least near universal access to electricity. But around 750 million people still lack access to electricity, and progress has been uneven, with only one-in-five of the people gaining access to electricity in this period living in Africa. As many Asian countries near universal access, attention is increasingly turning to Africa, where it has proved more difficult to regain momentum amid the lingering effects of the crisis years, including high debt levels in many countries.

While grid connections in some countries are gradually resuming, some of this slowdown is being offset by new business models such as Pay-As-You-Go solar PV (PAYGo) and digital payment systems, and by the decreasing cost of batteries and solar PV modules. Sales of solar home systems (SHS) have increased 2.5-fold in sub-Saharan Africa since 2018, and more than 90% of all the systems sold worldwide in 2023 were sold through PAYGo (GOGLA, 2024). The latest IEA estimates suggest that over 40 million people in sub-Saharan Africa had access to electricity via SHS in 2023, which is almost four-times more than five years before. An additional 30 million people in the region use SHS as a backup source of electricity, especially in places where the grid electricity supply tends to be unreliable. Innovative models like Energy as a Service are showing the potential to make SHS affordable even for the poorest and most remote populations (GET.Invest, 2024). In addition, around 48 million people globally benefited from a mini-grid connection in 2021, around 27 million of which are in sub-Saharan Africa (ESMAP, 2022). Recent analysis indicates that 2024 might be the fastest year on record for new mini-grid connections (Mini-Grids Partnership, 2024). A crucial ingredient for successful projects is a link to local productive uses as they underpin revenue and bankability and can lead to significant local economic benefits in the longer term (IEA, 2023).

While technological improvements and innovative models are helping, they will not by themselves achieve the scale needed to reach universal access and overcome the current affordability gap. Public interventions and targeted incentives are required if 120 million people are to gain access each year, as they must do to achieve the SDG 7.1 goal by 2030

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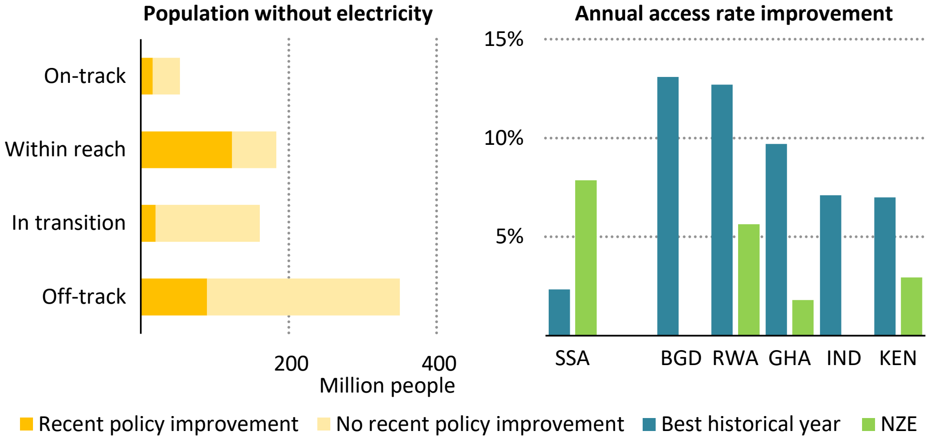
(Figure 1.22). Most of the progress needs to take place in sub-Saharan Africa, where around 7% of the population has to gain access each year to get on track. This pace of annual progress is not unprecedented, with comparable and higher percentages having been achieved in the past in Bangladesh, Kenya, Ghana, Rwanda and India. In 2018, India connected almost 100 million people – equivalent to the annual effort required in sub-Saharan Africa to close the gap by 2030 – thanks to government initiatives aimed at expanding rural electrification, such as the Saubhagya and the Deen Dayal Upadhyaya Gram Jyoti Yojana schemes.

Figure 1.22 ▷ Population without electricity access in 2023, and historical best versus progress in the NZE Scenario by country/region, 2024-2030



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Significant, but not unprecedented, effort will be necessary to achieve universal electricity access in sub-Saharan Africa, where 80% of people without access live

Notes: SSA = sub-Saharan Africa; BGD = Bangladesh; RWA = Rwanda, GHA = Ghana; IND = India; KEN = Kenya. NZE = NZE Scenario and in this figure it shows the average annual improvement in access in the 2024-2030 period. *Recent policy improvement* = policies announced or enacted in the last two years. *Off-track* = population in countries where current policies are expected to lead to very limited improvements in access. *In transition* = population in countries with weak but improving policy frameworks. *Within reach* = population in countries where fundamental policies are in place, but additional efforts are needed to achieve universal access by 2030. *On-track* = population in countries with strong policies to expand access and likely to reach universal access by 2030.

Around one-third of the population without access to electricity, about 250 million people, live in countries where new and improved access policies and programmes have been initiated, including six countries where previous policies were expected to lead to very limited improvements. New international financing commitments are helping draw policy attention to countries with large access gaps. However, there will still be around 650 million people without access to electricity by 2030 in the STEPS. More concrete measures are needed to boost progress.

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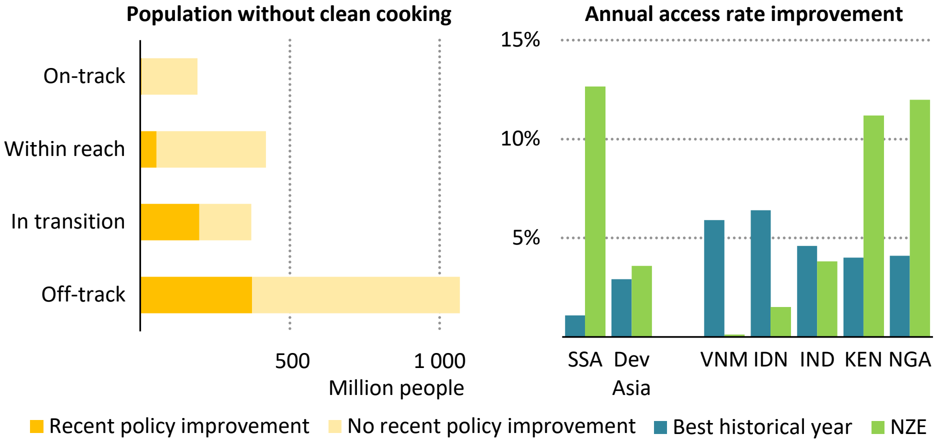
1.7.2 Access to clean cooking

Since 2000, around 1 billion people have gained access to clean cooking, and 16 countries have reached near universal access. Progress has been concentrated in Asia and Latin America. In much of Africa, population growth has continued to outpace improvements in access. There is much further to go. Today, more than 2 billion people still lack access to clean cooking, split almost equally between sub-Saharan Africa and developing economies in Asia.

Figure 1.23 ▷ Population without clean cooking access in 2023, and historical best versus progress in the NZE Scenario by country/region, 2024-2030



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Clean cooking policies and measures have recently improved the outlook for about 630 million people, but much more is needed to achieve universal access by 2030

Notes: SSA = sub-Saharan Africa; DevAsia = developing Asia; VNM = Viet Nam; IDN = Indonesia; IND = India; KEN = Kenya; NGA = Nigeria. NZE = NZE Scenario and in this figure it shows the average annual improvement in access in the 2024-2030 period. *Recent policy improvement* = policies announced or enacted in the last two years. *Off-track* = population in countries where current policies are expected to lead to very limited improvements in access. *In transition* = population in countries with weak but improving policy frameworks. *Within reach* = population in countries where fundamental policies are in place, but additional efforts are needed to achieve universal access by 2030. *On-track* = population in countries with strong policies to expand access and likely to reach universal access by 2030.

Among the main obstacles to further progress are affordability and limited clean cooking policies and programmes. Countries that have recently implemented or strengthened clean cooking policies have often seen rapid progress, particularly in urban and peri-urban areas. The majority of progress so far has been achieved through the provision of LPG stoves and cylinders, and improved solid biomass stoves. Other clean cooking fuels are proving capable of being rapidly scaled up in certain locations, notably bioethanol, biogas and electric

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cooking. Bioethanol cooking has grown strongly on the back of carbon credit revenues in Kenya and has the potential to expand quickly in urban and peri-urban areas in East Africa. Efficiency induction and hyper-efficient electric pressure cookers are also starting to make headway in Asia, often supported by government-led campaigns to reduce LPG imports.

Access to clean cooking has gained substantial political attention in recent years, prompting a wave of new domestic and international efforts to improve access. Around 630 million people without clean cooking access live in countries in which new and improved policy frameworks were implemented in the last two years or are under active development (Figure 1.23). This includes new national clean cooking strategies and plans in Kenya, Nigeria, Tanzania and Uganda. Support from the G7, G20, and the Conference of the Parties (COP) presidencies as well as from international finance institutions helped to move the dial. While this has improved the outlook for clean cooking since the *WEO*-2023, around 1.7 billion people still lack access to clean cooking by 2030 in the STEPS. Transitional solutions like improved biomass cookstoves (ISO Tier >=3) could provide prompt and meaningful benefits for remote and poor households in the short term before more sustainable longer-term solutions and infrastructure can be put in place.

1.7.3 Investment needs to ramp up quickly

To achieve universal energy access by 2030, around USD 55 billion in upfront investment is needed each year, around two-thirds of which is required in sub-Saharan Africa (Figure 1.24). This is less than 2% of current annual energy spending. Current investment levels are just below USD 10 billion annually. This is much less than is needed and has decreased around 75% from pre-COVID19 levels. However, the decrease is due in part to large economies having made rapid progress in the intervening years and achieving near universal access to electricity.

Affordability constraints mean that private capital can only cover a small share of the financing that is needed for energy access, while African governments already face rising debt sustainability concerns. This means that the allocation of official development assistance to energy in Africa is vitally important if faster progress is to be made, but the level of such assistance for energy projects has remained static over the past decade. Without a stronger international commitment to universal energy access, there is a risk that many developing economies may be left behind. The new collective quantified goal on climate finance could be used as a vehicle to close at least part of the funding gap.

Renewed attention to energy access issues within international climate finance and development assistance is already providing a boost to concessional capital for access. The "Mission 300" programme, which aims to provide 300 million people with electricity access, has received initial pledges of USD 30 billion and aims to reach around USD 90 billion. An additional USD 2.2 billion of private and public sector finance for clean cooking was pledged at the IEA Summit for Clean Cooking in Africa in May 2024, on top of the USD 2 billion committed by the African Development Bank at the COP28.

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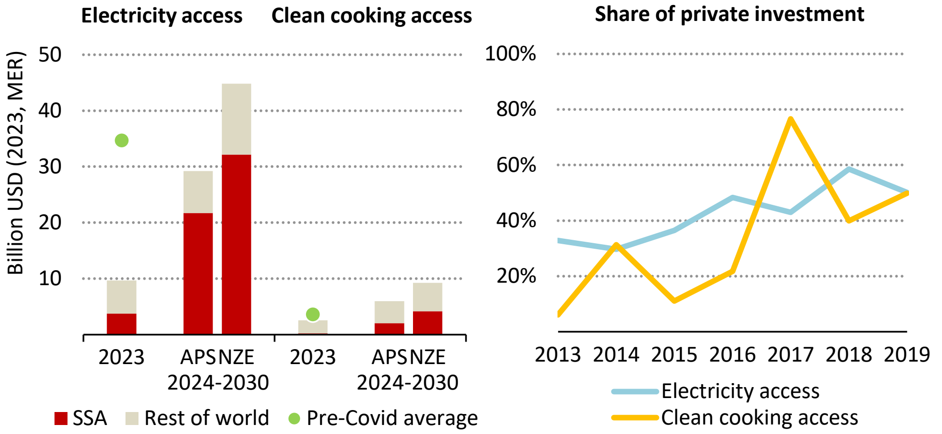
Figure 1.24 ▷ Average annual capital investment for energy access by scenario, and private capital in energy access projects, 2013-2019



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Current energy access investment is far below the USD 55 billion required annually to reach universal access by 2030, two-thirds of which is needed in sub-Saharan Africa

Notes: SSA = sub-Saharan Africa. Pre-covid average represents the period 2015-2019. APS and NZE represent the average annual investment between 2024 and 2030 in each scenario.

Source: IEA data and analysis based on SEforALL and Climate Policy Initiative (2021).

Implementing these commitments remains a challenge. The small size of projects, especially for clean cooking and rural off-grid electrification, and the lack of established private sector players in some locations, make it more difficult to disburse money fast and effectively. On top of this, household affordability constraints, evolving pricing regulation and a lack of credible benchmarks increase the real and perceived risks for energy access projects. Plans to improve electricity access are more likely to attract support and to succeed if they identify productive uses and anchor loads, e.g. small industries, agricultural pumps, communication towers, and if they lead to the displacement of diesel and petrol generators. Targeting institutional facilities and peri-urban areas has proved to be successful to extend access to clean cooking while creating momentum.

Recent shifts in the use of concessional finance such as guarantees and first-loss capital are helping to attract rising levels of private capital. The share of private finance in both electricity and clean cooking access projects neared 50% in 2019, up from 30% for electricity in 2013, and from less than 10% for clean cooking. The availability of commercial private capital is expected to continue to rise but is likely to focus on more profitable projects, such as those in urban and high demand areas. Public and concessional finance remains fundamental to reach poor and more remote areas. Carbon market financing for clean cooking projects has also been on the rise, with over 40 million credits issued in 2023,

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accounting for 15% of all carbon credits issued globally and up ten-times from 2013. Concerns about the rigour of cookstoves credits have hampered the market, but new initiatives and methodologies, notably the CLEAR [2] methodology, aim to meet those concerns.

Despite the progress that is being made, the goal of universal access cannot be delivered without improved policies and an increase in funding support, particularly in Africa. Calls for more climate finance need to be heeded, and to be accompanied by continued efforts to ramp up private sector involvement. All of this ultimately depends on unwavering commitment to achieve universal access on the part of the governments of the countries where progress is needed, together with strengthened commitment on the part of the international community, including international financial institutions.

1.8 How to scale up clean energy investment in emerging market and developing economies?

Global energy sector investment reached around USD 2.9 trillion in 2023 and is likely to exceed USD 3 trillion for the first time in 2024, with almost USD 2 invested in a range of clean energy technologies and infrastructure for every USD 1 spent on fossil fuels. Prior to the Covid-19 pandemic, this ratio was closer to 1:1. Global investment in clean energy has increased by 60% since 2015, driven not only by emissions reduction goals, but also by robust underlying economics, considerations of energy security during a period of extreme volatility in fossil fuel prices, and competition among leading economies for positions in the new clean energy economy that will be an important source of growth and employment in the coming years.

Recent increases in clean energy investment come mostly from advanced economies and China, making up 85% of the total, while other emerging market and developing economies, home to two-thirds of the global population, account for just 15% (Figure 1.25). This misalignment is a major concern, given that demand for energy services in developing economies will inevitably increase in the coming years to support rising standards of living, universal access to energy and construction of modern infrastructure. The high cost of capital and lack of affordable long-term financing is a key contributor to these regional imbalances and an impediment to increasing capital flows to emerging market and developing economies in the future.

Investment in clean energy projects increase in all parts of the world in the NZE Scenario, but the regional imbalances mean that the required increase is particularly steep in emerging market and developing economies other than China. In the NZE Scenario, annual spending on clean energy doubles in advanced economies and in China by 2035 compared with 2023 levels, while it grows more than six-fold in other developing economies (Figure 1.26).

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[2] The Comprehensive Lowered Emission Assessment and Reporting (CLEAR) is a new methodology for crediting emissions reductions from cookstove projects developed by the 4C consortium https://cleancooking.org/4c/methodology/

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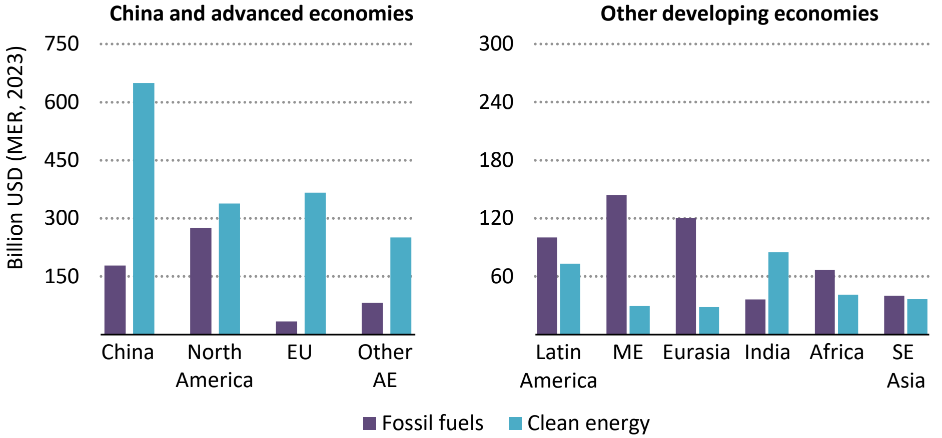
Figure 1.25 ▹ Estimated energy investment by type in selected regions, 2024



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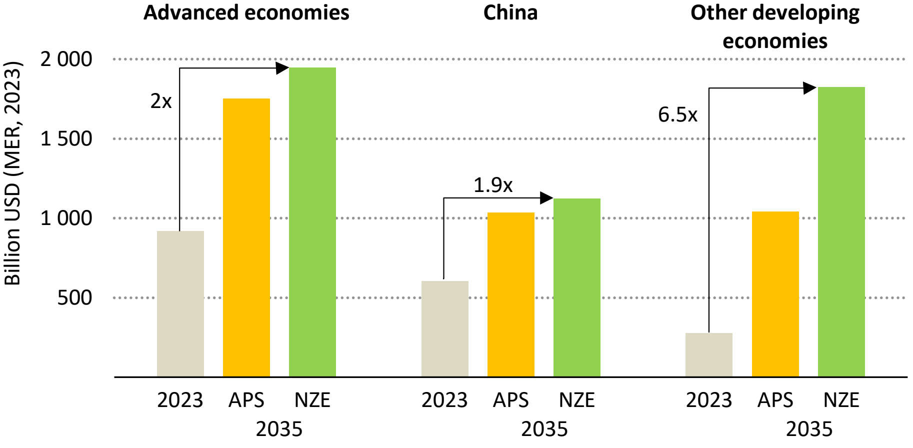
Around 85% of clean energy investment is made in advanced economies and China. Elsewhere, investment is mostly higher in fossil fuels than clean energy.

Note: EU = European Union; Other AE = other advanced economies; ME = Middle East; SE Asia = Southeast Asia.

Figure 1.26 ▹ Clean energy investment by region in the APS and NZE Scenario to 2035



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Meeting national and global climate goals require robust increases in investment in developing economies other than China

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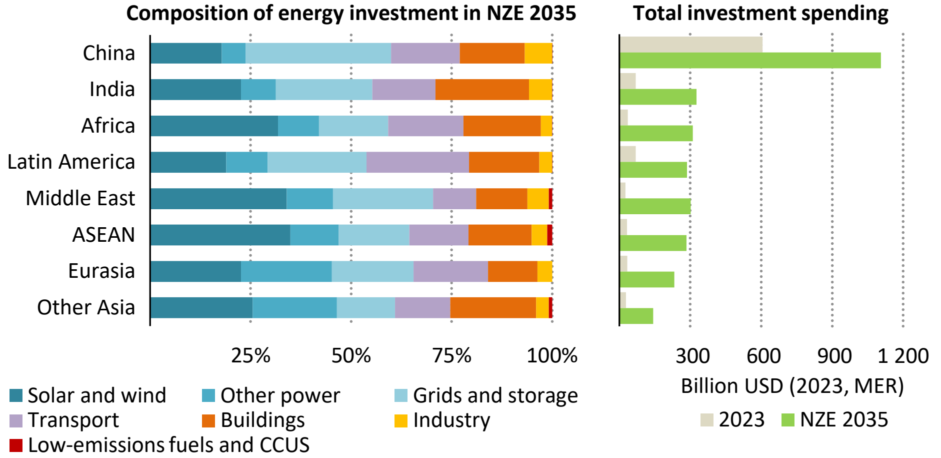
1.8.1 Breaking down investment requirements

The surge in clean energy spending that is required in both the APS and NZE scenario can appear daunting for emerging market and developing economies (Figure 1.27). But many examples show that a clear vision for energy transitions, supported by sound policies, regulations and private sector engagement, can drive growth in both the quantity and quality of clean energy investments. And the benefits of these investments go well beyond mitigating climate change (Box 1.7). Many clean energy facilities, once installed, tend to have lower operating costs than fossil fuel facilities, and are not financially exposed to volatile fuel costs. This can bring major long-term energy and economic security gains especially for economies highly dependent on fuel imports.

Figure 1.27 ▹ Clean energy spending by type and by selected regions in the NZE Scenario, 2023 and 2035



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Clean energy investment grows in all sectors with the largest increases seen in grids and storage, buildings and transport

Note: NZE 2035 = Net Zero Emissions by 2050 Scenario in 2035; CCUS = carbon capture, utilisation and storage; MER = market exchange rate.

Closing the clean energy investment gap in developing economies requires mobilising capital and channelling it to sectors that present different degrees and types of risks to investors. For instance, the challenges and business models that are relevant to a utility-scale solar PV project with a long-term contract are different from those that arise in connection with a transmission line financed on balance sheet by a state-owned utility, or an electric car that is paid for by a household with consumer finance or their own savings. Risks can also vary for different projects within a single sector and for similar projects in different countries, since factors like political and macroeconomic stability and the rule of law have broad consequences for risk perceptions and therefore also for the cost of capital.

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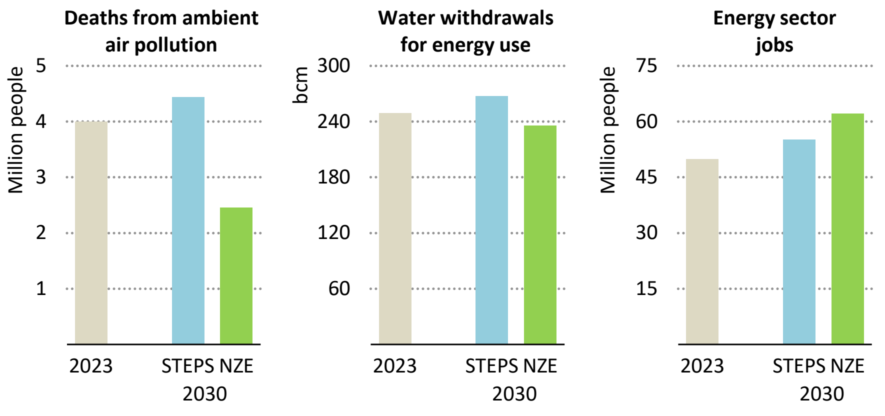
Box 1.7 ⊳ Multiple benefits of clean energy investment

To think of clean energy projects only in terms of their role in tackling climate change is to miss the broader picture. In many cases, these projects also offer the prospect of cheaper energy, efficiency gains and important co-benefits in terms of air quality, water use and employment.

Air quality is a particular concern as it accounts for over 4.5 million premature deaths worldwide each year due to ambient (outdoor) air pollution, and nearly 3 million deaths from household air pollution, primarily as a result of the use of traditional fuels and stoves for cooking. Nearly all these premature deaths are in emerging market and developing countries. In the NZE Scenario, efforts to achieve universal energy access through scaling up clean energy investment lead to a 40% decrease in premature deaths from ambient air pollution by 2030, and a 90% drop in premature deaths from indoor pollution (Figure 1.28).

Figure 1.28 ⊳ Selected health, environment and employment indicators in emerging market and developing economies, 2023-2030



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Scaling up clean energy helps countries reduce premature deaths from air pollution and water needs for energy operations while generating employment

Replacing thermal generation with renewable sources like wind and solar PV also results in large reductions in water use. In addition, the deployment of clean energy brings net gains in employment as demand increases for construction, manufacturing, installation and maintenance projects. Developing a skilled labour pool is vital for countries looking to be competitive in new clean energy industries, as is attracting more women to work in energy-related fields: women currently represent just 15% of the energy workforce.

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The prospects for scaling up clean energy investment in all sectors depend to a large extent on policy certainty, data reliability and strong governance. Making improvements in these areas is therefore critically important. This needs to be accompanied and facilitated by significant increases in international public financial and technical support, including larger volumes of concessional funding to bring in much higher multiples of private capital. By 2030 in the NZE Scenario, annual concessional funding for the energy sector triples to reach over USD 100 billion in developing economies other than China.

However, not all projects need public financial support. In considering how to scale up investment, it is useful to break down the overall requirement into categories that reflect particular characteristics and risk profiles. In work undertaken in support of the Brazilian G20 presidency in 2024, the following three groupings were proposed:

- The first group covers investment in mature clean energy technologies with relatively low risk and strong underlying economics in countries with relatively good credit rating. These can usually be **privately led**, provided that investors have confidence in the quality of the policy and regulatory environment. For example, utility-scale solar PV and wind projects in Brazil or in India have built up a successful track record of mobilising private capital for several years, and only limited interventions are required on the financing side from the public sector. In the NZE Scenario, the total clean energy investment requirement in developing economies other than China in 2035 is around USD 1.8 trillion, and our assessment is that around 40% of the investment falls into this privately led category.
- The second group of projects, accounting for around half of the 2035 clean energy requirement in the NZE Scenario, needs to be facilitated by some form of risk mitigation based on collaboration between the public and private sectors. These **facilitated interventions** cover technologies that have reached commercial maturity in some markets but have yet to take off in a specific developing economy, for example a utility-scale solar PV in a nascent market like Cambodia, and emerging technologies in relatively low risk jurisdictions that require additional support for the first commercial scale projects, for example a low-emissions hydrogen project in Chile. They also cover projects where the national creditworthiness is low and a constraint on investors, or where significant social returns, such as those arising from improved energy access, need some form of public support to ensure affordability and bankability.
- The third group, accounting for around 6% of projects, concerns investment for which commercial capital is either not available or is too costly to access because the real and perceived risks are very high. These investments need to be **publicly driven**. They include projects in some of the least developed countries in the world, and projects in countries involved in or emerging from conflicts, as well as those involving some nascent technologies or aspects of public infrastructure that require substantial public support to lower costs.

These three categories help to differentiate the types and scale of finance that may be required to advance clean energy transitions in emerging market and developing economies,

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and to provide a means of identifying the cases that require additional support from public financial institutions, including the strategic use of concessional financing to bring in much larger volumes of private capital.

1.8.2 Challenge of scale

Facilitated interventions need to be designed in ways that not only help individual projects to move ahead but also clear the path for more projects to follow without the same level of support. Concessional funding is scarce and needs to be deployed in ways that allow its impact to be sustained even when the funding itself is withdrawn. In essence this means helping projects to move to a point where they can be led by the private sector. The key to this is to consider reforms that address underlying barriers as part of the process of designing and implementing interventions, and to standardise, to the extent possible, the underlying documentation, e.g. for power purchase agreements.

Scaling up clean energy requires integrated policy approaches and system-wide planning. In the power sector, for example, bringing in new sources of generation, especially variable ones like solar PV and wind, requires the flexible operation of other generation assets and measures to expand and modernise grids and storage. In countries with large coal-fired power generation fleets, this means repurposing coal plants to provide balancing services, or making provisions for early plant retirements to allow clean sources to expand, prioritising the retirement of older, less efficient units. It also means full recognition of the importance of demand-side measures and energy efficiency.

Scaling up also means identifying and developing new sources of finance. For the moment, domestic sources of capital account for most of the financing for clean energy investment projects in developing economies. This finding is heavily conditioned by the weight of China in the overall numbers, as more than 90% of clean energy projects in China are funded by domestic sources. But domestic funding has also been crucial in other developing economies that have successfully scaled up clean energy investment, including India and South Africa. Deeper local capital markets in other jurisdictions can help finance flow to projects in clean energy, while developing secondary markets from operating assets with stable revenue streams can also help recycle capital into new projects.

The volume of investment required for successful clean energy transitions therefore necessitates a greater role for international capital. As an example, developing economies other than China see a sharp increase in capital flows from international sources, from 20% in 2023 to 35% in the NZE Scenario in 2035. Financing instruments such as green, social, sustainable and sustainability-linked bonds have the potential to mobilise private capital at scale by attracting institutional investors that do not typically invest in individual projects. Project aggregation platforms and securitisation vehicles are also necessary to overcome the asymmetry between the relatively small size of most clean energy projects, especially in the end use sector, in developing economies and the comparatively large minimum investment size that institutional investors typically require.

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Setting the scene

Context and scenario design

SUMMARY

- Total global energy demand rose by around 2% in 2023, with declines in advanced economies more than offset by large increases in emerging market and developing economies. A record high level of clean energy came online globally, including more than 560 gigawatts (GW) of new renewable power capacity. Around USD 2 trillion is expected to be invested in clean energy in 2024, almost double the amount invested in fossil fuels. However, two-thirds of the overall increase in energy demand in 2023 was met by fossil fuels and energy-related carbon dioxide (CO_2) emissions reached a record high.
- Governments cumulatively earmarked USD 2 trillion of financial support for clean energy between 2020 and mid-2024. They also spent around USD 940 billion on support for consumer energy affordability during the global energy crisis, though most of the measures put in place to provide that support have now expired.
- Many new energy policies, spending plans and regulations have been introduced or announced since the *Outlook* in 2023. Countries are now putting more emphasis on building domestic clean technology manufacturing capacity to improve energy security and boost economic activity, including through tying support to domestic production or jobs and through trade measures. Since 2020, nearly 200 trade measures affecting clean energy technologies have been introduced.
- This *Outlook* examines three main long-term scenarios – none of which are forecasts – to provide a framework for understanding possible energy futures. Policies are the critical differentiator between them. We also explore a number of sensitivity cases related to uncertainties in the pace of clean energy deployment, natural gas markets and electricity demand, and the wider implications these have for energy and emissions. Russia's invasion of Ukraine, conflict in the Middle East, broader geopolitical tensions, and elections in countries accounting for half of global energy demand today mean a very high level of uncertainty over the projections in this *Outlook*.
- In this *Outlook*, the global economy increases by 2.7% on average each year to 2050. We maintain a constant economic growth rate across all scenarios to facilitate a comparison of the impacts of energy and climate choices with a consistent backdrop. The global population expands from 8 billion today to 9.7 billion in 2050, an annual average growth rate that is around half the rate seen between 1990 and 2023.
- Prices for fossil fuels and critical minerals have fallen from the very high levels in 2022. Future price changes are assumed to follow smooth trajectories in all scenarios, but there remains an ever-present risk of volatility.

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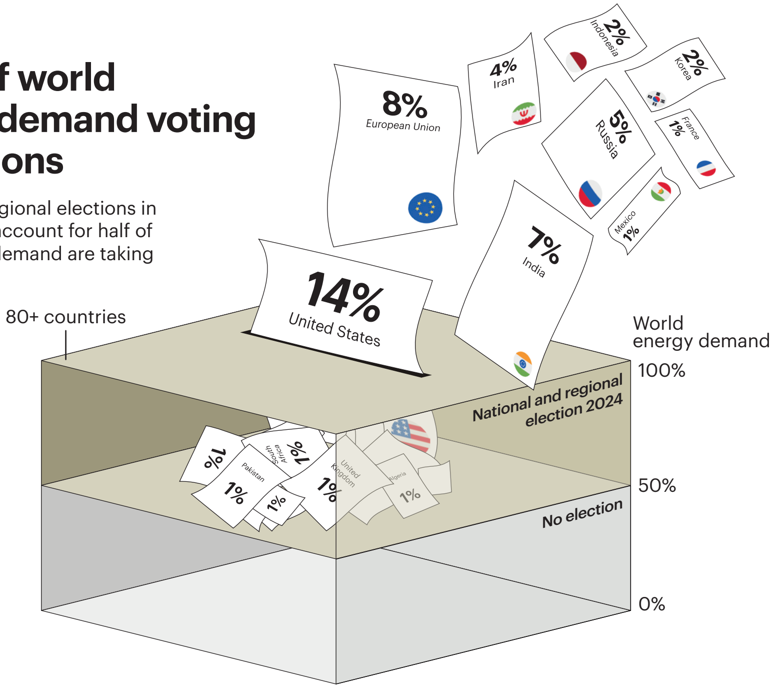
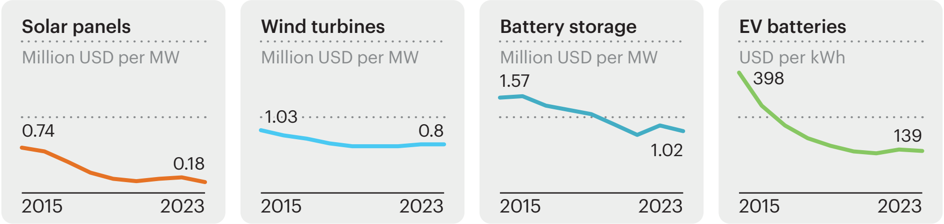
Share of world energy demand voting in elections

National and regional elections in countries that account for half of global energy demand are taking place in 2024.



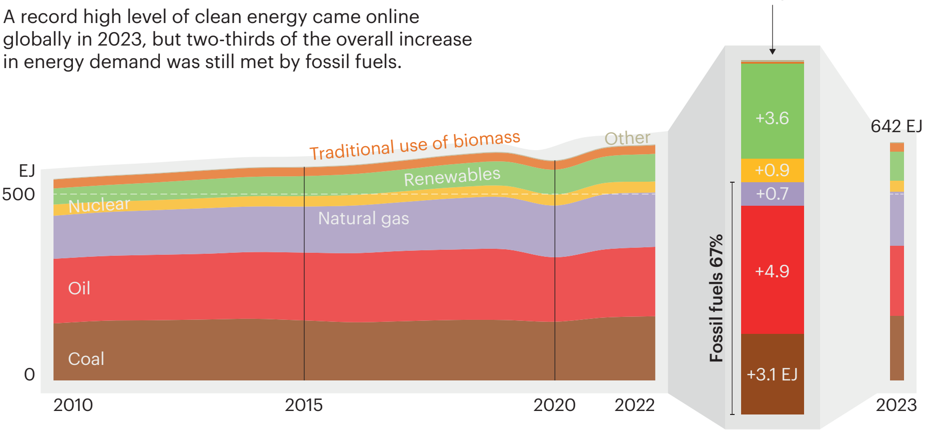
Falling clean energy prices

Recent years have seen large overall price reductions for many clean energy technologies.



Global energy demand

A record high level of clean energy came online globally in 2023, but two-thirds of the overall increase in energy demand was still met by fossil fuels.



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2.1 Context for the *World Energy Outlook-2024*

The *World Energy Outlook-2024* unfolds against a complex and uncertain backdrop. The immediate impact of the shocks from the Covid-19 pandemic and the global energy crisis spurred by Russia's invasion of Ukraine are diminishing, but the damage to public finances and to international co-operation will take longer to repair. Countries representing half of global energy demand are voting in national or regional elections in 2024; climate and energy-related issues feature prominently in many campaigns. The spectre of spiralling conflicts across the Middle East also highlights key energy security risks in the current system, while decades of accumulated emissions are accentuating the risks from extreme weather.

Today's broad trends underscore the urgency of transforming the energy sector even as they also complicate its achievement in practice. In these circumstances, the continued momentum and resilience of clean energy transitions is remarkable. Since 2020, investment in clean energy technologies and infrastructure has increased by 60%; the amount of capital invested each year to support clean energy projects is now twice the amount invested in fossil fuels. This is boosting the contribution that clean energy makes to the global energy mix, even though the majority of growth in global energy demand is currently still being met by fossil fuels.

The extent and speed of structural changes in the energy sector and their implications for energy security, affordability and emissions are central themes in this *Outlook*. Our scenario analysis is designed to inform decision makers as they consider options, not to predict how they will act, and none of the scenarios should be viewed as a forecast. The scenarios, all of which look out to 2050, are:

- **Stated Policies Scenario** (STEPS): This scenario provides a sense of the prevailing direction of travel for the energy system, based on a detailed assessment of current policy settings. Chapter 4 explores a number of sensitivity cases related to clean energy deployment, natural gas markets and electricity demand, and to assess the wider implications these have for energy and emissions.
- **Announced Pledges Scenario** (APS): This scenario outlines a trajectory for the energy sector if all national energy and climate pledges, including long-term net zero emissions goals, are met on time and in full.
- **Net Zero Emissions by 2050** (NZE) **Scenario**: This scenario portrays a pathway in which the energy sector achieves net zero carbon dioxide (CO_2) emissions globally by 2050, in line with limiting the long-term global average temperature to 1.5 degrees Celsius (°C), along with achieving universal energy access by 2030 and air quality objectives.

This chapter sets the scene for subsequent analyses by outlining the current context for energy use and emissions, broad macroeconomic and investment trends, and policy and geopolitical uncertainties. It then goes into more detail on the scenarios used in this *Outlook*, discussing how and why they differ from each other, the underlying policy, economic and demographic drivers, energy and carbon prices, and technology costs.

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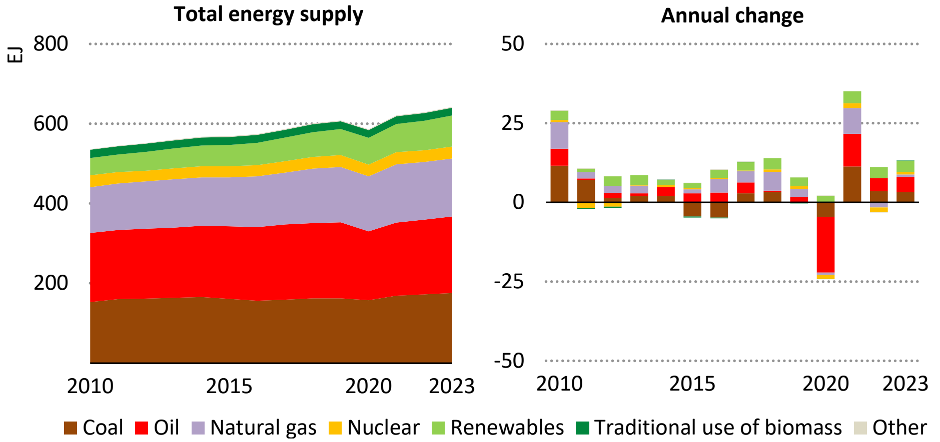
2.1.1 Recent trends in energy demand and CO₂ emissions

Following an increase of 8 exajoules (EJ) in 2022, global energy demand increased by around 13 EJ in 2023, pushing up global demand by 2%. This reflects a growing requirement for energy in emerging market and developing economies which more than cancelled out a fall in energy demand in advanced economies of around 2%. There was a large increase in both oil and coal use globally, and two-thirds of the total increase in energy demand in 2023 was met by fossil fuels (Figure 2.1).

Figure 2.1 ▹ Global total energy supply, 2010-2023



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Fossil fuels met two-thirds of the increase in global energy demand in 2023, mostly with more coal and oil, while the increase in clean energy in 2023 was twice as large as in 2022

Note: EJ = exajoule.

Global oil demand increased by 2 million barrels per day (mb/d) in 2023 to 99 mb/d. This increase was nearly double the average annual increase between 2010 and 2019 and was led by increases in oil use as a petrochemical feedstock in China – where total oil demand increased by 1.5 mb/d – and by continued global growth in oil demand in the transport sector. Demand in advanced economies fell by around 0.3 mb/d. Oil demand trends in 2024 show a sharp slowdown in demand growth, notably in China, which is expected to result in an overall rise for the year of less than 1 mb/d.

Global coal demand increased by just over 100 million tonnes of coal equivalent (Mtce) in 2023 to around 6 000 Mtce, mainly because of increased use in the power sector in China and India.[1] Demand in advanced economies fell by more than 120 Mtce, about 10%, with

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[1] Historical coal data has been revised in this edition of *World Energy Outlook* as new information became available. For example, global coal demand in 2022 was revised upwards by 70 Mtce (1.3%), mainly because of increases in China and in the power sectors of Indonesia and India.

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coal use in the United States and European Union power sectors dropping by 20-25%. Demand in 2024 is expected to be slightly higher than in 2023 as strong electricity demand in China and India result in higher coal demand that more than offsets continued cuts in coal use in the European Union.

Natural gas demand worldwide rose by 20 billion cubic metres (bcm) in 2023 to 4 190 bcm. There were large increases in demand in the power sector in North America and in the buildings and industry sectors in the Middle East. These were partially offset by a 40 bcm decline in Europe, which reduced its natural gas demand by around 7% in 2023. This follows a reduction of 13% in 2022 and means that gas demand in Europe is now at its lowest level since the early 1990s. Preliminary data suggest that global natural gas demand increased by 50 bcm in the first-half of 2024, mainly as a result of increases in natural gas use in the industry and power sectors in Asia.

Total energy supply from low-emissions sources of energy reached a record high in 2023, led by increases in China and Europe. In the electricity sector, more than 560 gigawatts (GW) of new renewable power capacity were added in 2023, accounting for around 80% of total new power sector capacity additions worldwide. China alone added more than 350 GW of new renewables capacity, and its renewable generation increased by 235 terawatt-hours (TWh), which is similar to the total amount of renewable electricity generated in Japan in 2023. Liquid biofuels supply increased by 7% in 2023 to 2.3 million barrels of oil equivalent per day (mboe/d), mainly because of new renewable diesel refining capacity in the United States and new bioethanol capacity in Brazil. The supply of biomethane, an upgraded form of biogas, rose by 10% in 2023 to around 10 bcm reflecting enhanced policy support in Europe and the United States. Nuclear generation rose by 3%, in large part due to the restart of some existing reactors in Japan.

The energy intensity of the global economy improved by around 1% in 2023, following a 2% decline in 2022, meaning that the efficiency with which the global economy uses energy is continuing to make progress. In the European Union, energy intensity improved by 5% in 2023 as measures put in place to tackle the energy crisis continued to drive down energy use and as energy-intensive industrial output declined. Globally, the share of total car sales accounted for by plug-in hybrid and battery electric models rose from 14% in 2022 to 18% in 2023 and is set to rise above 20% in 2024. Around 60% of all electric car sales in 2023 were in China. The number of heat pumps installed around the world fell slightly in 2023 as concerns around high natural gas prices eased and consumers continued to face harsh economic conditions.

The energy sector is responsible for around 85% of total global CO_2 emissions; energy-related CO_2 emissions rose by 1.3% in 2023 to a record high of 37.7 gigatonnes (Gt) (Figure 2.2). Emissions from coal drove most of the increase. Energy-related CO_2 emissions were about 1 Gt higher in 2023 than in 2019. The world has clearly not yet turned the corner on emissions. Nevertheless, the clean energy economy is having an effect: the increase in emissions since 2019 would have been three-times as large without the expanding deployment of clean energy technologies (IEA, 2024a).

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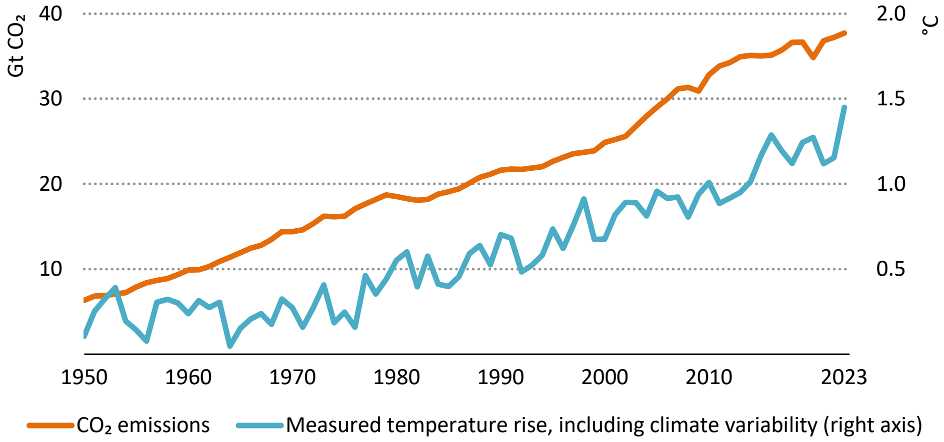
Figure 2.2 ▷ **Energy-related CO_2 emissions and global average temperature rise above pre-industrial levels, 1950-2023**



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Energy-related CO_2 emissions rose by 1.3% to an all-time high in 2023, which was the hottest year since temperature records began

Notes: Gt CO_2 = gigatonne of carbon dioxide. Temperature rise above pre-industrial levels is the combined land and marine near surface annual temperature anomaly compared with the 1850-1900 level based on the average of HadCRUT5, Berkeley Earth and National Oceanic and Atmospheric Administration data.

Sources: University of East Anglia and Met Office (n.d.); Berkeley Earth (2024a); NOAA (2024).

The hottest year in recorded history was 2023. Temperatures by mid-2024 suggest that this record is highly likely to be broken again. The 12-month period to May 2024 saw 76 extreme heat events worldwide, with damaging consequences for infrastructure, healthcare services, vulnerable populations and the natural environment (Climate Central, Red Cross Red Crescent, and Climate Centre World Weather Attribution, 2024; Berkeley Earth, 2024b; WMO, 2024a).

Although it is not yet possible to be certain, the 12-month period from July 2023 to June 2024 may have seen global average surface temperatures of 1.5 °C higher than pre-industrial levels (C3S, 2024), and the World Meteorological Organization (WMO) declared an approximately 50% chance that the temperature rise will exceed 1.5 °C on average over the 2024-2028 period (WMO, 2024b). The Intergovernmental Panel on Climate Change (IPCC) warns that the severity of the impacts of global warming are expected to escalate dramatically if the temperature rise does go above 1.5 °C. However, the 1.5 °C threshold, as set out in the Paris Agreement, applies to long-term warming, rather than single year or short-term periods, which are strongly affected by natural weather variability. The IPCC often uses an averaging period of 20 years to remove the impact of natural variability when considering whether a given warming level has been crossed. Even if the temperature rise exceeds 1.5 °C for a short period, the temperature rise can be brought back below 1.5 °C with concerted long-term action (IPCC, 2023).

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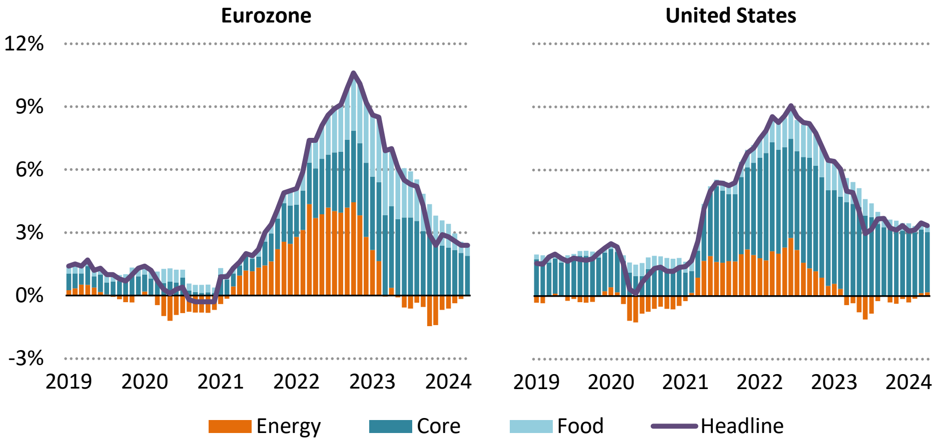
2.1.2 Macroeconomic context

Following a prolonged period of exceptionally low interest rates and inflation in the 2010s, the macroeconomic context was significantly changed in the space of a few years by the Covid-19 pandemic and the global energy crisis triggered by Russia's invasion of Ukraine. To combat the rising inflation that emerged as the landscape changed, central banks progressively tightened their monetary policy, which led to the steepest interest rate increases seen in decades. Advanced economies raised rates by an average of 290 basis points (2.9%) in 2023 over the average level in 2022 and emerging market and developing economies by 150 basis points (1.5%). Inflation has eased in most regions so far in 2024 and there have been interest rates cuts in a number of countries, particularly in advanced economies. However, inflation and interest rates currently are still much higher than they have been over the past 15 years in most economies. Inflation remains a particular problem in a number of emerging market and developing economies, including Brazil, India and South Africa, and interest rate cuts there are likely to be slower.

The energy crisis clearly showed the role that energy prices can play in inflation, with price spikes contributing approximately one-third of the increase in headline inflation between 2021-2023 (Figure 2.3). The driver was not clean energy; it was spikes in the prices of oil, natural gas and coal after the Russian invasion of Ukraine and cuts in Russian gas supply to Europe (IEA, 2022).

Figure 2.3 ▷ Inflation drivers in the Eurozone and United States, 2019-2024



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A sharp rise in inflation followed the onset of the global energy crisis in many advanced economies, driven in large part by higher energy costs

Notes: Core inflation is the change in the costs of goods and services excluding food and energy. The Eurozone includes the 20 countries that have adopted the euro as the single currency.

Sources: IEA analysis based on Eurostat (2024) and FRED (2024).

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Increases in energy prices, whether from temporary spikes or more structural changes, have a major impact on household bills. In both advanced and emerging market and developing economies, the median household spends around 10% of their disposable income on residential energy and transport fuels. Direct consumption of oil, electricity and gas in emerging market and developing economies is only one-third of the level in advanced economies, but disposable income is also much lower. Oil currently accounts for around half of total consumer energy expenditure worldwide, meaning that oil price volatility has a particularly significant impact on consumer energy expenditure.[2]

There are several near-term downside risks for global economic growth. In 2024 and 2025 growth is expected to be lower than the 2010-2019 average in countries comprising more than 80% of global output and population (World Bank, 2024). High debt levels and interest rates in many economies are likely to squeeze government spending, potentially delaying or decreasing investment in energy infrastructure. They are also likely to reduce household spending, which could lead to a slowdown of the economy and higher unemployment. Further macroeconomic risks include trade fragmentation as well as geopolitical and policy uncertainty (section 2.1.3).

The economic slowdown is pronounced in emerging market and developing economies: nearly 60% of the growth forecasts for these economies made by the International Monetary Fund (IMF) in April 2024 are lower than the forecasts made in April 2023 (IMF, 2024 and IMF, 2023) and their aggregate rate of economic growth is expected to slow from 4.2% in 2023 to 4% in 2024 (World Bank, 2024). Per capita income growth is set to average just 3% through to 2026, below the 2010-2019 average of 3.3%, and many emerging market and developing economies are now unlikely to see any relative economic catch-up with advanced economies in the near term. This slowdown puts recent progress on poverty reduction at risk of stalling or reversing.

These imbalances are also reflected in flows of capital to clean energy projects (Figure 2.4). Global clean energy investment has increased rapidly over the last five years, but nearly all of the increase has been in advanced economies and China, with China accounting for an especially large share of spending relative to its gross domestic product (GDP). Increasing capital flows to clean energy projects in other emerging market and developing economies will be essential to meet their rapidly rising demand for energy services in a sustainable way and to support economic growth. However, involvement of private capital in many of these countries is still limited and faces a variety of headwinds. The higher interest rate environment has pushed up financing costs, and expected levels of returns on investment are impacted by higher real and perceived risks of new clean energy projects in these markets.

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[2] Further discussion on the impact of energy costs across different income levels is in the *WEO Special Report: Strategies for Affordable and Fair Clean Energy Transitions* (IEA, 2024b).

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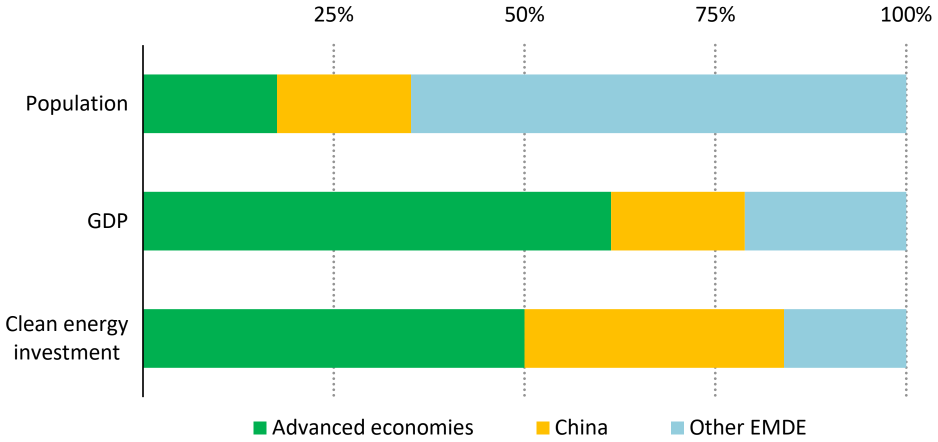
Figure 2.4 ▷ **Global population, GDP and clean energy investment, 2023**



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Emerging market and developing economies outside China account for 65% of the global population but only for 15% of clean energy investment

Note: Other EMDE = emerging market and developing economies except China.

2.1.3 Political and geopolitical uncertainties

A major reason for the uncertain political context is the large number of elections that have been or are being held in 2024 around the world, which affect the population in over 80 countries that account for half of global energy demand (Figure 2.5). The global energy crisis put energy and other pressures on the cost of living at the heart of many voter concerns. The prominence of energy-related issues in many campaigns suggests that elections could bring some changes in emphasis and direction for energy policies. In some cases, these could reinforce the momentum behind clean energy transitions; in others, they could lead to a slower pace of change. In the meantime, uncertainty may deter energy investment, particularly in large-scale projects in new or emerging technologies that are particularly sensitive to policy and regulatory changes (section 2.2.1).

Energy markets also remain vulnerable to geopolitical events. The initial price shocks from the global energy crisis and the Russian invasion of Ukraine abated during the first-quarter of 2024 as natural gas prices dropped to slightly above pre-crisis levels, though prices remain above their 2023 levels across the main Asian and European markets due to a combination of robust demand and short-term constraints on liquefied natural gas (LNG) supply. Further shocks arising from the continuing war in Ukraine cannot be ruled out.

There are other geopolitical tensions that could trigger disruption and price shocks in energy markets. There are particularly high risks in the Middle East with the spectre of spiralling regional hostilities, as well as attacks on shipping in the Red Sea. Since 2021, Europe, Japan and Korea have taken an increased share of their oil imports from the Middle East in the

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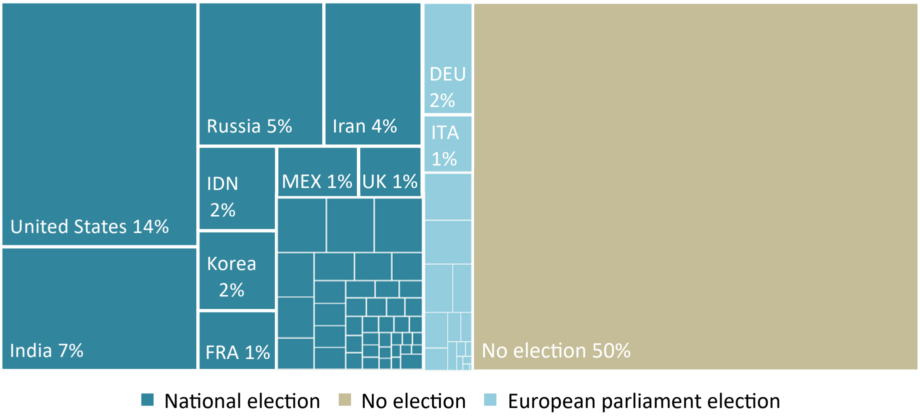
wake of sanctions imposed on Russia, and China has seen a similar trend (Figure 2.6). Imports of Russian oil to India increased from 2% of total oil imports in 2021 to 35% in 2023. For the moment, these geopolitical risks have not been reflected in prices, but a broader regional conflict could have major implications for oil and natural gas markets. More than 20 mb/d of oil passes through the Strait of Hormuz, 75% of which goes to Asia, and a further 7.5 mb/d of oil passes through the Suez Canal. Annual flows of LNG through the Strait of Hormuz are more than 100 bcm, nearly 80% of which is delivered to Asian markets.

Figure 2.5 ▹ Share of world energy demand voting in national or regional elections, 2024



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National and regional elections are taking place in 2024 in over 80 countries that account for half of global energy demand

Notes: IDN = Indonesia; FRA = France; MEX = Mexico; UK = United Kingdom; DEU = Germany; ITA = Italy. European Union election includes only EU member countries that do not have national elections in 2024 (otherwise in dark blue). The smallest boxes group multiple countries.

Clean energy supply chains are also subject to geopolitical tensions. At present, China produces more than 80% of the world's battery cells and solar photovoltaic (PV) modules, and 65% of wind nacelles (Figure 2.7). It dominates the midstream refining and processing of critical minerals, accounting for 65% of global processing for lithium and over 75% for cobalt and nearly all the graphite anode supply chain. China currently produces two-thirds of the world's electric vehicles (EVs). Investment in these areas has picked up in the United States, European Union, India and elsewhere, and China's share in global EV sales slipped from 70% in 2022 to 65% in 2023, but it is still very large. Consumers around the world have benefited from the reductions in technology costs that large-scale supply chain investment has brought. Nonetheless, such a high degree of concentration presents risks. If disruptions were to occur, the nature and severity of its effects might well depend on whether it resulted from geopolitical issues, extreme weather or industrial accidents.

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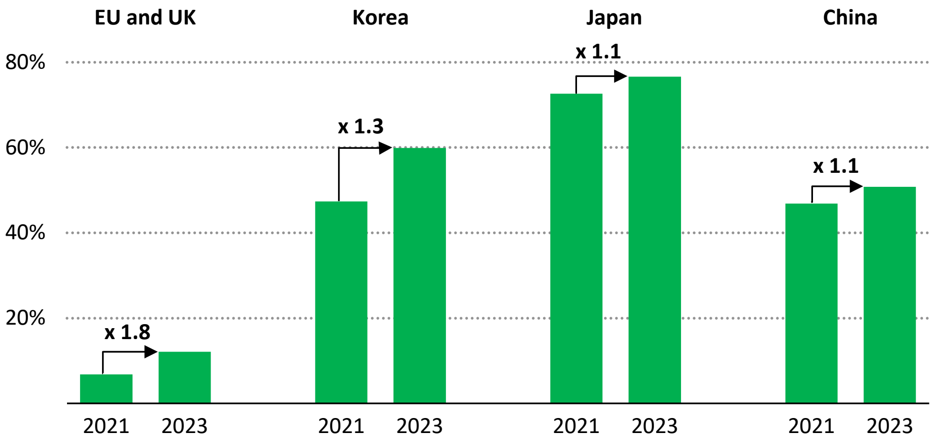
Figure 2.6 ⊳ Oil import share from the Middle East in selected markets



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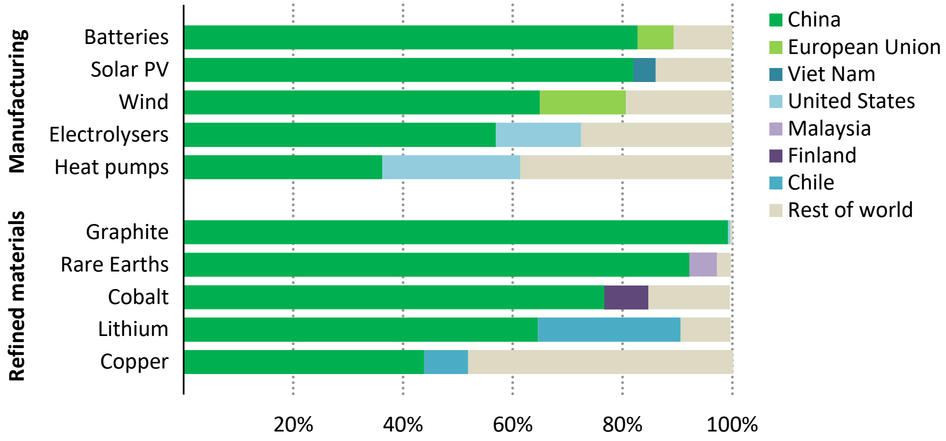
Reorientation of oil trade away from Russia in some major economies has pushed up reliance on imports from the Middle East

Notes: Includes seaborn trade only. EU and UK = European Union and the United Kingdom.

Source: Kpler (2024).

Figure 2.7 ⊳ Share of clean energy technology supply chains, 2023



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By far, China controls the largest share of manufacturing and critical material refining capacity for many clean energy technology supply chains

Sources: IEA (2024c) and (2024d).

Many countries are seeking to promote more diverse patterns of investment and manufacturing in clean energy supply, including for critical minerals. This has resulted in a marked increase in the number of trade policies and other measures focussed on clean energy technologies since 2020.[3] Tariff adjustments, antidumping duties and countervailing measures are at the centre of the most recent trade policies. For example, several regions, such as the United States and European Union, have announced additional duties on solar PV, EVs and batteries from China. There have also been revisions to import tariffs on some clean energy technologies and components in Brazil, Canada, China, Egypt, India, Mexico, Türkiye and United States. While these could lead to more diversified supplies, a balance is required that also recognises the value of clean energy equipment and mineral trade to clean energy transitions.

2.2 *WEO* scenarios

The *World Energy Outlook (WEO)* analyses provide a framework for understanding the future of energy by examining different potential scenarios for its development. Each scenario has the same starting point and incorporates the latest data for energy supply and demand, markets, technology costs and policies, and also similar levels of future population and economic growth. None of these scenarios is a forecast.

The energy system described in each scenario evolves in a distinctive pathway that delivers energy services with a different mix of technologies and fuels, and with varying implications for energy security, affordability and emissions. This is mainly due to variations in the assumptions made about how government policies develop, and how these variations affect the investment and technology choices made by households and firms.

- **Stated Policies Scenario** (STEPS): This scenario provides a sense of the prevailing direction of travel for the energy sector based on a detailed reading of the latest policy settings in countries around the world. It accounts for energy, climate and related industrial policies that are in place or that have been announced. The aims of these policies are not automatically assumed to be met; they are incorporated in the scenario only to the extent that they are underpinned by adequate provisions for their implementation. Each year many countries add new policies and some abandon existing ones. Each annual iteration of the STEPS takes account of these changes. This version is no exception. The STEPS is associated with a temperature rise of 2.4 °C in 2100 (with a 50% probability).
- **Announced Pledges Scenario** (APS): This scenario starts from the same detailed reading of government policies but takes a different view on their implementation. The key difference is that this scenario assumes that all national energy and climate targets, including longer term net zero emissions targets and pledges in Nationally Determined

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[3] *Energy Technology Perspectives 2024*, a forthcoming IEA publication, includes a detailed discussion on the production and trade of clean energy technologies, along with their main components and material inputs.

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Contributions, are met in full and on time. This is a strong assumption, given that most governments are still far from having policies in place to deliver their long-term pledges. Even those countries without long-term energy or emissions goals follow a different path than in the STEPS because their investment choices are shaped by and benefit from steeper cost reductions for a range of clean energy technologies made possible by the actions of other countries. The APS is associated with a temperature rise of 1.7 °C in 2100 (with a 50% probability).

- **Net Zero Emissions by 2050** (NZE) **Scenario:** This scenario portrays a pathway for the global energy sector to achieve net zero CO_2 emissions by 2050 which is consistent with limiting long-term global warming to 1.5 °C with limited overshoot (with a 50% probability). The NZE Scenario also meets the key energy-related UN Sustainable Development Goals, in particular by achieving universal access to modern energy services by 2030 and securing major improvements in air quality. Even though the global rise in temperature is already approaching or even exceeding the 1.5 °C limit in individual years, this does not mean that the target itself is out of reach. But every year in which global emissions rise and actions fall short of what is needed for the future makes this pathway steeper and harder to climb.

The NZE Scenario is a normative scenario in that it works backwards from a defined outcome. The Stated Policies and Announced Pledges scenarios are exploratory, in that they do not target a specific outcome but rather establish different sets of starting conditions and consider where they may lead.

The main scenarios in this *Outlook* are accompanied by a number of *sensitivity cases*. These are built around the STEPS and look at some of the most pertinent and topical dynamics affecting the energy sector and how these impact future energy demand and emissions levels (see Chapter 4). The sensitivity cases explored include: the pace at which consumers choose to purchase electric cars; future deployment of renewables in the power sector; uncertainties related to natural gas demand in the light of the new LNG supply that is set to come online; uncertainties about future electricity demand, particularly related to how much electricity data centres will use; and how far the efficiency of end-use appliances will improve.

2.2.1 Policies

A crucial part of each annual edition of the *World Energy Outlook* is an in-depth country-by-country review of government policies, regulatory measures, targets and announcements that could affect the way that the energy sector evolves. The modelling and analysis incorporate measures relating to fuel and power supply, end-use sectors, i.e. transport, buildings and industry, short- and long-term climate pledges, sustainable development objectives and energy access goals, and industrial and trade policies related to the energy sector. The policies that are considered in the STEPS and the APS are highlighted in Annex B.

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Energy and climate policies

There have been many new energy and climate initiatives since the *WEO-2023*, including policy announcements, investment plans and regulations. Some examples of the sorts of policies that were considered when developing the STEPS for 2024 include:

- Argentina passed major free-market reforms designed to stimulate investment in new oil and gas infrastructure.
- Australia adopted its first New Vehicle Efficiency Standard, which will apply to new cars sold from 2025.
- Australia, Indonesia, Japan and Korea all passed legislation designed to advance the development of new projects for carbon capture, utilisation and storage.
- Canada adopted a new Green Buildings Strategy to accelerate retrofits by providing financial support of close to CAD 1 billion in its 2024 budget.
- China's Ministry of Ecology and Environment issued a new Air Quality Improvement Policy targeting a reduction in the density of particulate emissions and in the number of severe pollution incidents.
- The European Union adopted its first-ever regulation on reducing methane emissions. The EU Carbon Border Adjustment Mechanism started its first transitional phase of operation, introducing a reporting requirement for importers of cement, iron and steel, aluminium, fertilisers, electricity and hydrogen.
- Indonesia's Comprehensive Investment and Policy Plan was finalised as part of the Just Energy Transition Partnership.
- Korea confirmed its 11th Basic Electricity Supply and Demand Plan, a 15-year blueprint for electricity supply and demand that includes a significant expansion of nuclear, wind and solar power.
- South Africa released a draft Gas Master Plan for public comment.
- A new government in the United Kingdom lifted the de facto ban on new onshore wind development.
- The United States Environmental Protection Agency released new regulations on greenhouse gas standards and guidelines for fossil fuel-fired power plants, along with multi-pollutant emissions standards for cars and trucks.
- New sanctions on Russian LNG developments and trade were announced by the United States and the European Union.
- The United States Federal Energy Regulatory Commission adopted Order no. 1920, that requires transmission providers to conduct long-term planning for regional transmission facilities and to determine how to pay for them.
- Viet Nam adopted an implementation plan for its National Power Development Master Plan for the 2021 to 2030 period, and also approved a new mechanism to allow renewable project developers to sell electricity directly to large consumers.

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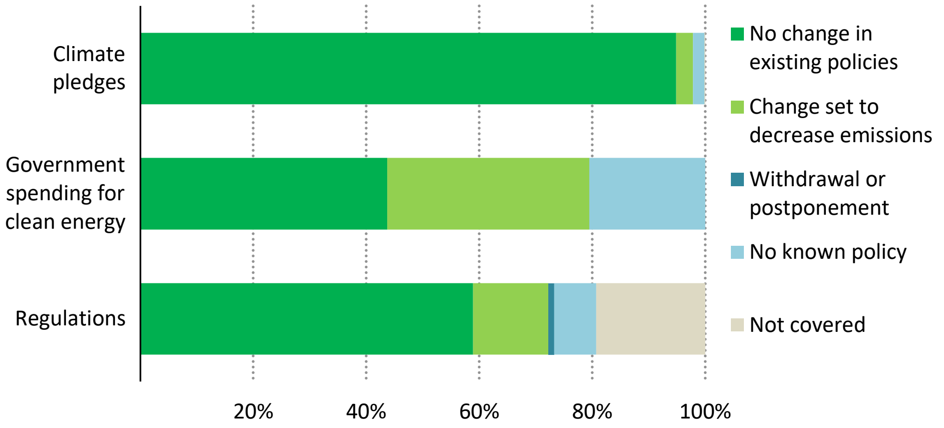
Since the *WEO-2023*, 38 countries, responsible for one-third of energy-related CO_2 emissions, have implemented new government spending measures for clean energy technologies. Around 35 countries, responsible for 20% of global emissions, have adopted new or updated energy-related regulations (Figure 2.8). There have also been some rollbacks and postponements of previous policies, although the impact of these remains relatively small.

Figure 2.8 ▷ Global energy-related CO_2 emissions covered by policy changes, 2022 and 2023



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Many countries announced new government spending on clean energy in 2023 and adopted new regulations for clean energy technologies

Notes: Climate pledges represent changes in Nationally Determined Contribution mitigation targets. Government spending shows countries that enacted increased earmarked government spending on clean energy technologies in 2022 and 2023. Regulations include: minimum energy performance standards; fuel efficiency standards; building codes; biofuel blending standards; power sector emissions standards; carbon pricing instruments; fluorinated gas regulations; coal phase out plans; and restrictions on sales of fossil fuel boilers or internal combustion engine cars.

The first global stocktake at COP28 in Dubai in 2023 agreed on a notable set of new policy-relevant considerations for the energy sector. It includes – for the first time – a call to "accelerate global efforts towards net zero emissions energy systems utilising zero- and low-carbon fuels well before or by around mid-century" and a call to "transition away from fossil fuels in a just, orderly and equitable manner". The COP28 outcome also set out some of the actions in the energy sector needed to achieve these goals, many of which were based on the NZE Scenario. They include: aims to triple global renewable energy capacity by 2030; double the rate energy efficiency improvement by 2030; accelerate efforts to phase down unabated coal-fired power; substantially reduce methane emissions; and to phase out as soon as possible inefficient fossil fuel subsidies that do not address energy poverty or just

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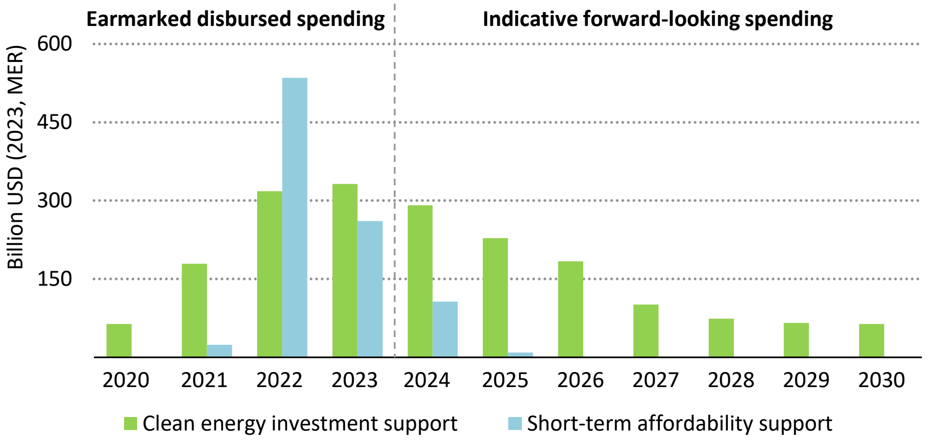
transitions. The objectives agreed at COP28 are not incorporated into the design of the STEPS or the APS.[4]

Support for energy investment and consumer energy affordability

The IEA tracks government support for energy investment, looking at licensing regimes, major project approvals and large infrastructure developments as well as direct support and tax credit provisions. Specific government support for clean energy investment was incorporated in a number of government recovery plans made in response to the Covid-19 pandemic and the global energy crisis. Announcements of government support for clean energy investment since 2020 cumulatively reached USD 2 trillion in the first-half of 2024 (Figure 2.9). More than 40% of these announcements were made in 2022, and many stemmed from the US Inflation Reduction Act and other responses to the energy crisis in that year.

Figure 2.9 ▷ Government support announced for clean energy and energy affordability by budget allocation year, 2020 to first-half 2024



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Government spending on affordability measures was very high during the global energy crisis while support for clean energy investment rose only marginally

Notes: MER = market exchange rate. Figure shows disbursed and planned direct incentives over their budget timelines based on announcements made between 2020 and the first-half of 2024. Clean energy investment support represents announced measures that support investment in energy infrastructure, renewables, electrification, efficiency and supply chains in the energy sector. Short-term affordability support represents announced measures that aimed to help shield consumers and industries from high energy prices during the global energy crisis.

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[4] The *WEO Special Report: From Taking Stock to Taking Action: How to implement the COP28 energy goals*, examines what full implementation of the COP28 goals would mean for energy and emissions, and assesses the risks and pitfalls of partial implementation (IEA, 2024e).

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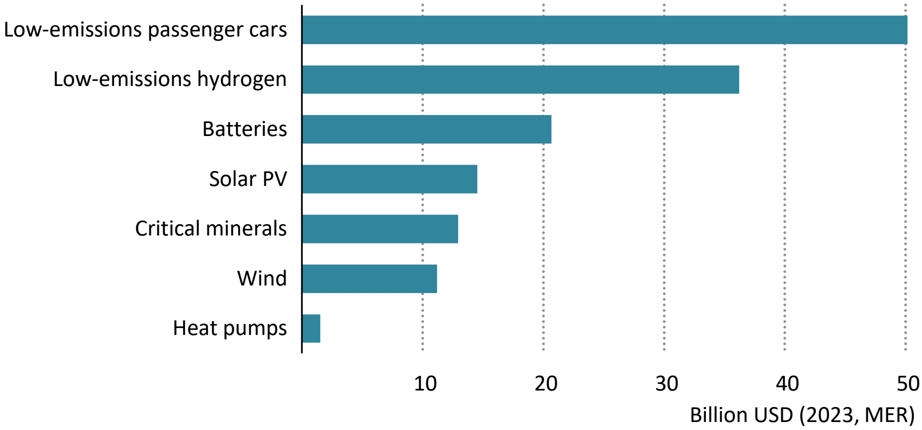
Governments also spent heavily on short-term consumer energy affordability during the global energy crisis – cumulatively around USD 940 billion – with the aim of helping to shield consumers and industries from very high energy prices. These measures have now mostly been rolled back.

Industrial policies

Recent years have seen countries place more focus on bolstering domestic manufacturing, with a particular interest in clean technology sectors (Table 2.1). For example, both the US Inflation Reduction Act and the EU Net Zero Industry Act marked a reorientation of industrial policies towards incentives for domestic manufacturing. Around 10% of the USD 2 trillion explicitly earmarked globally for direct clean energy investment support since 2020 comes with conditions that require local content in one way or another, for example by specifying minimum levels of local labour, domestically sourced materials and components, or by requiring the building of specialised factories in the country concerned (Figure 2.10). New project announcements for manufacturing capacity are taken into account when considering technology choices in all the *WEO* scenarios.

Figure 2.10 ⊳ Global direct government incentives for domestic manufacturing as part of clean energy support, 2020-2024



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A number of clean energy technologies have seen a large share of government incentives directed to promote domestic manufacturing activities

Notes: Figure represents approved fiscal spending allocated through federal programmes for producers and does not reflect indirect support for manufacturers administered through other channels, such as preferential terms via state-owned enterprises.

Governments employ measures other than direct production incentives to support domestic manufacturers, and not all appear directly on their fiscal balance sheets. Such support includes capital injections from state-owned entities, below-market rate lending and energy

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prices, preferential terms to access infrastructure and services, and allowances such as for land. Firms in countries with a large number of major state-owned enterprises sometimes receive disproportionately more support overall than firms based in other jurisdictions. For example, grants and below-market borrowing account for an estimated 3% of the revenues of firms based in China, compared with less than 0.1% in advanced economies (OECD, 2024).

Table 2.1 ⊳ Domestic direct manufacturing incentive schemes in selected governments enacted since 2020

	Direct incentive schemes	Budget (Billion USD)	Technologies covered
United States	• Inflation Reduction Act. • Infrastructure Investment and Jobs Act. • Presidential Determination Pursuant to Section 303 of the Defense Production Act.	51	Solar PV, wind, batteries, critical minerals, low-emissions vehicles, heat pumps, hydrogen.
Canada	• Clean Economy Investment Tax Credits, Net Zero Accelerator Initiative. • Strategic Innovation Fund. • Canada Growth Fund.	34	Hydrogen, batteries, low-emissions vehicles, renewable energy, critical minerals, CCUS, clean electricity, clean technology, clean technology manufacturing.
China	• New Energy Vehicle Promotion and Application Subsidy Funds.*	26	Batteries, low-emissions vehicles.
European Union	• European Green Deal. • New Batteries Regulation. • Strategic Technologies for Europe Platform. • Net Zero Industry Act.**	24	Solar PV, wind, batteries, hydrogen, low-emissions vehicles.
Australia	• Future Made in Australia Plan. • Hydrogen Headstart. • Powering Australia.	13	Batteries, critical minerals, low-emissions hydrogen, renewable energy.
India	• Production-linked Incentive Scheme. • National Hydrogen Mission. • Scheme for Viability Gap Funding.	12	Solar PV, low-emissions vehicles, batteries, hydrogen.
Japan	• Economic Security Promotion Act, including capital investment subsidies for battery production. • GX Green Transformation Policy.	3	Batteries, biofuels, wind, solar PV.
Korea	• Semiconductor Industry Comprehensive Support Plan. • Battery Industry Innovation Strategy.	1	Batteries, low-emissions vehicles.

*Disbursed through manufacturers. **Enacted in June 2024, but direct government support for domestic manufacturing is not specified.

Notes: CCUS = carbon capture, utilisation and storage. Listed measures only cover direct government support and do not cover capital injections from state-owned entities, below-market rate lending and energy prices, preferential terms to access infrastructure and services, or other allowances.

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Policy uncertainty

The STEPS is not a normative scenario: it does not assume an inevitable shift over time towards stronger action on emissions reductions. It simply maps out the implications of the prevailing policy settings, whatever they might be. Policy settings can and do change from year to year, and any such policy changes are incorporated into successive editions of the STEPS.

Some changes roll back commitments to emissions reductions or clean energy deployment. This applies both to sustainability targets and the enabling measures that are designed to reach them. In some cases, these changes happen because ambitions were set at a level that now appears to be unrealistic. In 2019, for example, the administration in Scotland committed itself to a 75% reduction in greenhouse gas (GHG) emissions by 2030 from their 1990 level. This target is now set to be dropped. At corporate level, there are many examples of firms adjusting their near-term targets, usually making them less stringent, in response to unfavourable market conditions, doubts surrounding government policy, or a realisation that achieving targets would be more difficult than initially assumed. In other cases, decision makers have argued that too much emphasis was being placed on energy transition measures at the expense of other goals, including those related to energy security and affordability, and changes in response to this sometimes mean longer timelines for introducing new technologies, or reduced incentives and policy support for their deployment.

The effects of such changes will vary by country and technology: supportive policies are important, but they are not the only driver of change (Spotlight). In a year of elections around the world, there is even more uncertainty than usual over the future evolution of energy and climate policies. In all cases, we will continue to track policies and their implementation very closely in the *WEO* and provide a neutral and dispassionate assessment of what they mean for the future of energy, as well as their implications for energy security, affordability and emissions.

SPOTLIGHT

How much do public policies matter for energy transitions?

Clean energy deployment has picked up strongly in recent years. Our latest estimate of energy investment flows suggests that clean energy projects are likely to attract almost twice as much capital in 2024 as fossil fuel projects. How much are these deployment and investment trends dependent on supportive energy policies?

Public policies typically play a key role in enabling and de-risking the early adoption of new technologies, including clean energy technologies. This was the case for solar PV, wind and EVs. Policies can also help markets price negative externalities, improve working conditions, promote standardisation, facilitate research and development, and knowledge access.

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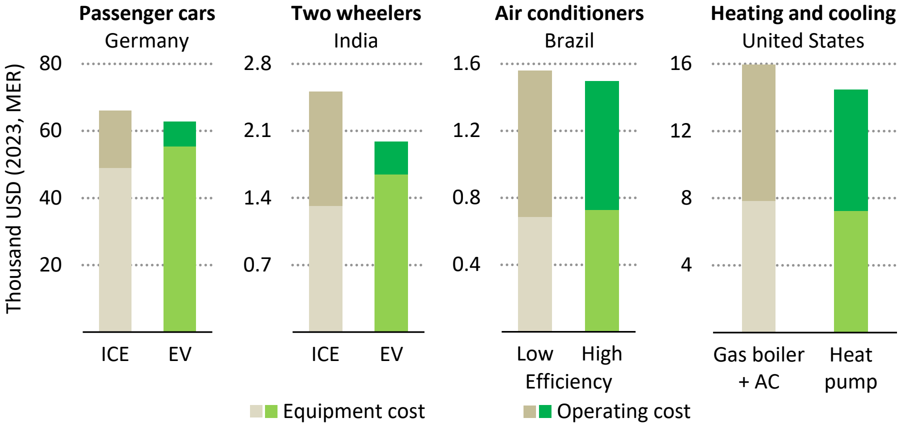
Many emerging clean energy technologies still require policy support to compete with traditional technologies, but some are now mature, and their deployment is increasingly driven by economic fundamentals. For example, it is now cheaper to build onshore wind and solar power projects than new fossil fuel plants almost everywhere around the world, and the economic arguments remain strong even when considering the accompanying investment required to cope with their variability of generation (IEA, 2023a).

The same is true for a number of end-use energy technologies, especially when comparing the total cost of ownership over the lifetimes with competing traditional technologies.[5] In many countries, electric cars and two/three-wheelers cost less over their lifetime than equivalent vehicles with internal combustion engines because lower re-fuelling and maintenance costs outweigh higher initial upfront costs (Figure 2.11). Efficient appliances, such as high efficiency air conditioning units, generally pay back any upfront premium through lower operating costs. Heat pumps can be more expensive than gas-fired boilers for heating alone, though this depends on the relative price of electricity and gas, but they are typically competitive when considering both cooling and heating (IEA, 2024b).

Figure 2.11 ⊳ Lifetime capital and operating costs of consumer equipment purchased in selected countries, 2023



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Lower operating costs mean clean energy equipment can have a lower total cost of ownership than traditional technologies despite higher upfront costs

Note: ICE = internal combustion engine; EV = electric vehicle.

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[5] The total cost of ownership is the cost of owning and operating a vehicle over its whole lifetime, combining the upfront purchase cost, financing costs and ongoing costs such as fuelling, charging and maintenance.

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Renewables deployment is driven in many cases by energy security considerations. This is especially the case where consumers have been exposed to supply shortfalls and high prices for fossil fuels during the global energy crisis. It is also driven by long-term strategic considerations, with countries and companies in some cases vying for position in clean energy sectors that are likely to be major sources of employment and revenue growth in future years.

Policies will continue to play a pivotal role in shaping the way that energy transitions unfold. Without government support, many new and emerging technologies are likely to struggle to gain momentum, and many lower income countries, communities and households will find it difficult to afford the upfront costs of clean energy technologies, causing them to miss out on the life cycle benefits. Transparent and robust policies and regulations are also crucial to provide the confidence that private sector actors need to finance and invest in clean energy transitions. Even though they are not the only drivers of change, policy changes will therefore affect the pace of energy transitions to a greater or lesser degree – accelerating them in some cases, slowing them in others.

2.2.2 GDP and population

The global economy is assumed to grow on average by 2.7% each year to 2050 in all three scenarios (Table 2.2). This growth rate varies by country, region and over time, influenced by factors such as investment dynamics, employment rates and shifts in trade. We recognise that the speed, structure, and selection of policy and regulatory mechanisms driving changes in the energy system will have broader economic effects, both positive and negative, across various countries and regions. However, we maintain a constant economic growth rate across scenarios to facilitate a comparison of the impacts of different energy and climate choices with a consistent backdrop.

The global population is assumed to expand from 8 billion people in 2023 to 9.7 billion in 2050, based on the median population projection of the United Nations. This represents an annual average growth rate of around 0.7%, which is around half the average annual growth rate seen between 1990 and 2023. Fertility rates have fallen in many parts of the world, and projections of the world's population in 2100 are now 700 million lower than they were ten years ago (Box 2.1). Population increases to 2050 in countries in sub-Saharan Africa account for more than half of the overall increase at the world level, and increases in India, Pakistan and Bangladesh for a further 20%. Urban populations bulge in all regions, while rural populations decline in all regions other than Africa (Figure 2.12).[6]

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[6] The physical impacts of climate change are not incorporated into our projections of population and GDP, but these could lead to large changes in global and regional economic growth and in migration patterns, with important implications for energy demand.

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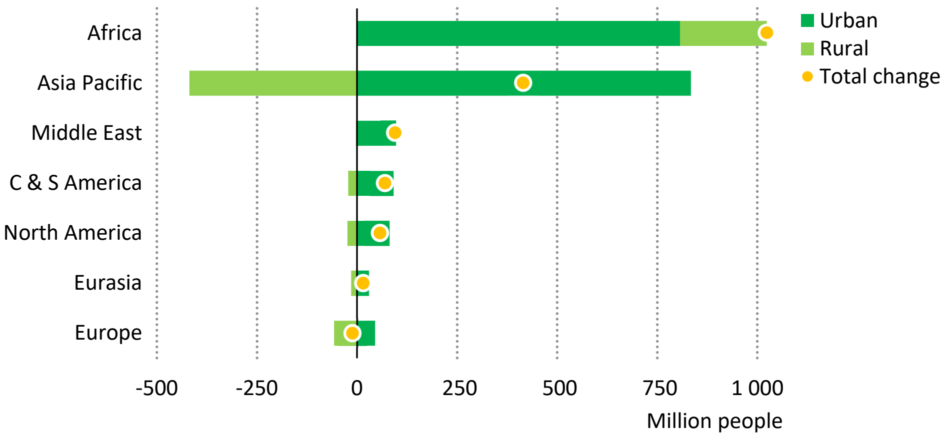
Table 2.2 ⊳ GDP average growth assumptions by region

	Compound average annual growth rate			
	2011-23	2023-35	2035-50	2023-50
North America	2.2%	2.1%	1.9%	2.0%
United States	2.3%	2.1%	1.9%	1.9%
Central and South America	1.0%	2.5%	2.3%	2.4%
Brazil	0.8%	2.1%	2.3%	2.2%
Europe	1.7%	1.8%	1.4%	1.5%
European Union	1.4%	1.5%	1.1%	1.2%
Africa	3.0%	4.0%	4.0%	4.0%
South Africa	1.0%	1.3%	2.7%	2.3%
Middle East	2.1%	3.3%	3.1%	3.2%
Eurasia	1.9%	1.7%	1.4%	1.5%
Russia	1.4%	1.0%	0.6%	0.7%
Asia Pacific	4.7%	4.1%	3.0%	3.3%
China	6.2%	3.7%	2.4%	2.7%
India	5.9%	6.5%	4.3%	4.8%
Japan	0.8%	0.7%	0.7%	0.7%
Southeast Asia	4.2%	4.7%	3.4%	3.7%
World	**3.0%**	**3.1%**	**2.5%**	**2.7%**

Note: Calculated based on GDP expressed in year-2023 US dollar at purchasing power parity terms.

Figure 2.12 ⊳ Projected change of population in urban and rural areas by region, 2023 to 2050



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98% of the projected increase in global population to 2050 is in emerging market and developing economies, and urban populations increase in all regions

Note: C & S America = Central and South America.

Sources: IEA analysis based on UN DESA (2022, 2018).

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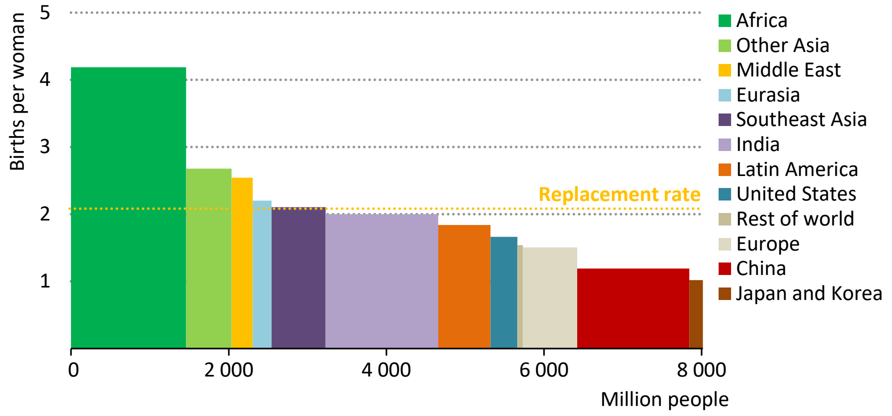
Box 2.1 ⊳ Declining fertility rates are tempering expectations for future population growth

A large number of countries currently have a fertility rate below 2.1, which is the average level needed to sustain long-term replacement of the population (Figure 2.13). The global average total fertility rate has fallen by around 10% over the past ten years and is now around 2.3. Several factors contribute, including broader female education and career opportunities, high housing and living costs, and a delay in the age of starting families. Declines have been most marked in the Asia Pacific region, with India, China, Pakistan and Bangladesh all having fertility rates about one-third lower than 20 years ago.

Figure 2.13 ⊳ **Fertility rates by country and region, 2023**



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Regions and countries accounting for just under 60% of the world population today have fertility rates below replacement levels

The decrease has become even more pronounced in the past five years, with China's fertility rate falling by 35%, and India, Japan, Kenya, Egypt and many European countries seeing a drop of around 10%. These trends are expected to continue in the years ahead and are a key determinant of slowing growth in the global population. Future declines in the fertility rate are forecast to be steepest in countries in sub-Saharan Africa: by 2050, the total fertility rate of sub-Saharan Africa is expected to be around 2.8, similar to the level in Egypt today.

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2.2.3 Prices

Table 2.3 ▷ Wholesale fossil fuel prices by scenario

		STEPS			APS			NZE Scenario		
USD (MER, 2023)	**2023**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
IEA crude oil (USD/barrel)	82	79	77	75	72	63	58	42	30	25
Natural gas (USD/MBtu)										
United States	2.7	3.9	4.1	4.2	3.2	3.0	2.9	2.1	2.0	2.0
European Union	12.1	6.5	7.6	7.7	6.0	5.2	5.2	4.4	4.1	4.0
China	11.5	7.2	8.2	8.3	6.9	6.2	6.2	5.0	4.8	4.8
Japan	13.0	8.3	8.8	8.7	6.8	6.1	6.2	5.0	4.8	4.8
Steam coal (USD/tonne)										
United States	57	51	42	40	42	31	27	28	23	23
European Union	129	68	69	64	64	51	48	57	43	39
Japan	174	105	86	82	81	66	61	66	53	49
Coastal China	150	101	88	82	78	67	61	64	54	49

Notes: MBtu = million British thermal units. The IEA crude oil price is a weighted average of import prices among IEA member countries. Natural gas prices are weighted averages expressed on a gross calorific-value basis. The US natural gas price reflects the wholesale price prevailing on the domestic market. Natural gas prices in the European Union and China reflect a balance of pipeline and LNG imports, while the Japan gas price is solely for LNG imports. LNG prices are those at the customs border, prior to regasification. Steam coal prices are weighted averages adjusted to 6 000 kilocalories per kilogramme. The US steam coal price reflects mine mouth prices plus transport and handling costs. Coastal China steam coal price reflects a balance of imports and domestic sales, while the European Union and Japanese steam coal prices are solely for imports. Wholesale prices exclude any emissions pricing applied at the point of use.

Oil

Oil prices in our scenarios act as intermediaries to balance global supply and demand, ensuring markets remain in equilibrium. They are assumed to follow smooth trajectories in all scenarios despite the ever-present risk of volatility. The STEPS sees near-term downward pressure on prices, which remain below 2023 levels all the way through to 2050; as noted, much depends on the investment and market management strategies followed by major producers (Table 2.3). In the APS, stringent policy measures lead to a stronger decline in demand and the oil price falls to USD 58/barrel in 2050. In the NZE Scenario, there is a sharp decline in the oil price to 2030 as a marked decrease in demand means that the price is set by the operating costs of the marginal producer, and by 2050 prices fall to around USD 25/barrel. In the APS and NZE scenarios, policies are sufficiently strong to counteract any effect of lower prices on demand that could jeopardise climate goals (IEA, 2024f).

The production plans and resilience of major resource-holders strongly influence prices in our scenarios. In the STEPS and APS, continued market management by major producers is assumed to keep prices at higher levels than implied by the global supply cost curve. In the

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NZE Scenario, producer economies may struggle to manage strains placed on their fiscal balances from reductions in oil and gas income, and this could lead to higher and more volatile prices.

Natural gas

Natural gas markets gradually rebalanced in 2023 as a result of timely policy actions in response to the global energy crisis, increased global LNG exports, and favourable weather conditions. In the STEPS, the US natural gas price rises to 2030 to ensure a smooth balance between domestic supply, demand and exports. In parallel, global gas trade continues to pivot toward LNG, and portfolio players act as important intermediaries between supply and demand. The large number of new LNG liquefaction facilities coming online over the period to 2030 leads to supply capacity in excess of global LNG demand. Prices in 2030 in Europe, Japan and China fall to levels substantially lower than those seen in 2023, as rapid growth in renewables and electrification limits the potential for a robust demand response to ample LNG supply. For LNG projects under construction, average delivered costs are estimated to be around USD 8 per million British thermal units (MBtu), and so some LNG investors may struggle to recoup their invested capital within an acceptable timeframe. Natural gas prices gradually increase around the world after 2030 as the overhang in LNG is worked off. In the APS and the NZE Scenario, demand and prices are much lower around the world.

Coal

Global coal consumption reached a record high in 2023, but coal prices fell from the unprecedented highs reached in many regions in 2022. Prices further decline through to 2050 in all three scenarios. In the STEPS, there is a need to maintain existing mines and open some new mines as demand falls steadily, but prices still fall by around 30-50% to 2030 in importing regions. In the APS, a faster decline in demand allows for the closure of some high-cost mines, leading to a deeper fall in prices. In the NZE Scenario, only the lowest cost mines are needed, and prices drop to very low levels. Higher-than-expected growth in coal consumption in China or India, as well as unfavourable conditions for renewable energy production, e.g. low precipitation, light winds, could pose upside risks to coal prices. Conversely, the development of new coal mines could weigh on prices if coal-fired power plants face tougher competition from solar power.

Critical mineral prices

We do not yet model full long-term supply-demand balances for critical minerals in the same way as for fuels, but we do undertake market monitoring and scenario benchmarking. The prices of many critical minerals – particularly for batteries – fell in 2023 after two years of dramatic increases. Lithium spot prices fell by 75% and other key materials such as nickel, cobalt, manganese and graphite saw price drops of 30-45%. However, copper prices remained at elevated levels, and with the exception of cobalt and graphite, the prices of most critical minerals are higher than the average levels seen in the 2010s.

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The drop in critical mineral prices stemmed mainly from a rapid ramp-up in supply in 2023. A number of new projects came online relatively quickly, adding sizeable volumes to the supply pool, and the ramp-up of new supply has outpaced demand growth over the past two years. An inventory overhang in the downstream battery sector also played a role. Price declines helped reduce the cost of clean technologies, but also caused financial difficulties for some existing and planned supply projects.

Carbon prices

Today, just under one-quarter of global GHG emissions are covered by a carbon price of some type through carbon taxes and/or emissions trading systems. Aggregate revenues from carbon pricing initiatives rose to more than USD 100 billion in 2023, a record high. Half of these revenues were generated by the European Union Emissions Trading Scheme (EU ETS).

The STEPS incorporates existing and scheduled carbon pricing initiatives, with market-based initiatives rising continuously and carbon taxes and other non-market mechanisms remaining constant unless scheduled to increase. It sees the EU ETS CO_2 price for power generation rise to just under USD 160/tonne CO_2 in 2050. In the APS, net zero emissions pledges lead to higher CO_2 prices across all regions, with prices rising by 2050 to USD 200/tonne CO_2 on average in advanced economies, and to USD 160/tonne CO_2 in China, India and Indonesia. In the NZE Scenario, carbon prices are introduced in all regions and cover most sectors: they rise to USD 250/tonne CO_2 in 2050 in advanced economies and USD 200/tonne CO_2 in major economies including China, Brazil, India and South Africa, with lower price levels elsewhere (see Annex B).

As with other policy measures, carbon prices are assumed to be introduced with careful consideration of the consequences for tax burdens and the potential for negative distributional impacts. The level of carbon prices included in our scenarios should be interpreted with caution: the scenarios include several other energy policies and accompanying measures designed to reduce CO_2 emissions, and this means that the carbon prices shown do not necessarily reflect the marginal costs of abatement.

Wholesale and retail prices

There is a large difference between wholesale prices for fuels and the retail prices paid by consumers. Retail prices reflect the cost of producing fuels that end-users need and the cost of delivering them: they commonly include the costs of transport, refining, marketing and distribution, as well as customs duties, excise taxes, value-added taxes and subsidies, all of which vary between, and sometimes within, countries. Retail prices are generally higher than wholesale prices, and sometimes much higher. For example, the average retail price of gasoline in Europe is around two-and-a-half times the wholesale price of oil, with taxes accounting for around half of the retail price paid by consumers. Conversely, in the Middle East, subsidies mean the retail price for gasoline is on average lower than the wholesale price

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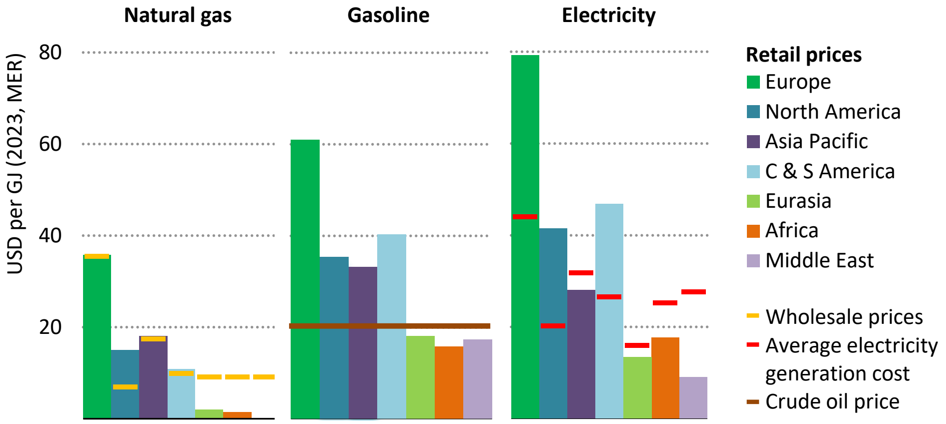
(Figure 2.14).[7] Assumptions about the phase-out of fossil fuel consumption subsidies vary by scenario: in the STEPS, for example, they are only removed if there is a specific commitment to do so.

Retail prices and wholesale prices do not always move in tandem. For example, the average wholesale natural gas price in Europe fell by two-thirds in 2023, while the average retail price increased by 14% as measures introduced by governments to keep retail prices from rising significantly during the global energy crisis came to an end in many countries. Retail electricity prices tend to be less volatile than other retail fuel prices because around half of electricity demand globally is in markets with regulated prices based on average costs.

Figure 2.14 ▷ Average natural gas, gasoline and electricity wholesale and retail prices in selected regions, 2022



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Retail prices vary markedly around the world, and differ significantly from wholesale prices mainly due to consumption-based government taxes and subsidies

Notes: GJ = gigajoule; C & S America = Central and South America. Retail prices for natural gas and electricity are for the residential sector. Gasoline is compared to global average crude oil price.

2.2.4 Technology costs

Supply chain pressures and higher critical minerals prices pushed up the cost of a number of key clean energy technologies in 2021 and 2022 (Figure 2.15). These pressures eased in 2023, and costs in most cases started to fall back. The IEA Clean Energy Equipment Price Index tracks price movements in a global basket of solar PV modules, wind turbines and lithium-ion batteries for EVs and battery storage, weighted by shares of investment. Costs for most clean

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[7] See *Fossil Fuels Consumption Subsidies 2022* for a discussion on the methodology used to calculate fossil fuel subsidies (IEA, 2023b).

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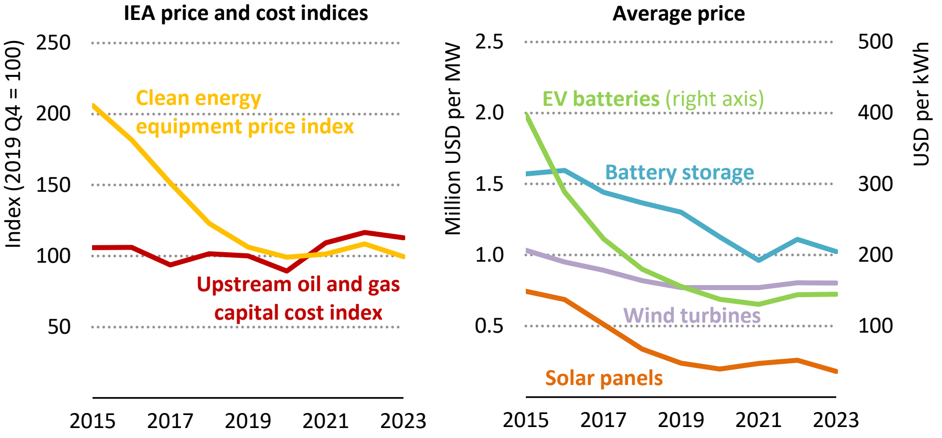
energy technologies have resumed a downward path and the fourth-quarter of 2023 saw the index falling to its lowest ever level.

The drop in critical mineral prices in 2023 led to a 10% reduction in that industry's revenue and a 34% fall in operating profits. Lower prices may stimulate an acceleration in clean energy technology deployment in the medium term, but they could lead to longer term risks if they constrain investment and the critical mineral industry's ability to develop new supply projects. Given the importance of critical minerals to the cost of clean energy technologies and expected demand growth in the use of clean technologies, reduced investment could lead to future supply shortages and price spikes. This could slow reductions in clean energy technology costs, or even increase them, as happened in 2022 with battery pack prices, potentially hindering clean energy technology deployment.

Figure 2.15 ▹ IEA indices for clean energy and upstream oil and gas, and global average price of selected clean energy technologies



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Increased manufacturing capacity and falling minerals prices have underpinned large price reductions for clean energy technologies

Notes: Q4 = fourth-quarter; MW = megawatt; kWh = kilowatt-hour. The IEA Clean Energy Equipment Price Index tracks price movements of a fixed basket of solar PV panels, wind turbines and lithium-ion batteries (for EVs and energy storage). Prices are weighted based on the shares of global average annual investment between 2019-2023. Prices are tracked on a quarterly basis with Q4 2019 defined as 100. Nominal prices.

Source: IEA analysis based on company financial reports and BNEF (2023).

In the IEA Global Energy and Climate Model, the future evolution of technology costs depends on continued research, improvements in manufacturing and learning-by-doing. These costs are linked to levels of deployment and vary by scenario. They do not follow a linear path. A typical curve has the steepest rate of cost reduction in the earliest phases of innovation and deployment, when overall costs are still high: costs then fall more slowly as technologies mature. Policies play a crucial role in this process, particularly in determining

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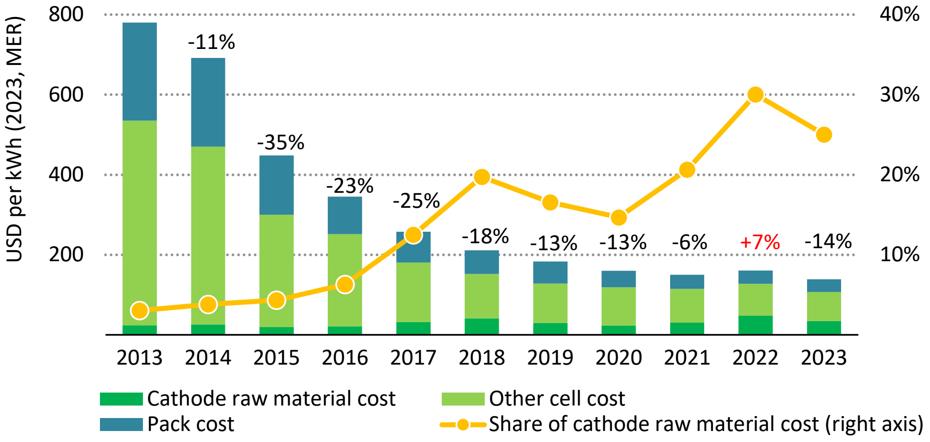
how quickly new clean technologies are scaled up in sectors such as shipping, aviation and heavy industry.

The recent evolution of upstream oil and gas costs also shows short-term fluctuations. The IEA Upstream Oil and Gas Capital Cost Index, which tracks how the capital costs of a set of representative upstream oil and gas projects around the world evolve over time, rose by close to 7% in 2022 as a result of higher raw material prices and constrained markets for services and labour. Costs fell slightly in 2023 as inflation eased, but the drop was smaller than seen in batteries and solar PV. Upstream costs in 2023, however, were still nearly 15% below 2014 levels following extensive efforts by operators in recent years to downsize and simplify project designs to maintain competitiveness.

Solar PV module prices fell by 30% in 2023. A recent surge in solar production capacity in China is decreasing margins for solar PV manufacturers setting the stage for a possible market consolidation among manufacturers in the near term. Chinese exports of solar cells and modules reached 255 GW in 2023, triple the 2019 level.

Figure 2.16 ⊳ Global average lithium-ion battery pack price and share of cathode raw material cost, 2013-2023



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Battery pack prices fell as critical minerals prices declined, but are now becoming increasingly vulnerable to critical mineral price volatility

Notes: kWh = kilowatt-hour; MER = market exchange rate. Cathode raw material cost is based on the refined battery-grade critical mineral products such as lithium carbonate and hydroxide, and nickel, cobalt and manganese sulphate. Cathode material processing costs are excluded. Average price is weighted by volume.

Source: IEA analysis based on BloombergNEF (2023).

Battery pack prices dropped by 14% in 2023 to a record low of USD 139 per kilowatt-hour (kWh) following reductions in battery critical mineral prices and a surge in battery cell production capacity (Figure 2.16). Since 2013, battery pack costs have fallen almost sixfold

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due to economies of scale and manufacturing optimisation. However, the proportion of costs accounted for by the cost of cathode raw materials in the battery pack price has been rising. Around 30% of the cost of a battery pack now depends on the cost of critical minerals, and battery costs are increasingly susceptible to mineral price volatility. Material substitution can mitigate price volatility to an extent, as it did when lithium iron phosphate battery chemistry displaced nickel-rich battery chemistries during the recent years of high nickel and cobalt prices. However, there is no alternative at present for some of the critical minerals used for particular functions in battery packs, including copper in the current collector in lithium-ion battery anodes and graphite in lithium-ion batteries.

Manufacturing costs for wind turbines rose in second-quarter 2023 as a result of an increase in steel and freight costs. Companies in China have so far proven able to produce wind turbines at lower cost than their European counterparts. However, this has not translated into a large increase in exports due in large part to the costs and logistical complexities of moving large wind turbines very long distances.

Offshore wind has higher upfront costs than onshore wind and solar PV. In 2023, developers struggled with project profitability due to inflation, high interest rates and supply chain challenges in connection with large turbine manufacturing and installation. Several contracts were cancelled because previously agreed prices became unviable. As ever, governments will need to pay close attention to market and cost dynamics as they design policies and support schemes for emerging technologies.

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Pathways for the energy mix

Peaks coming into view?

SUMMARY

- Global energy markets found a tentative new balance in 2023, with natural gas prices coming down after skyrocketing in 2022 in Europe and other parts of the world, and with an increase of 2.1% in global energy demand, in line with the average rate in the two decades before 2020.
- While a growing global population and higher incomes increase the need for energy services, energy demand growth slows to 0.7% per year from 2023 to 2030 in the Stated Policies Scenario (STEPS), half the rate of the past decade. Most growth occurs in emerging market and developing economies. Efficiency gains and electrification lead to a slight decline in global energy demand in the Announced Pledges Scenario (APS), and to a more significant fall in the Net Zero Emissions by 2050 (NZE) Scenario.
- Strong electricity demand growth is a feature of all three scenarios, driven not just by economic growth but also by increasing electrification of end-uses, notably electric vehicles, and by rising demand for data centres. The share of electricity in final consumption increases from 20% today to 26% in 2035 in the STEPS, 29% in the APS and 36% in the NZE Scenario. Electricity demand in China rises particularly fast and is set to surpass the level of demand in all advanced economies combined by 2030.
- Low-emissions sources, led by renewables, increase faster than electricity demand in all scenarios, thereby pushing down the share of fossil fuels in electricity generation. In 2023, renewables provided 30% of global electricity supply, while fossil fuels edged down to 60%, their lowest share in 50 years. By 2035, the share of solar PV and wind in electricity generation exceeds 40% globally in the STEPS, and by 2050 increases to nearly 60%. The share of nuclear power remains close to 10% in all scenarios.
- Fossil fuels met 80% of global energy demand in 2023. As in the *WEO-2023,* our scenarios indicate that demand for oil, natural gas and coal is set to peak by 2030, though oil use for aviation and petrochemicals increases to 2050 in the STEPS, natural gas demand remains robust in emerging market and developing economies, and the decline in coal use is relatively gradual. Higher clean energy investment and a faster descent from these peaks is needed to fulfil announced pledges and move the world towards a net zero emissions pathway.
- Seven clean energy technologies – solar PV, wind, nuclear, electric vehicles, heat pumps, hydrogen and carbon capture – are key to affordable and secure transitions. Together they account for three-quarters of the CO_2 emissions reductions to 2050 in the APS and the NZE Scenario, complemented by other renewables such as bioenergy and geothermal, and energy efficiency. Overcoming barriers to their deployment, including network and storage infrastructure, should be a priority worldwide.

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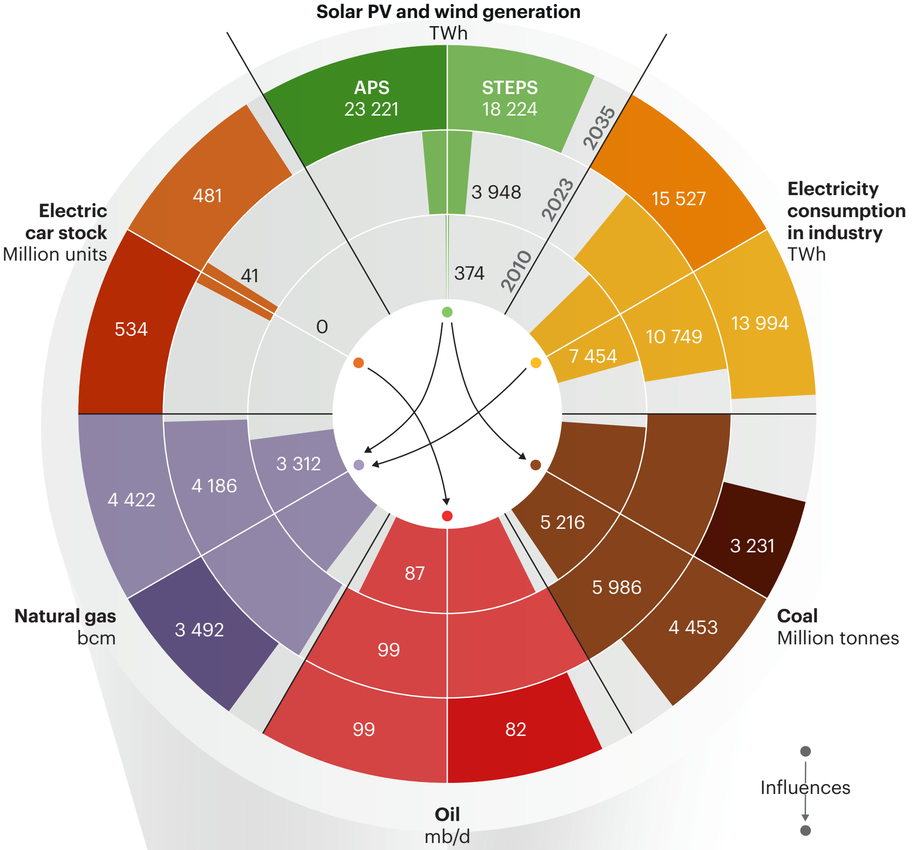
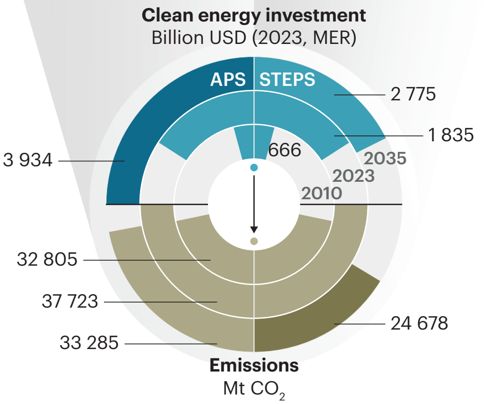


Clean technologies are re-shaping the global energy mix

Despite growing needs for energy services, more efficiency and electrification are slowing the rate of global energy demand growth while the uptake of clean technologies like renewables and electric vehicles lead to a peak in demand for oil, natural gas and coal by 2030, though more clean energy investment is needed to accelerate CO_2 emissions reductions.



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3.1 Introduction

Tensions in global energy markets calmed to a degree in 2023, and global energy demand rebounded by 2.1%, which means that the rate of growth was above its average rate from 2000 to 2019. Population growth and rising incomes continued to spur higher consumer demand for energy services, and patterns of demand continued to evolve, with data centres and artificial intelligence requiring increasing amounts of energy, for example.

This is the starting point for our modelling process in this *World Energy Outlook (WEO-2024)*. The first step in producing our scenario projections is not to look at emissions, investment or resources, but to look in detail at demand for energy services. In other words, we look first at how much light, heat, mobility and information services communities, industries and countries around the world are likely to need over the decades to 2050. Government policies lay the foundation, and over 5 000 policies in countries around the world have been collected, documented and analysed by technology and sector.

Levels of energy services demand increase at broadly the same rate in each of our scenarios as the global economy grows, with two important exceptions. The first concerns progress towards universal access to modern energy: this varies by scenario, which affects the level of demand for energy services because progress towards achievement of this goal invariably leads to higher use of energy services in many countries for lighting, cooling, and appliance and equipment use. The second concerns the adoption of behavioural changes and mode shifts: these too vary by scenario, and the differences affect the level of energy service demand, for example when substituting public transport, walking or cycling for short car journeys or increasing the recycling of plastics.

Rising energy services demand is common in each scenario, but how this translates into overall energy and emissions trends is subject to the technologies deployed and innovation unlocked in each outlook. A range of technology mixes can meet needs for heating, cooling or mobility, each with distinctive implications for cost, resource use and pollution. We explore various pathways in this chapter, examining how decisions to invest in different technologies and resources could meet the world's future energy needs and how policies shape the choices ahead. We have four focus areas.

- First, we examine trends in global final energy consumption in the industry, transport and buildings sectors, and how that demand is met in each scenario.
- Second, we examine the outlook for electricity, including the drivers of electricity demand growth, the evolving electricity supply mix, emissions and investment.
- Third, we consider oil, natural gas, coal and bioenergy, and the ways in which they will be shaped by the speed at which clean energy technologies are deployed.
- Fourth, we probe the role of and outlook for specific key clean energy technologies that include solar photovoltaics (PV) and wind power, nuclear power, electric vehicles (EVs), heat pumps, hydrogen and carbon capture, utilisation and storage (CCUS).

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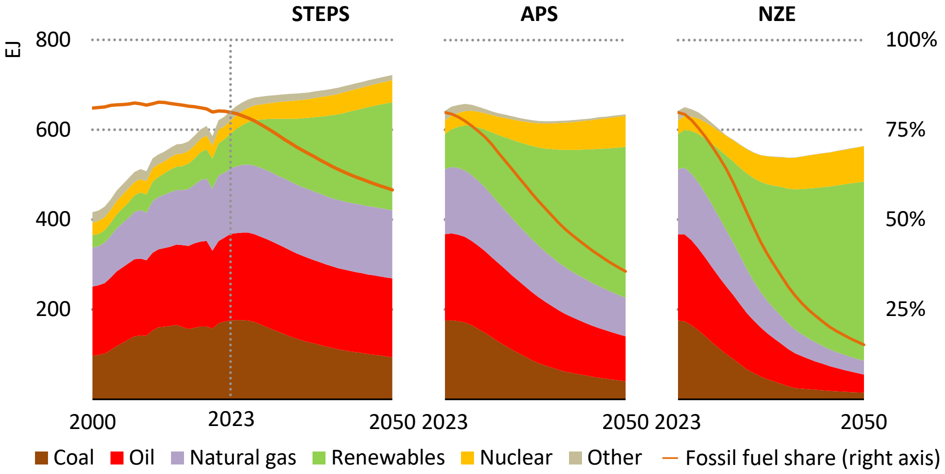
3.2 Overview

Today, global energy demand stands at around 640 exajoules (EJ). By 2035, it rises to 680 EJ in the STEPS, falls slightly to around 625 EJ in the Announced Pledges Scenario (APS) and declines to 540 EJ in the Net Zero Emissions by 2050 (NZE) Scenario – three distinct trends based on the same economic and population growth assumptions. In the STEPS, the only scenario which sees continued growth in global energy demand, the rate from now to 2035 is only around one-third as high as it was over the past decade, and all the growth in energy demand comes from emerging market and developing economies.

Figure 3.1 ⊳ **Global total energy supply by source and fossil fuel share by scenario, 2000-2050**



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Each fossil fuel peaks by 2030 in all scenarios and then declines over time as renewables and other low-emissions sources of energy increase strongly

Notes: EJ = exajoules; STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario; NZE = Net Zero Emissions by 2050 Scenario. Renewables includes modern bioenergy. Other includes the traditional use of biomass and non-renewable waste.

As first presented in the *World Energy Outlook 2023 (WEO-2023)*, in each scenario, demand for each fossil fuel peaks by 2030 (Figure 3.1). In the STEPS, coal demand begins to decline around 2025, while oil and natural gas demand both peak towards the end of the decade. After decades of the fossil fuel share of total energy supply hovering around 80%, it declines to 75% by 2030 and below 60% by 2050. In the APS, each fossil fuel reaches its peak by 2025 and the overall fossil fuel share declines to around 35% in 2050. The NZE Scenario involves a more complete transition with all fossil fuels declining from today to make up less than 65% of total energy supply by 2030 and around 15% by 2050.

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Box 3.1 ▹ How does the Stated Policies Scenario 2024 differ from the 2023 version?

Each scenario is modified annually to incorporate adjustments to historical data as countries gain a better understanding of what has already happened in terms of energy supply and demand. In this year's scenarios for example, updated data in China, India and Southeast Asia in particular mean that global coal demand starts at a baseline about 3.5% above the value in *WEO-2023*.

The trajectories of the *WEO* scenarios are also updated each year to reflect the latest changes in policies and the most recent market and investment data. Changes since the *WEO-2023* have had a material impact on the outlook for coal, natural gas and electricity.

In the STEPS, the outlook for coal has been revised upwards particularly for the coming decade, principally as a result of updated electricity demand projections, notably from China and India. Total coal demand is 300 million tonnes of coal equivalent (Mtce) or 6% higher in 2030 than in the *WEO-2023*. Even with this revision, coal demand declines by an average of 2% each year through to 2050.

The outlook for total natural gas demand in the STEPS is also higher in 2024. This is mostly the result of stronger projected electricity demand growth, particularly in China, and an increase in natural gas supply reflecting expansion of liquefied natural gas (LNG) capacity. By 2035, total natural gas demand is around 175 billion cubic metres (bcm) or 4% higher in this year's STEPS than in 2023. As in the *WEO-2023*, however, total natural gas demand flattens by the end of this decade.

Higher electricity demand in the STEPS 2024 mainly reflects projected increased light industry activity, notably in China, much of it associated with a rapid rise in clean technology manufacturing. Upward revisions also reflect faster adoption of EVs, increased demand from data centres, and increased electrification of industrial processes in emerging market and developing economies. By 2035, electricity demand is over 2 000 terawatt-hours (TWh) or 6% higher in this edition than in the *WEO-2023*.

3.2.1 Energy efficiency

Global energy intensity reduced by 1% in 2023, a smaller improvement than the 2% reduction seen in 2022. Certain emerging market and developing economies made relatively slow progress, while there were significant energy intensity improvements elsewhere, including in the United States and European Union, largely driven by mild weather, high energy prices and reduced industrial activity. Annual investment in energy efficiency exceeded USD 390 billion in 2023, up from USD 300 billion in 2020. Many major economies have adopted legislative and policy measures that are set to deliver further efficiency gains over the coming years, including: the Inflation Reduction Act in the United States; the Energy Efficiency Directive in the European Union; the revised Act on Rationalizing Energy Use in Japan; and the most recent cycle of the Perform, Achieve and Trade scheme in India.

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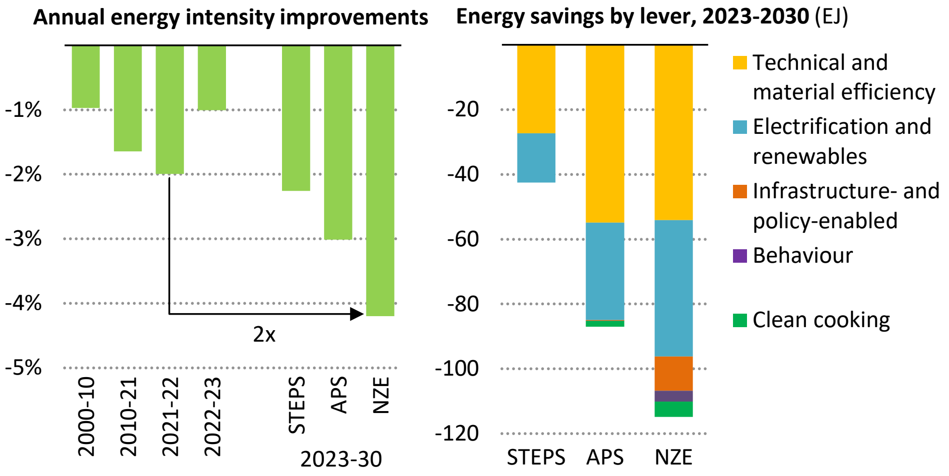
Annual intensity improvements worldwide from today to 2030 average 2.3% in the STEPS and 3% in the APS. Only in the NZE Scenario do annual improvements exceed 4%, to achieve a doubling from the 2022 baseline of 2% by 2030 in line with the pledges made by nearly 200 countries at the 28th Conference of the Parties (COP28) (Figure 3.2). The benefits of doubling efficiency improvements include reducing energy bills; alleviating fuel poverty; creating almost 5 million jobs globally; contributing half of emissions reductions needed in the NZE Scenario by 2030; and helping to create healthier living environments. In each scenario, intensity improvements occur at a similar pace in both groupings – advanced economies and emerging market and developing economies – with advanced economies remaining on average about 35% less energy intensive than emerging market and developing economies through to 2030.

Figure 3.2 ▷ Global annual energy intensity improvements, 2000-2030, and cumulative energy savings by lever and scenario, 2023-2030



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Energy intensity improvements this past year fell far short of what is needed to double energy efficiency by 2030; action is needed on a number of fronts to close the gap

Notes: EJ = exajoules. Energy intensity is defined as the ratio of global total energy supply per unit of gross domestic product.

Technical efficiency improvements such as building retrofits and vehicle fuel economy advances contribute the largest share of energy savings by 2030 in each scenario. Switching from direct combustion of fossil fuels to renewables, electricity and other more efficient energy sources contributes the second-largest share. Behavioural changes as well as infrastructure- or technology-enabled changes such as mode shifting and enhanced recycling also contribute. Providing clean cooking in lieu of highly inefficient and polluting traditional cooking methods is a particularly important source of energy savings in sub-Saharan Africa and other emerging market and developing economies.

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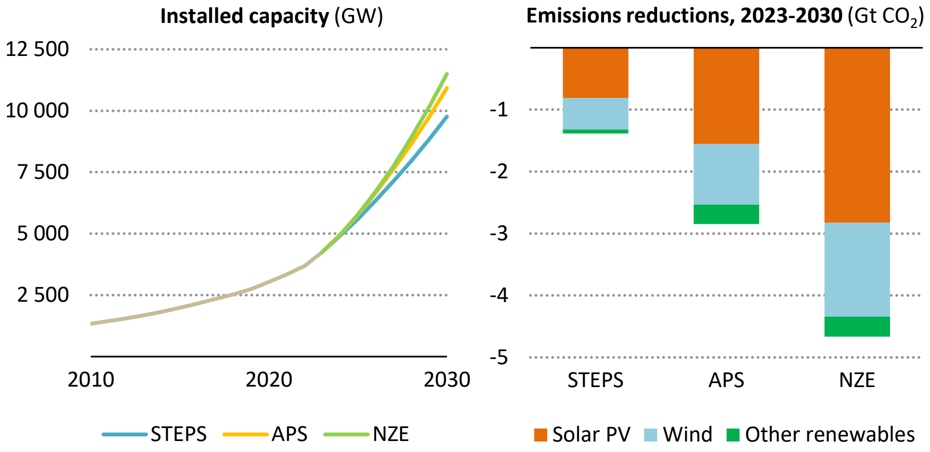
3.2.2 Renewables

Total supply of modern renewables[1] increased by 5% year-on-year to nearly 78 EJ in 2023, providing 12% of total energy supply. Global investment in renewables increased by 20% in 2023 to nearly USD 750 billion, equivalent to nearly 1% of global gross domestic product (GDP) (IEA, 2024a). In 2023, global manufacturing capacity increased by 76% for solar PV modules and 22% for wind nacelle assembly (IEA, 2024b). Global renewable capacity additions totalled over 560 gigawatts (GW) in 2023 – a 60% increase from the previous year, led by a boom in solar PV, particularly in China – and they are set to exceed 670 GW in 2024.

Figure 3.3 ▷ Global installed capacity of renewables, 2010-2030, and emissions reductions by scenario, 2023-2030



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Installed capacity of renewables increases between 2.5- and 3-times by 2030 in each scenario, leading to significant emissions savings

Notes: GW = gigawatt; Gt CO$_2$ = gigatonnes of carbon dioxide. Other renewables include hydropower, bioenergy and renewable waste, geothermal, concentrating solar power and marine power.

Installed renewables energy generation capacity expands from 4 250 GW today to more than 9 750 GW in 2030 in the STEPS, 10 900 GW in the APS and almost 11 500 GW in the NZE Scenario (Figure 3.3). Despite the gains made in the STEPS and APS, these scenarios do not meet the COP28 pledge to triple renewables capacity by 2030, which is consistent with the NZE Scenario. From today to 2030, renewables make up at least four-fifths of total capacity additions in each scenario, heavily outweighing additions of unabated fossil fuel capacity, with solar PV and wind power dominating new capacity in all major markets. The share of electricity generation from renewables increases from 30% today to 45% in the

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[1] Modern renewables include all uses of renewables except for the traditional use of biomass, for power and heat generation and direct final consumption.

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STEPS by 2030, 50% in the APS and nearly 60% in the NZE Scenario, reducing cumulative emissions in 2030 from today's level by around 1.5 gigatonnes of carbon dioxide (Gt CO_2), 3 Gt CO_2 and 4.5 Gt CO_2 respectively.

While most modern renewables are used in the power sector, 24 EJ of modern renewables were consumed directly in end-use applications in 2023, largely in the form of modern bioenergy, solar thermal and geothermal energy. These direct uses rise modestly in the STEPS, but they gain ground more rapidly in the APS and NZE Scenario in large part due to increased use of biofuels in transport, which provide an important decarbonisation pathway in sectors such as shipping and aviation where electrification is a less cost-competitive solution. The use of modern bioenergy in residential buildings also increases in tandem with faster progress to provide universal access to clean cooking.

SPOTLIGHT

When will energy-related CO_2 emissions peak?

Global carbon dioxide (CO_2) emissions reached a record high in 2023, with the vast majority stemming from the energy sector. Following a rise of 1% in 2022, global energy-related CO_2 emissions rose 1.3% in 2023 (Figure 3.4). Coal use was the single largest contributor to CO_2 emissions, accounting for 15.7 gigatonnes (Gt) of the 37.7 Gt CO_2 released by the energy sector in 2023, followed by oil (11.3 Gt CO_2) and natural gas (7.5 Gt CO_2). Coal also accounted for almost 80% of the increase in CO_2 emissions in 2023. However, fossil fuel demand is projected to peak in all scenarios by 2030, which means that a turning point in emissions should be near. Rapidly increasing deployment of clean energy technologies, in particular solar and wind, has already begun to dampen the upward trajectory of CO_2 emissions, and to bring about a structural slowdown in energy-related CO_2 emissions.

Over 3 900 Mtce of coal was consumed in the power sector – by far the main source of coal demand – and this emitted 11.3 Gt CO_2 in 2023. Emerging market and developing economies accounted for 84% of coal use in the power sector in 2023, of which China alone was around 55% of the global total. Yet, rapid expansion of solar PV and wind in many power systems is already making inroads into coal use for power generation.

Coal faces less competition in the industry sector, where demand remains stable in the STEPS to 2030. Around 1 200 Mtce – roughly three-quarters of total industrial coal demand – are consumed in the production of iron, steel and cement, mostly for use in building new infrastructure. However, the substitution of coal by other sources of energy, such as electricity, bioenergy or natural gas, does augment in the latter years of this decade, prompting downward trends in coal demand in industry and CO_2 emissions.

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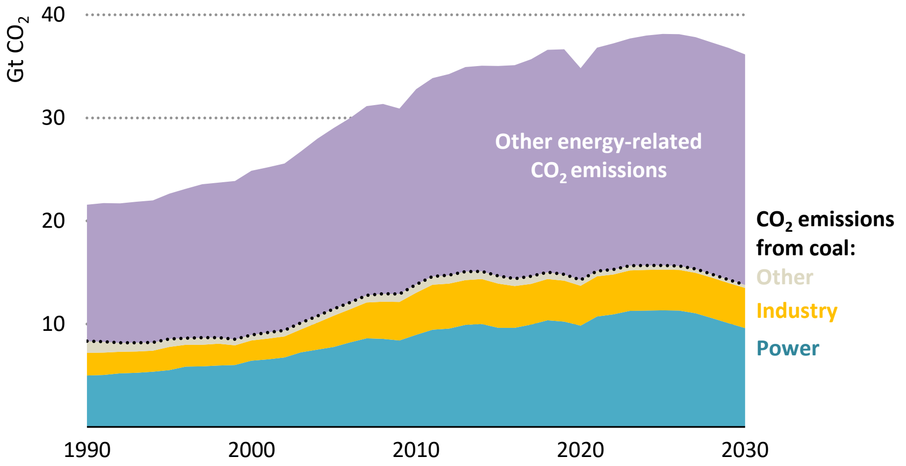
Figure 3.4 ⊳ **Total energy-related CO_2 emissions and from coal use in the Stated Policies Scenario, 1990-2030**



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Coal use in the power sector sees an inflection point in the mid-2020s, ushering in a gradual decline in total energy-related CO_2 emissions

Note: Other energy-related CO_2 emissions in this figure include emissions from oil, natural gas, non-renewable waste, industrial process, and flaring.

3.3 Total final consumption

Total final energy consumption across end-use sectors increased by 1.7% to 445 EJ in 2023, split between the industry sector (more than 170 EJ), buildings (about 125 EJ), transport (around 120 EJ), and agriculture and other non-energy uses (around 25 EJ) (Figure 3.5). Consumption continues to climb steadily for the rest of the decade in the STEPS, increasing at an average annual rate of 1.3% to 2030, in line with the rate seen over the last ten years: then the pace slows, with the annual growth rate between 2030 to 2050 falling to an average of only 0.5%. In the APS, efficiency gains and higher electrification rates curb energy consumption growth: despite economic growth and improved energy access, it rises only modestly to 2030 and then falls slightly between 2030 and 2050. In the NZE Scenario, even faster electrification and energy efficiency improvements mean that energy consumption declines by 2030 and falls significantly further by 2050.

By 2035, total final consumption increases by nearly 55 EJ in the STEPS, bringing it to almost 500 EJ. This increase takes place solely in emerging market and developing economies. In advanced economies, most increased consumption this decade comes from the industry sector, but this is offset by declines in other sectors, notably transport, where rising mobility needs are more than cancelled out by the use of more efficient energy carriers such as

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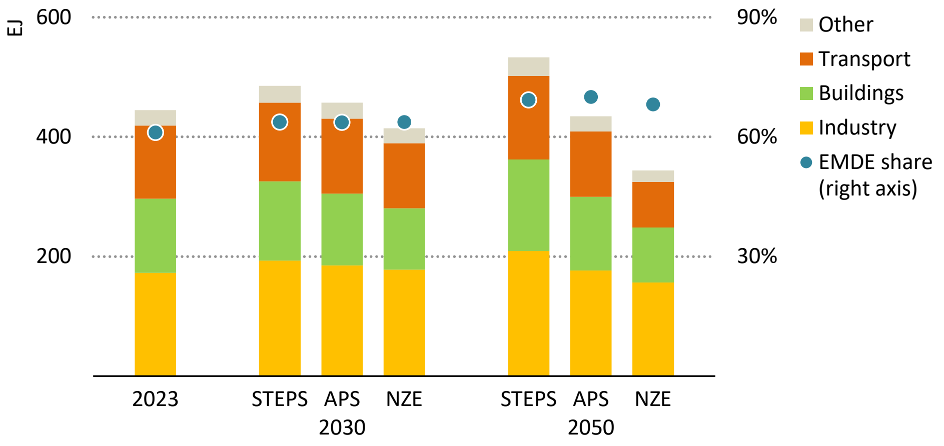
electricity; these trends lead to further declines after 2030. In emerging market and developing economies, industry is the leading growth sector, contributing nearly 20 EJ of additional demand by 2030, but buildings and transport play increasingly important roles in the longer term as ownership levels of appliances and vehicles rise. Car ownership is currently five-times higher in advanced economies than in emerging market and developing economies: this ratio falls to four-times by 2035 and just over three-times by 2050 as the global car fleet expands to 1.6 billion vehicles in 2035 and 1.9 billion in 2050.

Figure 3.5 ⊳ Total final consumption by end-use sector and scenario, 2023, 2030 and 2050



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Final consumption increases to 2050 in the STEPS, declines in the APS and falls faster in the NZE Scenario; the difficulty of applying efficient technologies in industry increases its share

Note: EJ = exajoules; EMDE = emerging market and developing economies; NZE = Net Zero Emissions by 2050 Scenario.

Direct energy use in end-use sectors accounted for around 55% of total energy-related CO_2 emissions of 37.7 Gt CO_2 in 2023. Current annual emissions in industry are close to 10 Gt CO_2, in transport over 8 Gt CO_2 and in the buildings sector less than 3 Gt CO_2 (Figure 3.6). Across all scenarios, industry consistently accounts for 40% or more of total end-use sector emissions. In the STEPS, CO_2 emissions from end-use sectors stabilise by 2030 due to the increasing use of low-emissions fuels such as biofuels, hydrogen and hydrogen-based fuels, and electricity: the transport sector, which currently has the highest emissions intensity, sees the biggest absolute declines. In the APS, CO_2 emissions start to decline from the mid-2020s and fall much further by 2050. In the NZE Scenario, emissions from end-use sectors fall more rapidly to around 1 Gt CO_2 in 2050: much of these remaining emissions come from transport, reflecting the difficulty of decarbonising end-uses like air travel.

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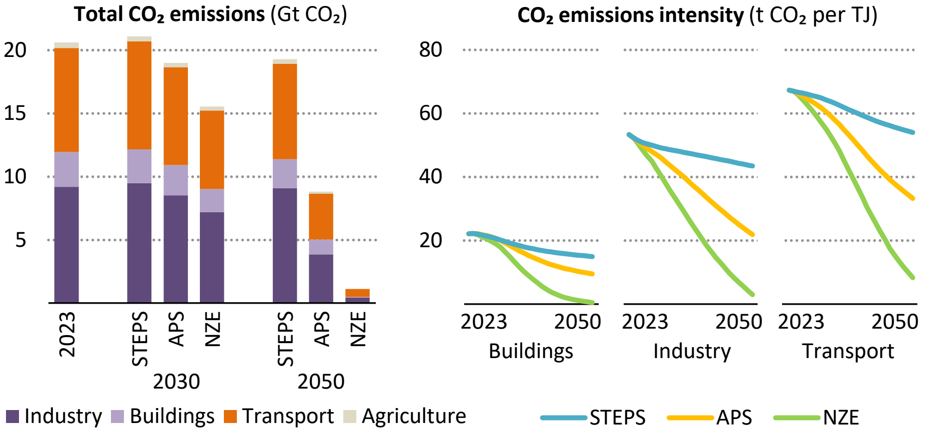
Figure 3.6 ▷ **CO_2 emissions and emissions intensity by end-use sector and scenario, 2023, 2030 and 2050**



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Industry and transport contribute most of the total emissions from final consumption, but transport sees the biggest drop in emissions intensity thanks to rising electrification

Note: Gt CO_2 = gigatonnes of carbon dioxide; t CO_2 per TJ = tonnes of carbon dioxide per terajoule.

The share of fossil fuels in final consumption in the STEPS declines from nearly 66% today to 64% in 2030, and then falls further to 55% in 2050 (Figure 3.7). In the APS, the decline is steeper, with the share of fossil fuels falling to slightly over 60% in 2030 and little over 35% by 2050. In the NZE Scenario, the fossil fuel share drops to just over 55% in 2030 and less than 20% in 2050. By contrast, the use of low-emissions fuels and electricity rises, with their share of final consumption overtaking that of fossil fuels by the early 2040s in the APS, and more than five years earlier in the NZE Scenario. The move away from fossil fuels is mainly driven by electrification of end-uses, in parallel with increasing decarbonisation of power generation, with the share of electricity in total consumption rising from 20% in 2023 to over 30% in 2050 in the STEPS, over 40% in the APS and nearly 55% in the NZE Scenario. Bioenergy, hydrogen and hydrogen-based fuels also play key roles in the long term, especially in hard-to-abate sectors where electrification faces challenges.

Improved energy efficiency and rising rates of electrification are key factors in reducing the share of fossil fuels in final consumption, but their impact differs by sector. Energy use in 2030 varies the most across scenarios in the buildings sector, with a rise of around 8 EJ from 2023 in the STEPS contrasted with a 4 EJ drop in the APS and a 22 EJ drop in the NZE Scenario. These variations are largely driven by more rapid gains in access to modern, efficient energy largely for cooking in developing economies in the APS and particularly in the NZE Scenario, and by varied speeds in the rollout of mature low-emissions technologies in other end-uses. Industry sees the smallest variations, with light industry increasing mainly through the electrification of low- and medium- temperature heat. In the transport sector, variations in

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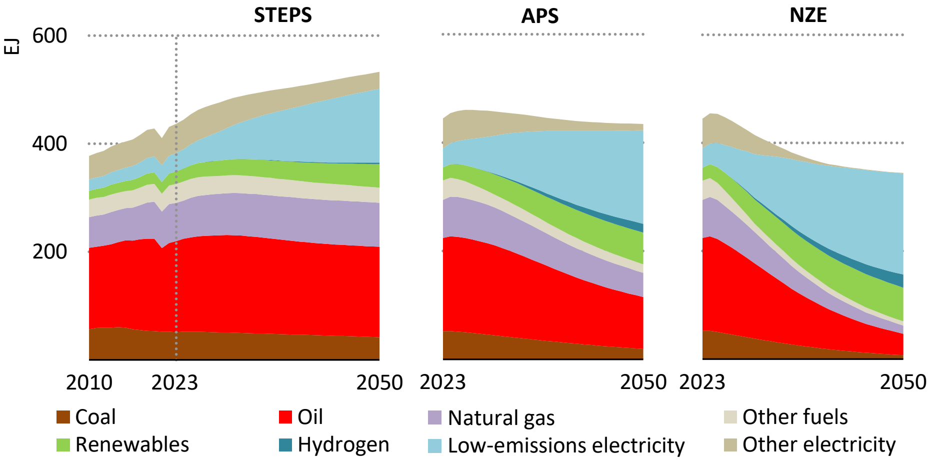
the pace of electrification of road vehicles and fuel economy improvements slow the rate of demand growth by 2030 in the APS and stimulate a sharp fall in the NZE Scenario, even as road activity increases by around 15% by 2030.

Figure 3.7 ⊳ Total final consumption by fuel and scenario, 2023-2050



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The share of fossil fuel use in final consumption declines this decade in all scenarios, and falls from 66% today to 55% in 2050 in the STEPS, declining faster in other scenarios

Notes: Renewables refers to the direct use of renewable energy sources. Hydrogen includes hydrogen-based fuels, such as ammonia and synthetic fuels. Low-emissions electricity includes output from renewable energy technologies, nuclear and fossil fuel-fired power plants fitted with CCUS, hydrogen and ammonia. Other fuels includes traditional use of biomass, district heat, non-renewable waste and fossil fuel methanol.

After 2030, electrification becomes the critical driver of shifting energy consumption patterns, but the uptake of electricity varies by end-use within each sector. In the buildings sector, progress in space and water heating is relatively slow, with electricity providing only a 20% share of the total in 2035 in the STEPS (Figure 3.8). For other end-uses in buildings, electrification reaches around 65% by 2030 in the STEPS. Most of the increase comes from cooking as traditional use of biomass declines, especially in the NZE Scenario. Light industry sees faster electrification than heavy industry, which remains reliant on fossil fuels for high-temperature processes, with the result that the electricity share of total consumption in heavy industry remains below 15% until 2050 in the STEPS. Today, transport has by far the lowest share of electrification, but the uptake of electric cars and electric two/three-wheelers is well underway and on track to rise with current policy settings. The market share of electric medium- and heavy-freight trucks is also projected to increase, albeit more slowly, reaching around 12% in 2030 in the STEPS. By contrast, relatively little progress is made in non-road transport sub-sectors such as aviation and shipping, where the potential for electrification is restricted by technical and cost limitations.

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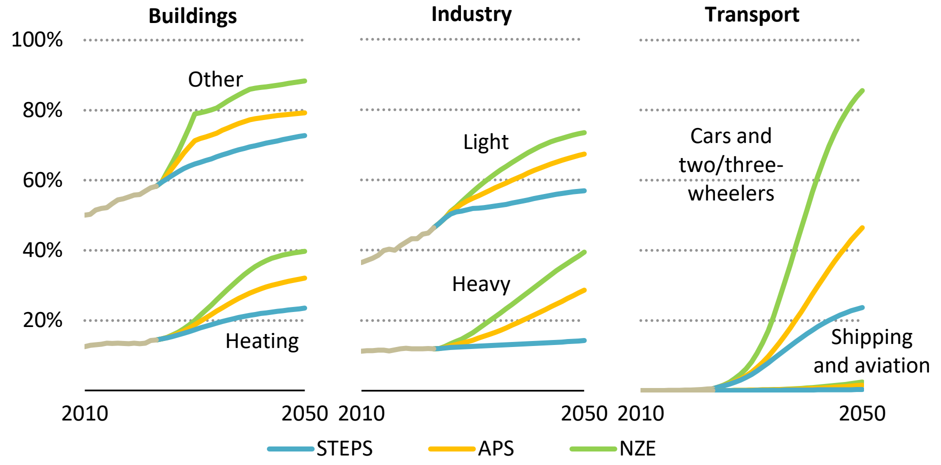
Figure 3.8 ▷ Share of electricity in total final consumption by end-use sector and scenario, 2010-2050



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End-use electricity demand increased in recent years, with substantial growth projected to 2050; the more climate-aligned a scenario, the more electricity demand rises

Note: The analysis shown does not cover the full scope of the industry or transport sectors.

3.3.1 Transport

In 2023, energy demand in the transport sector increased by close to 4%, which is similar to the rate seen in 2022. Much of this stemmed from increased aviation activity, which rebounded to over 90% of pre-pandemic 2019 levels. Road transport also contributed significantly to the increase, up about 2%, reflecting an expansion of the passenger car fleet by over 20 million vehicles, mostly in China, India and Southeast Asia, reflecting rising incomes and population growth.

By the end of this decade, energy demand in the transport sector increases by nearly 10% in the STEPS (Figure 3.9). Road transport is the primary contributor, followed by aviation. Even though the car fleet expands by over 10%, energy use in road transport rises around 5%, reflecting energy efficiency gains and the uptake of EVs. In 2023, 12% of all new cars sold worldwide were battery electric, almost 10% were internal combustion engine hybrids, and almost 6% were plug-in hybrids. EV market share, including battery electric and plug-in hybrids, is expected to exceed 20% in 2024, with around 5% of passenger cars on the road being electric. By 2030, more than 15% of the global car fleet is electric, as is nearly one-in-two new cars sold in the STEPS.

Electrification in road transport extends beyond passenger cars. For example, zero emissions heavy-duty trucks accounted for a 10% share of sales in China in December 2023 (BNEF, 2024), and electric buses for a 16% share of sales in the European Union in the first-half of

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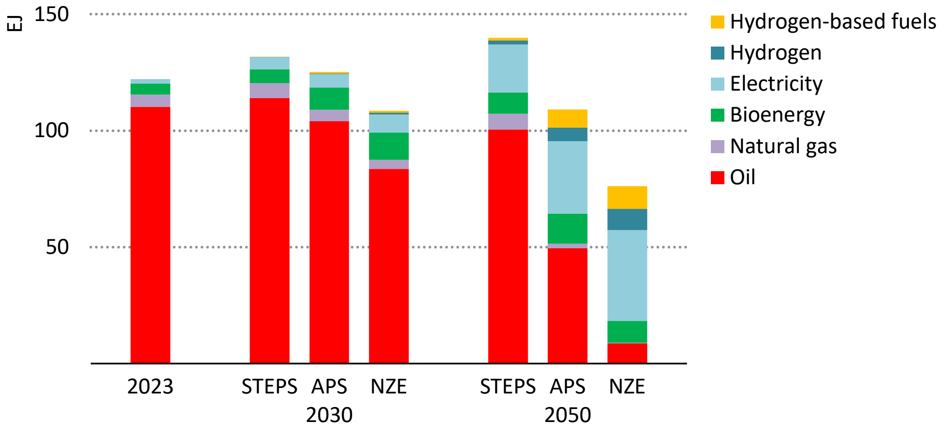
2024 (ACEA, 2024). Globally, the bus fleet is set to be over 10% electrified by 2030, and the heavy-duty trucks fleet to be 3% electric. By 2035, 30% of vehicles on the road are electric in the STEPS, increasing to 35% in the APS. In the NZE Scenario, nearly 50% of the stock are EVs, cutting emissions from road transport in half and energy demand by a third relative to current levels.

Figure 3.9 ▷ Energy demand in transport by fuel and scenario, 2023-2050



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Electricity reduces the dominance of oil across scenarios, while hydrogen and hydrogen-based fuels contribute to aviation and shipping

In 2024, some automakers in the United States appeared more cautious about investment in EV manufacturing plants, as customer demand fell short of industry expectations. However, despite challenges in meeting short-term targets, automakers still aim for more than 40 million EV sales in 2030, which is reflected in the STEPS. Affordability and charging infrastructure need to be addressed to overcome potential bottlenecks. Declining battery prices should enable automakers to offer increasingly cost-competitive EV models, supported by policies such as the Infrastructure Investment and Jobs Act in the United States which aims to improve charging infrastructure. In other regions, notably in Asia, battery swapping presents a promising option to alleviate range anxiety for both cars and trucks.

By 2030, oil demand in the transport sector in the STEPS remains at current levels despite an increase in passenger activity of more than 30% and of nearly 15% in freight activity. EVs are largely responsible for this change, as their dissemination shifts an increasing share of energy demand in transport from oil to electricity. The share of road transport activity accounted for by EVs rises from 4% today to around 17% in 2030 in the STEPS, around 20% in the APS, and nearly 30% in the NZE Scenario which leads to additional electricity demand of 850 TWh, 1 000 TWh and 1 500 TWh respectively. Other changes also contribute. Micromobility,

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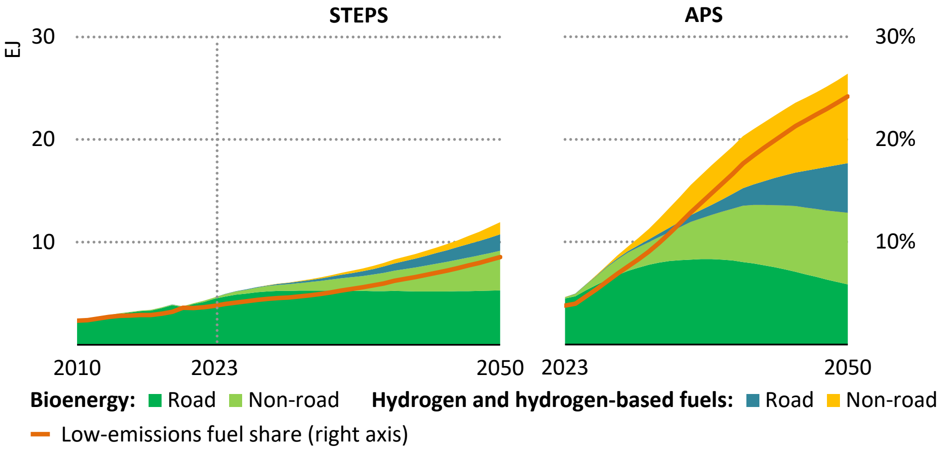
particularly with uptake of electric bikes (e-bikes)[2], is gaining traction, especially in urban areas (Box 3.2). Public transportation continues to play a crucial role, with the world's bus fleet increasing by over 15% by 2030 and urban rail activity rising 25% by then (see Chapter 5).

Figure 3.10 ▷ Low-emissions fuels in transport by type in the Stated Policies and Announced Pledges scenarios, 2010-2050



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Hydrogen and hydrogen-based fuels overtake bioenergy in aviation and shipping by the early 2040s in the APS

Electrification and energy efficiency are the key pillars to decarbonise road transport. It also plays a central part to decarbonise rail transport, with 75% of rail activity electrified by 2030 in the STEPS. Low-emissions fuels such as biofuels and hydrogen also contribute to decarbonisation, particularly in non-road modes of transport such as aviation and shipping. In aviation, sustainable aviation fuels have a pivotal role to reduce emissions, meeting 2% of energy demand for aviation by 2030 and over 10% in 2050 in the STEPS. In the APS this rises to 5%, and in the NZE Scenario to over 10% of aviation energy demand by 2030, slightly increasing overall aviation costs (IEA, 2024c). In shipping, International Maritime Organization (IMO) targets for decarbonisation play a central part in ammonia and hydrogen taking a 4% share of shipping energy demand by 2030 in the APS, with low-emissions methanol accounting for another 8% and bioenergy for a further 10%. The reduction in global oil demand in road transport also contributes to lower emissions from shipping by decreasing oil shipments. By 2030, lower global oil demand in the APS reduces energy demand from international oil tankers by 15%.

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[2] E-bikes include pedal-assisted bikes with an electric motor and do not include electric motorbikes or three-wheelers. E-bikes are not included as two/three-wheelers in the IEA GEC model.

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Low-emissions fuel consumption in the transport sector is set to rise by 30% in 2030 and to more than double by 2050 from current levels in the STEPS (Figure 3.10). Bioenergy plays a significant role in this, particularly in shipping and aviation. In the APS, low-emissions fuels help avoid 550 million tonnes of carbon dioxide (Mt CO_2) emissions in road transport by 2030, and additional bioenergy is used in subsequent years to meet announced pledges, mostly in aviation and shipping. Hydrogen and hydrogen-based fuels see substantial growth as they become more cost competitive in this scenario, with levels of use rising from 7 petajoules (PJ) today to 900 PJ in 2030 and 13 500 PJ in 2050: most of the hydrogen is used for road transport, and all of the ammonia is used in shipping. While low-emissions fuels are crucial to decarbonise challenging sectors like aviation and shipping, energy efficiency improvements remain vital, and they result in 2 100 PJ of avoided demand by 2030 in the STEPS and 2 600 PJ in the APS in non-road transport sub-sectors, mostly thanks to new and more efficient stock replacing older models.

Emissions reductions in shipping and aviation are driven in part by policy changes. The European Union is setting the pace with its ReFuelEU Aviation Regulation that seeks to boost the uptake of sustainable aviation fuels in the European Union by setting targets for a 6% blend share by 2030 and a 20% share by 2035. The FuelEU Maritime Regulation meanwhile targets a reduction of 80% in the emissions intensity of fuel used in shipping in the European Union by 2050, while intergovernmental policies such as the IMO Energy Efficiency Design Index, the Energy Efficiency Existing Ship Index and the Carbon Intensity Indicator are also set to drive significant efficiency improvements in shipping.

Box 3.2 ⊳ Micromobility and the role of e-bikes

More than 65 million e-bikes were sold worldwide in 2023, of which 80% were in China. E-bike sales have already surpassed conventional two/three-wheelers, which sold 55 million units in 2023. E-bikes have rapidly gained popularity in urban and suburban areas. They contribute to a sustainable transportation mix. IEA analysis suggests that e-bikes displaced 70 thousand barrels per day (kb/d) of oil demand in 2023 by reducing the use of cars. Their impact is set to broaden further in the years ahead (Figure 3.11).

E-bikes provide affordable private transport, solving the “last-mile” problem of public transit by helping passengers to reach their destinations while also reducing local air pollution. E-bike user surveys show that e-bikes typically are used to cover distances of 3-24 kilometres, and that they replace a wide range of other modes of passenger transport in urban areas, including public transport, walking, non-electric cycling and journeys by car (Bourne et al., 2020). E-bike sharing schemes, when complemented by adequate cycling infrastructure, further add to the potential of e-bikes to reduce emissions. Charging stations in urban areas are essential to encourage the widespread adoption of e-bikes and to help with the management of e-bike parking area consolidation. Currently, over 1 500 cities worldwide offer e-bike park-and-ride share programmes (Bike Sharing World Map, 2022) (see Chapter 5).

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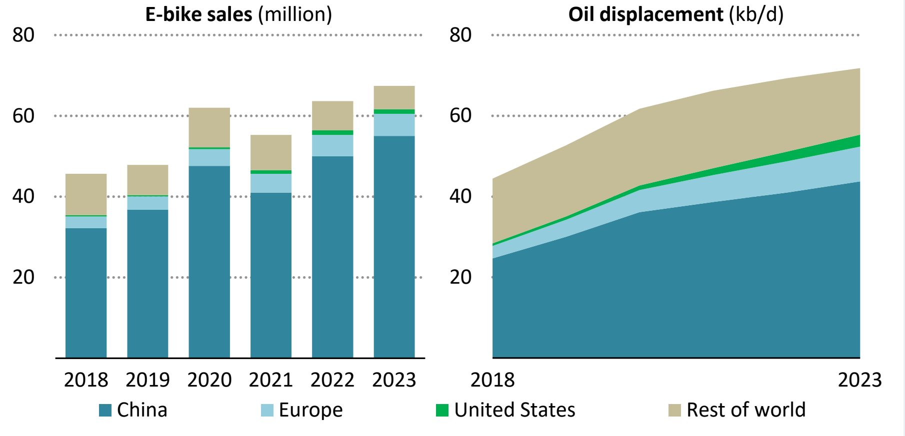
Figure 3.11 ▷ E-bike sales and displaced oil demand, 2015-2023



Continued growth in e-bike adoption and usage displaced 70 kb/d of oil from passenger cars globally in 2023

Note: kb/d = thousand barrels per day.

Sources: IEA analysis based on data from US DOE (2023), Huajing Industry Research Institute (2023) and CONEBI (2024).

Conventional cycling also has an important part to play in urban and suburban transport. In Bogotá and Guangzhou, around 6% of passenger-kilometres travelled on bicycle lanes would have otherwise been undertaken by car (ITDP, 2022). In Seville, construction of a bicycle lane network led to increased cycling and public transit use, while the expansion of the Vélib bike sharing network in Paris in recent years has contributed to cycling becoming more popular than driving.

3.3.2 Buildings

Energy demand in the buildings sector declined by 0.7% in 2023. After a decade when annual growth averaged over 1%, the recent fall was primarily due to a warmer winter leading to less demand for space heating, which outweighed increased demand in other end-uses. Natural gas use fell the most in 2023, dropping by over 4%, which added to the cut in demand seen in 2022 after the Russian invasion of Ukraine. Use of other fossil fuels in the buildings sector also declined in 2023. By contrast, electricity use continued to rise with its share of buildings sector demand at 37% in 2023, up from 31% in 2010, underpinned by expanding use in appliances.

This decade, energy demand growth in the buildings sector slows slightly to under 1% annually in the STEPS to reach 132 EJ in 2030 (Figure 3.12). This modest deceleration continues after 2030, with annual growth averaging 0.7% from 2030 to 2050, when energy

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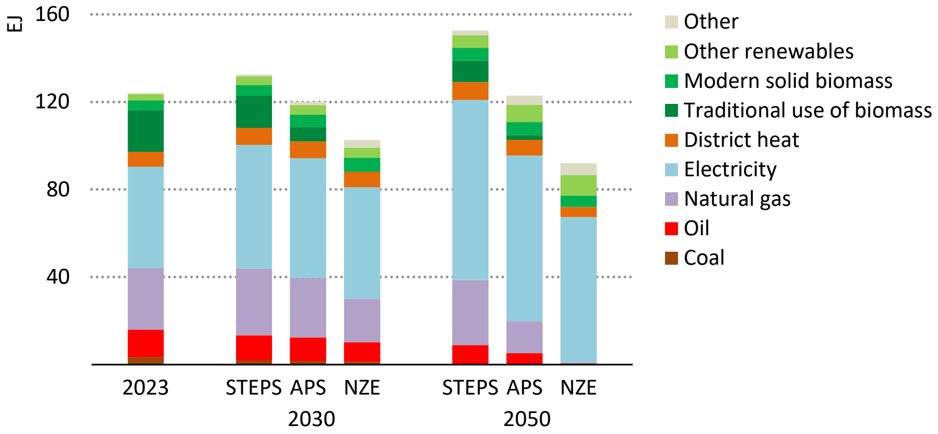
demand in the sector reaches 153 EJ. However, demand falls by an annual average of 0.5% in the APS to reach 120 EJ in 2030. It declines further in the NZE Scenario to just over 100 EJ by 2030. These varied outcomes are primarily shaped by the pace of advances in access to modern energy, with the faster shift away from highly inefficient traditional use of biomass to clean cooking in the APS and the NZE Scenario which bring substantial energy savings as well as social benefits (see Chapter 5). The wide variation across scenarios also reflects the different pace at which mature technologies are rolled out for other end-uses, with faster progress in the APS and NZE Scenario underpinned by higher levels of policy support.

Figure 3.12 ▷ Energy demand in buildings by fuel and scenario, 2023-2050



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Electricity use in buildings rises significantly in all scenarios through to 2050 while fossil fuel consumption declines from the mid-2020s

Notes: Other includes low-emissions gases, liquid biofuels and non-renewable waste. Other renewables include solar thermal and geothermal.

Electricity use in the buildings sector rises significantly both as a share of energy consumed and in absolute terms. In the STEPS, electricity increases to over 40% of energy consumed in buildings in 2030 and over 50% in 2050. This equates to an increase of 10 EJ by 2030 and over 35 EJ by 2050, mostly in emerging market and developing economies. Mounting demand for cooling and for data centres helps drive electricity demand growth (see Chapter 4, section 4.6.1). In contrast, fossil fuel use in buildings declines from the mid-2020s. Natural gas demand, which accounts for a larger share of energy demand in buildings than other fossil fuels, peaks in the late 2020s in the STEPS: it declines sooner and faster in other scenarios.

Energy use trends in the buildings sector vary sharply by economic grouping. The share of advanced economies in total consumption in buildings falls from around 50% in 2000 to 30% in 2050 in the STEPS (Figure 3.13). Demand from the buildings sector in advanced economies

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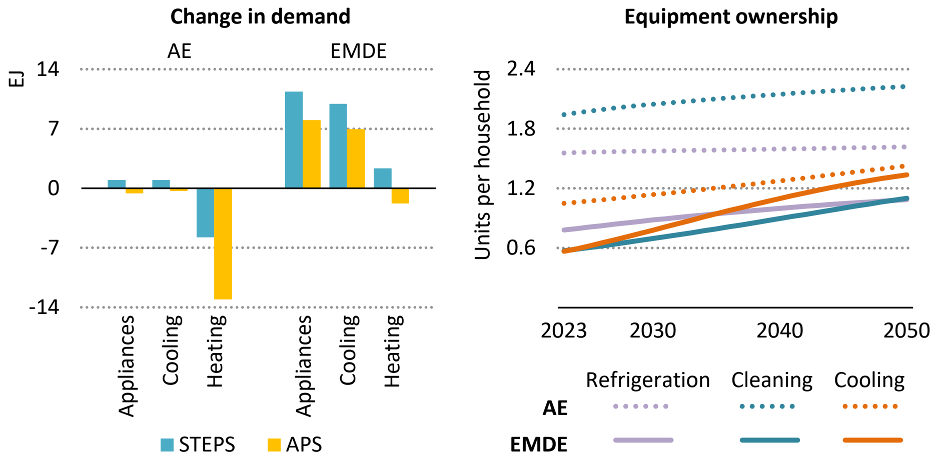
is only slightly higher in 2030 than it was in 2023: it then declines at an average annual rate of around 0.3% to 2050. Energy demand in the sector in emerging market and developing economies, by contrast, increases by an annual average 1.5% to 2030 in the STEPS, and then by 1.3% until 2050. As a result, emerging market and developing economies add over 30 EJ to global energy demand in the buildings sector by 2050, including over 7 EJ in China, nearly 4 EJ in Southeast Asia and over 2 EJ in India. In the APS and NZE Scenario, this demand growth slows after 2030, respectively averaging 0.9% and 0.3% annually.

Figure 3.13 ▷ Energy demand in buildings by end-use and scenario, and equipment ownership rates, 2023-2050



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Demand for space heating falls sharply in advanced economies, while demand for appliances and cooling rises rapidly in emerging market and developing economies

Notes: AE = advanced economies; EMDE = emerging market and developing economies. Appliance demand includes cleaning, refrigeration and consumer electronics, but excludes space cooling. Heating demand is space heating. Cleaning equipment includes washing machines, clothes dryers and dishwashers. Cooling equipment refers to air conditioners only.

The balance of energy consumption in the buildings sector by end-use shifts significantly from space heating to space cooling and appliances over the coming decades. In the STEPS, space heating demand drops by nearly 6 EJ by 2050 in advanced economies as a result of existing policies and incentives, and a warming climate. In the APS, demand falls by 13 EJ reflecting new initiatives such as the European Union's revised Energy Performance of Buildings Directive, the 6th Strategic Energy Plan in Japan, and the Zero Emissions Building Standard in the United States. In emerging market and developing economies, space heating demand is heavily concentrated in a few large markets, notably China and Russia. Objectives for new buildings and retrofits outlined in China's Action Plan for Carbon Peaking help to reduce heating demand in emerging market and developing economies in 2050 by nearly 2 EJ in the APS.

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Meanwhile demand for space cooling in emerging market and developing economies is set to rise by nearly 10 EJ by 2050 in the STEPS. Driven by rising incomes, growing population and a warming climate, it accounts for around 14% of total energy demand in buildings by 2050, up from below 7% today. Energy demand for use in other appliances rises more moderately but from a higher base, increasing by 11 EJ by 2050 in emerging market and developing economies. While partly due to population growth, the biggest driver is economic growth leading to higher appliance ownership. In lower-middle income countries, such as India and Indonesia, current ownership rates are often around a third of those in advanced economies, and their rapid economic growth is set to reduce this gap significantly by mid-century. Conversely, in upper-middle income countries, such as China and Brazil, ownership rates for certain appliances, e.g. refrigerators and washing machines, are nearing those in advanced economies.

Can new global initiatives moderate fast-growing cooling demand?

Momentum is picking up in efforts to moderate rapid growth in energy demand for cooling. At the international level, dedicated fora have been established through the Buildings Breakthrough, the Chaillot Declaration and Global Cooling Pledge. Many countries are now assessing what measures should feature in national plans to manage growth in cooling demand. Stringent minimum energy performance standards for air conditioners and mandatory building codes for new construction are needed.

Space cooling has seen faster growth than any other major end-use in the buildings sector since 2000, increasing an average of 4% per year. This continues in the STEPS through to 2050, with an annual average rise of 3.2%. Energy demand for cooling worldwide increases by almost 4.5 EJ by 2035, which is more than all current electricity use in the Middle East. Around 75% of this increased energy demand for cooling is in non-OECD Asia, with the largest absolute growth in India and China. Mounting energy demand for cooling is the largest driver of increasing peak electricity demand from buildings in emerging market and developing economies (see Chapter 5, section 5.2.2). Ownership levels for air conditioners in emerging market and developing economies rise from below 0.6 per household in 2023 to close to 1 per household by 2035, in line with the current level in advanced economies (Figure 3.14). A warming climate also increases energy demand for cooling applications. Some regions are more exposed than others, and rising demand could be amplified if extreme temperatures become more common (see Chapter 4, section 4.6.2).

In the STEPS, energy demand growth for cooling is partly mitigated by energy efficiency measures, with nearly all efficiency savings related to minimum performance standards for air conditioners. While such standards are already widespread – covering around 90% of global energy consumption from space cooling – many of these measures are in their infancy and set requirements that fall far short of current potential. On a life cycle basis, efficient air conditioners cost no more than less efficient options, and in some countries they cost less. The APS reflects commitments from countries to raise energy performance standards over time to garner this cost-effective potential.

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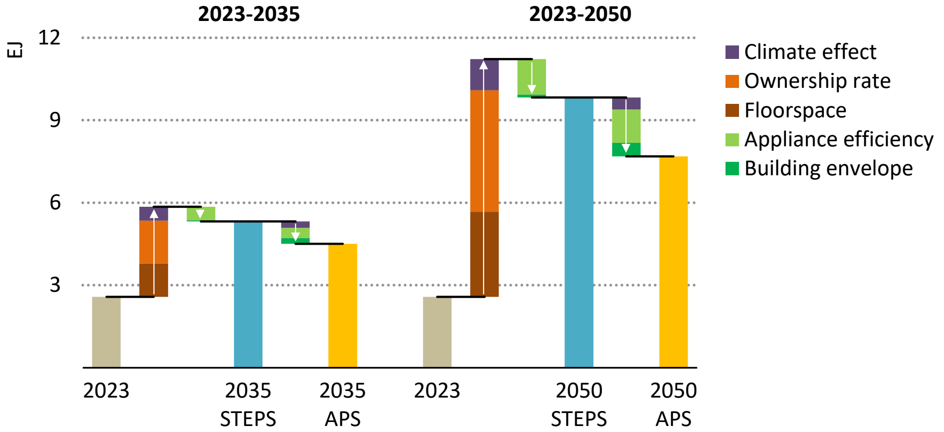
Figure 3.14 ⊳ Residential cooling demand in emerging market and developing economies by driver and scenario, 2023-2050



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Energy use for residential cooling rises 280% by 2050 in the STEPS; with only limited efforts to address building envelopes, it still rises by nearly 200% in the APS

Notes: Climate effect reflects higher utilisation rates of air conditioners due to higher temperatures, whereas ownership rate reflects higher ownership level due to economic and population factors. Rising temperatures increase cooling demand over time, but lower projected emissions decrease this climate effect in the APS compared to the STEPS.

Even in the APS, residential cooling demand in emerging market and developing economies triples from 2.6 EJ to 7.7 EJ by 2050. Among countries that have established net zero emissions targets, pledges to cut cooling emissions by 2030 have so far focussed on appliance efficiency. Few countries have set goals to improve building envelopes this decade, and less than half of new construction in emerging market and developing economies in 2030 is compliant with building codes in the APS. However, there are signs of change. Under the Buildings Breakthrough initiative, 27 countries committed to make nearly zero-energy and resilient buildings the norm by 2030. This includes 15 emerging market and developing economies, the majority of which currently lack mandatory building codes for new construction. More recently, 70 countries signed the Chaillot Declaration, which aims to improve the resilience and efficiency of new buildings, as well as material efficiency and passive performance of building retrofits. This follows a variety of recent national initiatives that address the efficiency of both building envelopes and technical building systems, e.g. new national cooling strategies in Cambodia, Viet Nam and Kenya. Translating these initiatives into effective national policies can help mitigate increased energy demand for cooling applications. In the NZE Scenario, where minimum energy performance standards and mandatory codes for new construction are matched by policies that significantly boost retrofit rates, the demand increase by 2050 is limited to 90%.

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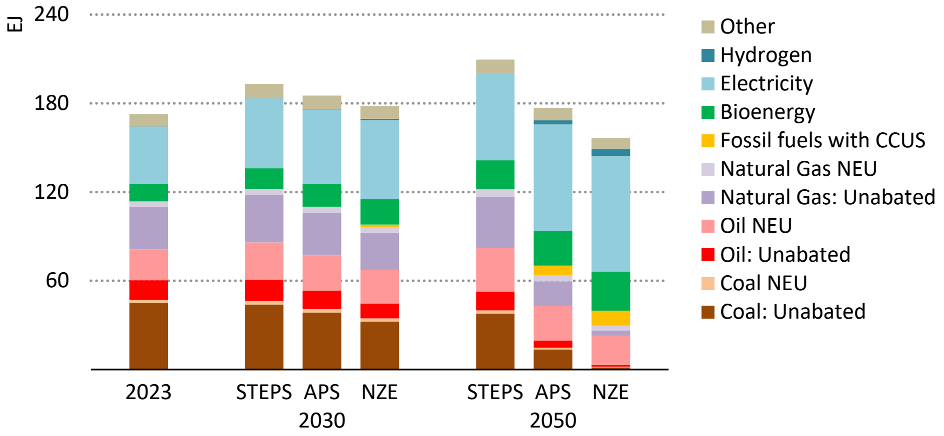
3.3.3 Industry

The industry sector produces basic materials used across the global economy, including the materials required for decarbonisation. However, it is also the most CO_2-intensive end-use sector, accounting for almost half of total final consumption emissions. Industrial energy use is concentrated in emerging market and developing economies, which account for more than 70% of the global total. Energy demand from industry increased by 2% in 2023 and emissions by less than 1%.

Fossil fuels continue to play an important role in the industry sector in the STEPS, meeting a broadly constant share of demand (Figure 3.15). Coal is widely used for steel and cement production: its use begins to fall towards the end of the decade in some regions with large industrial consumption, notably China, Europe, Japan, Korea and United States, but global natural gas consumption rises moderately as additional LNG capacities come online. However, fossil fuel use does reduce significantly in the APS and NZE Scenario after 2030 (Box 3.3).

Figure 3.15 ▷ Energy demand in industry by fuel and scenario, 2023-2050



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Fossil fuels continue to dominate energy demand in the industry sector until the end of this decade; electrification, bioenergy and CCUS reduce this reliance after 2030 in the APS

Notes: CCUS = carbon capture, utilisation and storage; NEU = non-energy use. Where low-emissions hydrogen is produced and consumed onsite at an industrial facility, the fuel input, such as electricity or natural gas, is reported as final energy consumption, not the hydrogen output.

The share of electricity in industry energy demand increases gradually over time, rising from 22% in 2023 to 25% in 2030 in the STEPS and to 27% in the APS by 2030. More than half of the additional electricity demand is in China, where electricity-intensive clean energy technology manufacturing gains importance. Bioenergy already plays an important role in non-energy-intensive industries; its consumption also increases in the APS by 50% in energy-

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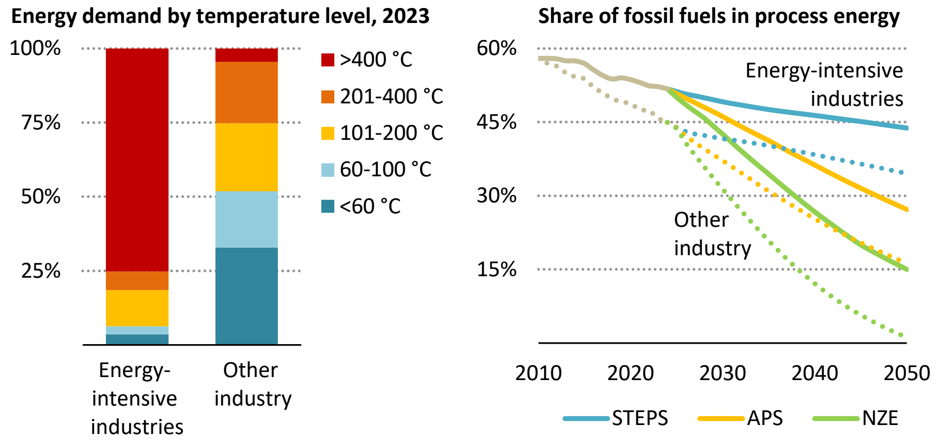
intensive industries, rising from 5 EJ to 7.5 EJ between 2023 and 2030. By contrast, bioenergy demand in STEPS only increases by 10% to 5.5 EJ.

The industry sector is reliant on high-temperature heat to drive chemical processes, particularly in energy-intensive industries (Figure 3.16). These industries accounted for almost three-quarters of energy use in the sector in 2023, but only around one-fifth of the value added. Technology options to avoid emissions from fossil fuel use for high-temperature applications mostly are not yet mature. Yet, many technologies are now advancing beyond the prototype stage: most of them use CCUS and electrolytic hydrogen, but some involve direct electrification, for example, electric steam crackers. Direct electrification is more straightforward for non-energy-intensive industries: around half of the thermal energy that they require is used at less than 100 degrees Celsius (°C) and can be supplied at competitive prices by heat pumps, which can also be competitive at higher temperatures (in the 100-200 °C range). Resistance heating, bioenergy or low-emissions hydrogen are alternative solutions: their growing use plays a major part in reducing unabated fossil fuel use to 20% by 2050 in the APS and phasing it out almost completely in the NZE Scenario.

Figure 3.16 ▷ Energy demand by temperature level and fossil fuel use in industry by type and scenario, 2010-2050



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Energy-intensive industries rely on high-temperature heat and source more energy from fossil fuels

Current project announcements featuring near-zero emissions technologies fall short of what is required in the NZE Scenario. For example, only 19 Mt CO_2 of CCUS capacity is installed in the STEPS by 2030, which is 31% of the amount captured in the APS and just 7% of what is needed in the NZE Scenario. Asset lifetimes in heavy industry, particularly steel and cement plants, are usually at least around 25 years, so changing technologies is a slow

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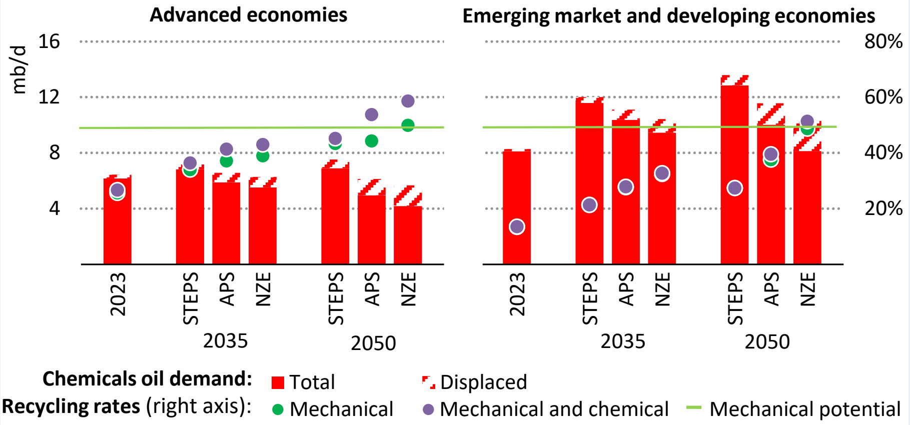
process. For example, while additions of conventional capacity without abatement potential end in the NZE Scenario by 2030, slow turnover of the stock of older capacity means that it takes until after 2040 for most of the stock to be using innovative technologies. Investment certainty is needed to enable near-zero emissions technology projects to go ahead. Some countries are moving in that direction: for example, Germany launched first carbon contracts for difference auctions in 2024 to reduce price risks for energy-intensive industries, while the Green Innovation Fund in Japan will support the decarbonisation of manufacturing-related industries until 2030.

Box 3.3 ▷ Increasing recycling potential through chemical processes

Recent policy initiatives stimulated over 90 countries to pass a full or partial ban on single-use plastics and more than 20 to establish recycling targets and collection policies. Nonetheless, plastic waste collection for recycling has increased only relatively modestly: 12% of global plastic waste was collected for recycling in 2010, which rose to just 19% in 2023, with marked differences between the collection rates in advanced economies (27%) and emerging market and developing economies (13%). Policy momentum would be boosted by the conclusion of the United Nations' treaty to end plastic pollution, which has been under negotiation since 2022.

Figure 3.17 ▷ Chemicals oil demand and plastic recycling by region and scenario, 2023-2050



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Chemical recycling can expand recycling rates beyond mechanical recycling potential; both methods help to offset 2.7 mb/d of oil by 2050 in the APS

Notes: mb/d = million barrels per day. Total recycling = mechanical + chemical recycling.

Sources: Mechanical recycling potential is based on IEA analysis. IEA GEC model results are based on the OECD plastics database, OECD (2024).

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Most recycled waste today is processed mechanically[3], but the variety of plastics being used limits the growth potential of this technology.[4] Chemical recycling is gaining traction as a complementary technology with the potential to raise recycling rates above the mechanical recycling potential. It is currently used to process around 1.3 million tonnes (Mt) of plastic waste each year, and this rises in the APS to 6 Mt by 2035, or 5% of total recycled waste (Figure 3.17). In the NZE Scenario, chemical recycling is widely adopted in advanced economies and leads by 2050 to the recycling of 23 Mt of plastic waste, displacing an additional 0.5 million barrels per day (mb/d) of oil beyond what can be achieved through mechanical processing alone. Advanced economies nearing their mechanical recycling limits are well-positioned to lead in adopting chemical recycling. Its uptake at scale is dependent on investment in research, development and deployment to improve the efficiency of chemical recycling technologies and to reduce their costs. This would benefit not only advanced economies but also emerging market and developing economies as they reach the limits of their mechanical recycling capabilities in the coming decades.

Yet however efficient plastic recycling becomes, significant amounts of virgin plastic will still be needed because recycled plastic is not suitable for all uses and industries. Even in the NZE Scenario, oil use in the chemical sub-sector remains close to the current level, over 12 mb/d, in 2050. Reducing emissions from continuing plastics production calls for a range of measures to reduce demand for plastic, advance the development of bioplastics (within biomass availability constraints), electrify the steam crackers used to produce plastics, and make use of CCUS. (For more details about plastics, see *The Future of Petrochemicals* [IEA, 2018]).

3.4 Electricity

The electricity sector is the largest emitting sector in the world today, accounting for 36% of global energy-related CO_2 emissions in 2023. Electricity demand has grown at nearly twice the rate of overall energy demand over the last decade and is accelerating as the global economy becomes increasingly electrified. Clean energy transitions are underway, with solar PV and wind regularly setting records for growth, helped by policy support, low technology costs and the widespread potential for their deployment. Coal nevertheless remains the largest source of electricity, and fossil fuels still account for 60% of global electricity supply. The speed of clean energy transitions in the electricity sector in the years

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[3] Mechanical recycling involves the processing of plastic waste without altering the molecular structure. Chemical recycling changes the structure of the polymeric waste and transforms it into chemical building blocks, including monomers, which can then be used as raw material in chemical processes, reducing the need for virgin fossil resources. Some examples are gasification, pyrolysis and depolymerisation.

[4] The wide variety of plastic compositions, additives and manufacturing methods makes it difficult to process them together effectively. Different types of plastics can contaminate each other, leading to lower quality recycled materials. Also, food residues, dirt and other contaminants can affect the quality of recycled plastic.

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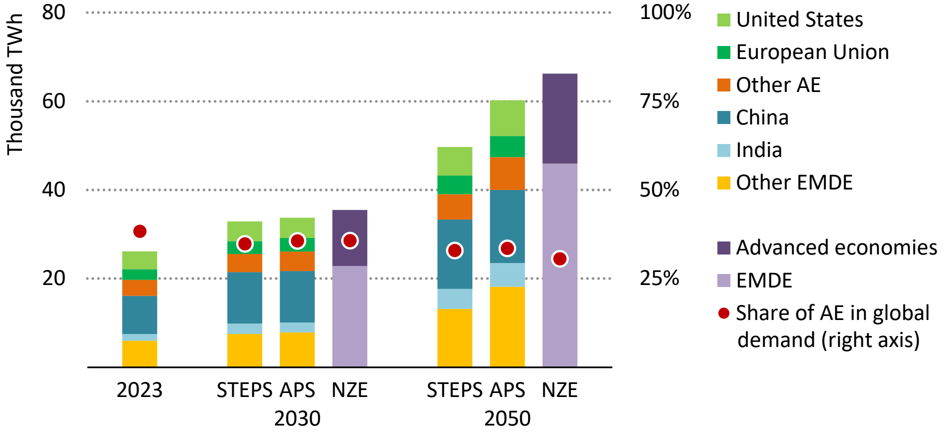
ahead will be a critical determinant of global CO_2 emissions trends and the level of long-term temperature increases.

3.4.1 Electricity demand

Global electricity demand rose by more than 2.5% in 2023, a rate similar to the average over the past decade. Two-thirds of the increase in demand since 2013 was from China, driven by electrification of industrial processes and by growth in electricity demand for appliances and cooling. Other regions where demand has increased rapidly include India, the Middle East and parts of Southeast Asia, where buildings have played a major role in electricity demand growth. Uncertainties around electricity demand growth are explored in Chapter 4.

From 2023 to 2030, average annual electricity demand growth accelerates to 3.3% in the STEPS, over 3.5% in the APS, and 4.5% in the NZE Scenario. From 2023 to 2050, these growth rates range from 2.4% in the STEPS to over 3% in the APS and 3.5% in the NZE Scenario. Emerging market and developing economies account for about 70% of the additional electricity demand through to 2050 across all scenarios (Figure 3.18). China alone contributes about 45% of the increase to 2030, and around 25% between 2030 and 2050. India becomes the third-largest electricity consumer in the world by 2050 on the back of growth in demand of over 4% a year in all scenarios. Other emerging market and developing economies also experience robust demand growth, while advanced economies see lower annual average growth rates through to 2050 which range from 1.8% in the STEPS to 2.6% in the NZE Scenario.

Figure 3.18 ▷ Electricity demand by country/region and scenario, 2023, 2030 and 2050



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Advanced economies currently account for nearly 40% of global electricity demand, but their share decreases over time across scenarios

Note: TWh = terawatt-hours; AE = advanced economies; EMDE = emerging market and developing economies.

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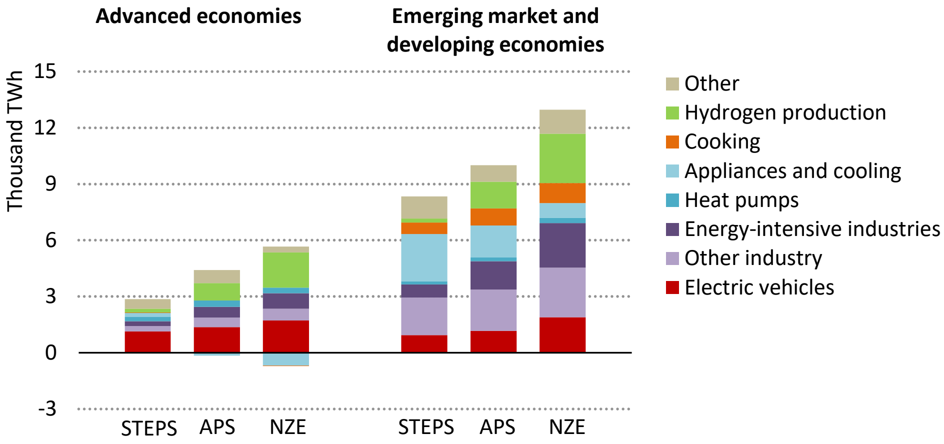
Global electricity demand nearly doubles by 2050 in the STEPS, more than doubles in the APS and increases 2.5-times in the NZE Scenario. These are big differences: the additional demand in the APS compared with the STEPS is roughly equivalent to the current combined electricity demand of China and India, while the additional demand in the NZE Scenario compared with the APS is roughly equivalent to the current demand of the European Union and United States combined. By 2030, the share of electricity in total final consumption reaches 23% in the STEPS, up from 20% today: it reaches around 30% in China, Japan and South Africa. In the APS, the share of electricity rises to 25%, and in the NZE Scenario it reaches nearly 30%.

In advanced economies, ambitious policies supporting the adoption of EVs drive 40% of the additional electricity demand until 2035 in the STEPS (Figure 3.19). Heat pumps, appliances and air conditioning units also help drive up demand, as do the burgeoning power demands of artificial intelligence and data centres. Much of the additional demand projected in the APS comes from the industrial sector, where an increasing number of demonstration projects use electricity in energy-intensive industries while at the same time the electrification of light industries proceeds more rapidly than in the STEPS.

Figure 3.19 ▷ Electricity demand growth by application and scenario, 2023-2035



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EVs drive electricity demand growth in advanced economies; economic progress raises demand for appliances and light industries in emerging market and developing economies

In emerging market and developing economies, the building sector contributes the majority of additional growth by 2035. Increasing ownership of appliances and rising demand for air conditioning also make major contributions to rising demand, together with the electrification of industrial production, especially in China. In the APS, more stringent minimum energy performance standards and widespread development of energy ratings for

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appliances and air conditioners reduce buildings electricity demand by 10% in 2035 compared with the STEPS.

Buildings remains the sector that uses the most electricity in both the STEPS and APS, with the industry sector in second place. In the NZE Scenario, however, industry becomes the largest sectoral user of electricity by late 2020s as a result of the rapid electrification of light industries and the use of electricity in onsite hydrogen production for steel and chemicals. Rising EV sales are responsible for over 20% of total electricity demand growth by 2050 in the STEPS, and for an even higher proportion in the APS and NZE Scenario. Hydrogen production via electrolysis also increases electricity demand by 7 000 TWh in the APS by 2050, or about 25% of current total electricity demand, and by 12 000 TWh in the NZE Scenario: this accounts by itself for 20% of the increase in the APS, and 30% in the NZE Scenario.

Box 3.4 ▷ How will electrification change demand patterns?

Increasing electrification, especially of new end-uses, is set to change the magnitude and patterns of hourly electricity demand. Electricity load patterns will look very different in 2050 from today's limited variations across the day, but action can be taken to manage them: heat pumps and air conditioners will increase winter and summer demand, while EV charging will drive a surge in the evening. In the European Union, evening peak demand in 2050 is set to dominate the daily pattern of demand, significantly changing the daily profile that is visible today (Figure 3.20). This reflects to a large extent growth in EV ownership: while EVs account for around 22% of daily electricity demand by 2050 in the STEPS, their share in the evening is much higher at almost 30%. In India, the daily variability of electricity demand averaged 15% in 2023 and is set to almost triple by 2050. Cooling will become the most important driver of daily variability in demand, though higher levels of appliance ownership and EVs are set to affect it as well.

However, if well-incentivised and planned, the end-uses that are on course to generate peaks in the future can also provide demand management solutions that lower those peaks. By 2050, solar PV capacity is sufficiently large to drive electricity prices down for several hours a day, every day: this could be reflected in retail tariffs, which could in turn incentivise a shift to the hours when tariffs are low and reshape demand patterns. Demand flexibility can thus be planned in advance and managed, and our scenarios assume that this is what happens. EVs, heating and cooling provide the largest potential, and contribute to 80% of activated demand flexibility. Around 10% of electricity demand is shifted over the day in both the European Union and India. Evening peaks are reduced by up to 20% and midday consumption increased by around 20%, maximising efficient integration of renewables and reducing the need for peaking power plants (see Chapter 5, Box 5.2). The increasing adoption of smart meters and other advanced technologies as well as dynamic pricing mechanisms is essential if electricity demand is to be successfully managed in this way in response to grid needs.

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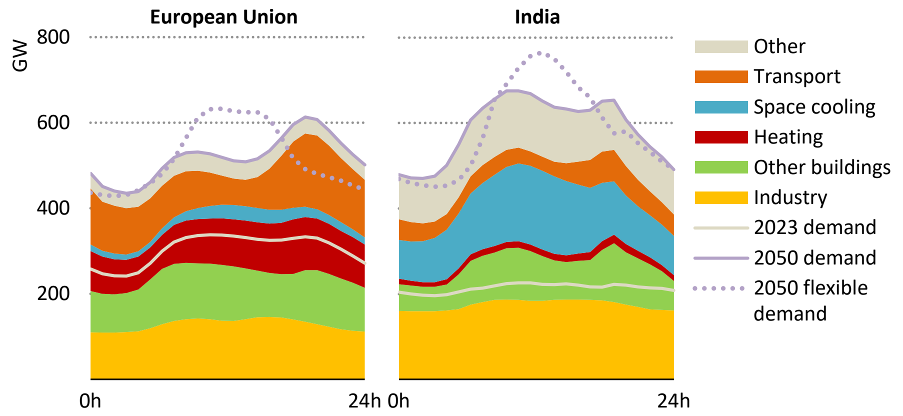
Figure 3.20 ▷ Daily average electricity demand by end-use in European Union and India in the STEPS, 2023 and 2050



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Daily electricity demand is reshaped as end-uses are electrified, with new technologies providing opportunities to make demand more flexible

Notes: GW = gigawatts; h = hour. Heating covers space and water heating; other buildings includes lighting and cooking; other includes agriculture.

3.4.2 Electricity supply

In 2023, fossil fuels provided 60% of global electricity supply — their lowest share of the total in the past 50 years. Coal accounted for the largest share of the total, 36%, with natural gas also playing a major part at 22%. Beyond fossil fuels, nuclear power declined slightly to a 9% share, which is half as much as 30 years ago. Despite a decline in hydropower output, renewables reached 30% of global electricity generation for the first time, with wind and solar PV together providing 13%, double the level just five years before.

Renewables, led by solar PV and wind, are set to play a much larger role in power systems over the next decade and beyond. In the STEPS, solar PV and wind combined generation nearly triples from 2023 to 2030, accounting for over 90% of electricity supply growth and overtaking coal, which peaks around 2025 and then starts a steady decline (Figure 3.21). By 2035, solar PV and wind provide over 40% of electricity generation, a level that few countries have managed to date. Increased use of solar and wind on this scale requires action to modernise grids and expand power system flexibility, including through the development of multiple forms of energy storage (see Chapter 5). Hydropower output depends on precipitation and air temperatures and therefore varies from year to year, but the overall trend is one of slow growth. Nuclear power also steadily increases at the global level, while natural gas-fired power reaches a peak in the late 2020s before stabilising at around the current level.

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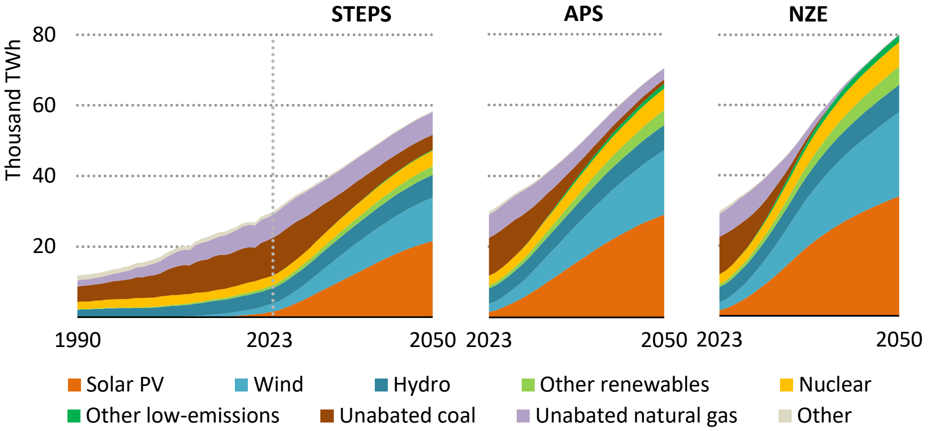
More ambitious scenarios rely heavily on renewables to accelerate transitions. In the APS, the expansion of wind and solar PV is faster than in the STEPS and is complemented by stronger growth of other renewables and nuclear power: this drives down unabated coal-fired power by almost 60% by 2035 and cuts natural gas use by 20%. In the NZE Scenario, additional renewables, further nuclear power, and the development and deployment of carbon capture technologies and low-emissions hydrogen fully decarbonise the electricity sector by 2040: unabated coal is fully phased out by this date, and unabated natural gas is reduced by 80%.

Figure 3.21 ▷ Global electricity generation by source and scenario, 1990-2050



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After decades of fossil fuels generating most of the world's electricity, renewables are set to become the main pillar of electricity supply

Notes: TWh = terawatt-hours. Other renewables includes bioenergy, geothermal, concentrating solar power and marine; other low-emissions includes fossil fuels with CCUS, hydrogen and ammonia. Other includes non-renewable waste.

Many governments around the world have policies in place to help drive clean energy transitions in the power sector. Alongside electricity security, a key priority is the provision of support to expand renewable energy, which is often linked to specific targets. By 2023, 152 countries had set renewable electricity targets (REN21, 2024). A pledge to triple renewables capacity was announced by governments at the COP28. Many major economies now aim to increase renewable energy by 50% or more from its 2023 level by 2030, either in terms of capacity or share of electricity generation (Figure 3.22). Targets are set out in documents such as national energy and climate plans in the European Union, the 6th Strategic Energy Plan in Japan, the 10th Basic Plan in Korea, the 14th Five-Year Plan in China, the National Electricity Plan in India, the Development Plan in Indonesia, and various state-level renewable portfolio standards in the United States. Korea and India aim to more than double and Indonesia aims to more than triple the role of renewables by 2030.

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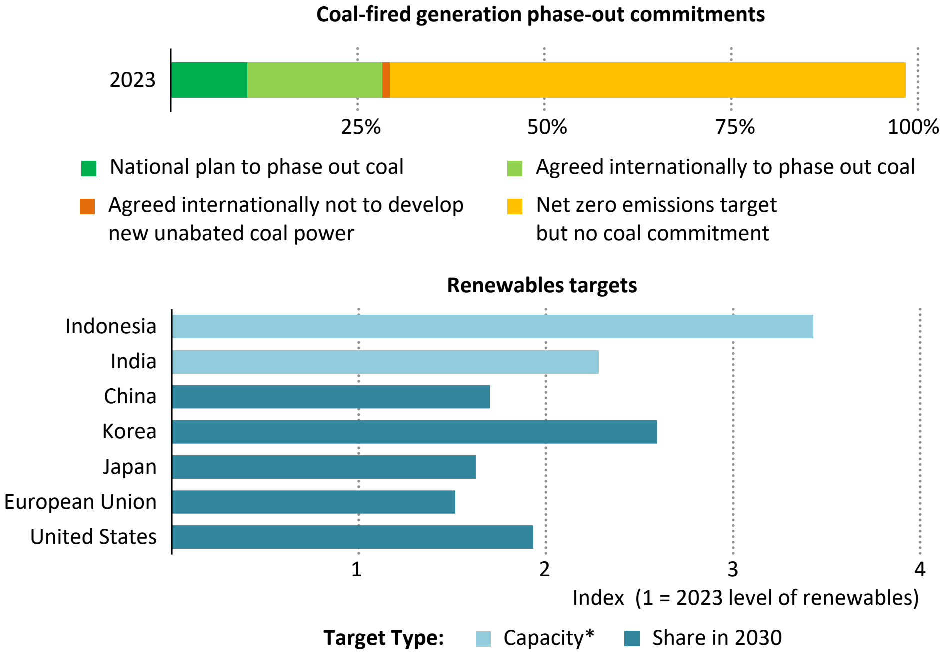
Figure 3.22 ⊳ **Share of global coal electricity generation with phase-out commitments in 2023, and renewables targets in selected countries/regions**



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Two clear priority areas have emerged in electricity sector policies: support for the expansion of renewables and measures to transition away from coal

Notes: Renewables targets estimated based on regional and national policies in the United States, European Union and China. *The renewable capacity target year in India is 2032 and in Indonesia is 2033.

A second key policy priority for many governments is the need to reduce or phase out the use of unabated coal-fired power generation. This reflects a recognition that the transition away from unabated coal is critical to any clean energy transition. Currently more than 95% of electricity generated from coal plants is covered by phase-out commitments or net zero emissions pledges. However, while many countries have net zero emissions targets, countries responsible for just 10% of electricity generation from coal have national plans in place to phase out the unabated use of coal. Although countries responsible for a further 20% have agreed internationally to phase out unabated coal or not to develop new unabated coal-fired power, there is a strong case for more to be done to announce and implement specific plans for coal in the context of wider emissions reduction goals. Austria, Belgium, Portugal and Sweden have already phased out coal-fired power. The United Kingdom closed its last coal-fired power plant in September 2024 and Slovakia aims to do so by the end of 2024.

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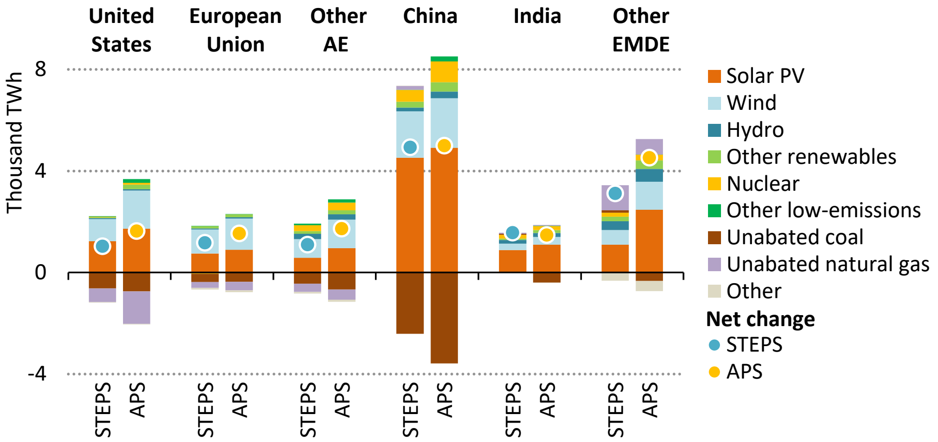
Beyond renewables and coal, there is widening policy support for energy storage, including the G7 agreeing to contribute to a global target of 1 500 GW of installed capacity by 2030, a sixfold increase from the level in 2023, with the aim of strengthening energy security and helping to integrate rising shares of renewables. Although pumped hydro and other forms of storage remain important, battery storage is poised to provide the lion's share of energy storage expansion in support of the target to triple renewables capacity by 2030 (IEA, 2024d). Installed battery storage capacity rises from almost 90 GW in 2023 to 850 GW in 2030 in the STEPS, over 1 000 GW in the APS and over 1 250 GW in the NZE Scenario, with the average duration increasing from around two hours currently to three hours in 2030.

Policy support for nuclear power has also risen in recent years. In December 2023, more than 20 countries pledged to triple global nuclear capacity by 2050. Notable developments in several European countries include extending operations for existing reactors in Belgium, lifting a ban on developing new nuclear plants in Switzerland, the identification of new builds as a priority in Sweden and Poland, and confirmation of the importance of nuclear in France. Many countries are showing interest in small modular reactors and the first projects outside China and Russia are expected to come online around 2030.

Figure 3.23 ▷ Change in electricity generation by source and country/region in the STEPS and APS, 2023-2035



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Solar PV and wind meet all electricity demand growth to 2035 in the STEPS in advanced economies and China, while other regions also see growth for natural gas-fired power

Notes: AE = advanced economies, EMDE = emerging market and developing economies. Other low-emissions includes fossil fuels with CCUS, hydrogen and ammonia. Other includes non-renewable waste.

In many countries, including China, the European Union and the United States, the expansion of wind and solar PV in the STEPS is able to meet all electricity demand growth over the next decade and also to displace some fossil fuel use (Figure 3.23). While renewables expand

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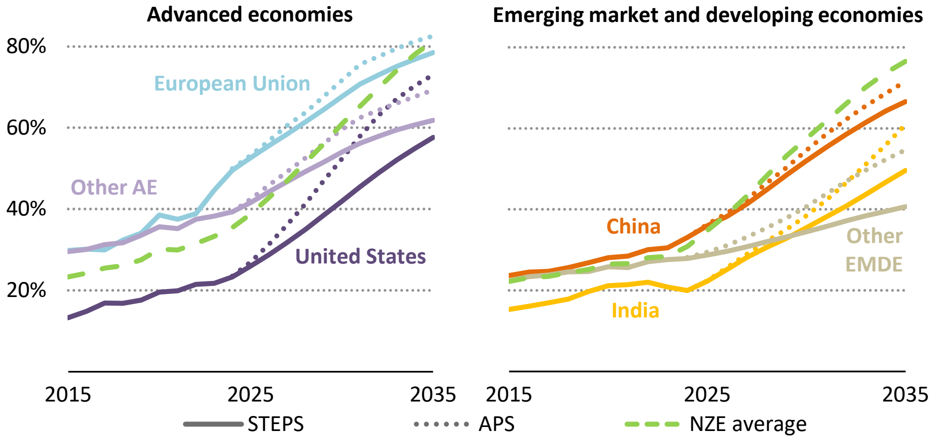
strongly in the STEPS, they are not able to meet all demand growth in India or other emerging market and developing economies to 2035, and those countries see increases in the use of coal and natural gas in their power systems. In the APS, faster renewables deployment and more robust action on energy efficiency mean that low-emissions sources of electricity are able to meet all electricity demand growth in nearly all major economies. While limitations of land availability present a challenge to the rapid expansion of renewables in some countries, globally there is more than enough available space for all solar PV and wind needed by 2050 in all our scenarios (IEA, 2023).

The share of renewables – including solar, wind, hydro, bioenergy, geothermal and marine – is set to increase significantly in most regions by 2035. In the European Union, it rises to over 70% of electricity generation by 2035 in the STEPS, which is almost in line with what is needed in advanced economies overall in the NZE Scenario, and to over 80% in the APS, which would deliver what is required by the NZE Scenario (Figure 3.24). The United States currently has a lower share of renewables in its electricity mix, and it makes up ground in the STEPS: further action to fulfil announced pledges, as in the APS, would not quite reach the NZE pathway, but would get it much closer. In emerging market and developing economies, China is set to obtain two-thirds of its generation from renewables by 2035 in the STEPS: another 10% would match the average rate needed in the NZE Scenario. India also makes significant gains, with renewables reaching 50% of electricity generation in 2035. Renewable energy technologies can also be deployed to produce low-emissions hydrogen, and in some cases individual projects may produce both electricity and hydrogen (Box 3.5).

Figure 3.24 ▷ Share of renewables in electricity generation by country/region and scenario, 2015-2035



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Renewables boost their share in electricity generation in all major economies in the STEPS, yet faster growth is needed to achieve national ambitions and net zero emissions targets

Note: AE = advanced economies, EMDE = emerging market and developing economies.

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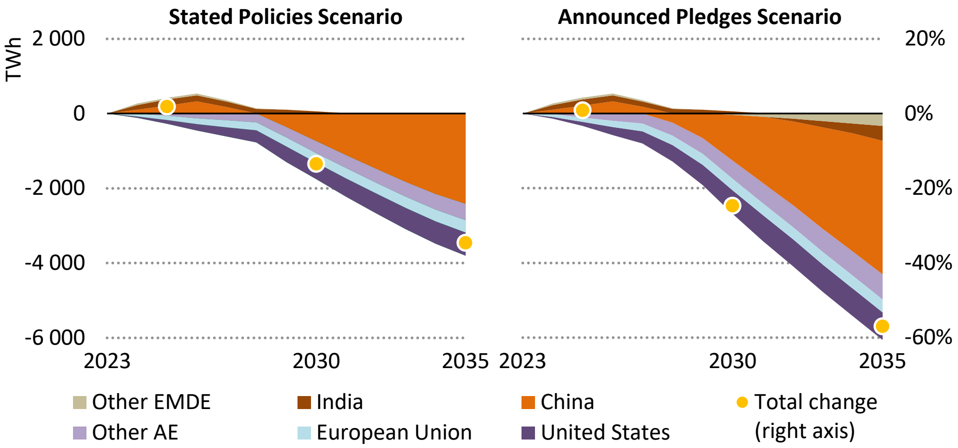
Global coal-fired power generation is set to peak around 2025 in the STEPS, with continued growth in the near term in China, India and Southeast Asia offset by reductions in the European Union, United States and other advanced economies (Figure 3.25). By 2030, however, coal use for power generation starts to decline in most regions, and by 2035 coal-fired power is down by one-third compared to today. In the APS, the fulfilment of all announced pledges, including Nationally Determined Contributions (NDCs), means that coal-fired power declines by more than 50% by 2035, with the biggest changes compared with the STEPS in China, India and other emerging market and developing economies. The NZE Scenario calls for an even steeper 85% reduction of unabated coal-fired generation by 2035 and a complete phase out by 2040. In the APS and NZE Scenario, the early retirement of coal plants accelerates, with electricity security maintained through an increase in energy storage capacity and in power system flexibility, some of which comes from demand-side management (see Chapter 5).

Figure 3.25 ⊳ Change in coal-fired power generation by country/region in the Stated Policies and Announced Pledges scenarios, 2023-2035



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Coal-fired electricity generation is set to peak around 2025, after near-term growth in China and India slow and reverse; advanced economies are already cutting the use of coal

Note: AE = advanced economies, EMDE = emerging market and developing economies.

Box 3.5 ⊳ Offshore wind for electricity or hydrogen production?

Offshore wind is a growing industry and is projected to capture an increasing amount of investment in 2030 and beyond in all scenarios. Its prospects are helped by falling technology costs and government policy support, as set out for example in the Ostend Declaration signed by the North Sea countries in Europe, the PDP8 in Viet Nam and the Offshore Wind Energy Roadmap in Colombia. Offshore wind projects today are focussed

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on generating electricity, but they are also increasingly being considered as a future means to produce low-emissions hydrogen.

Global offshore wind capacity is projected in the STEPS to increase from 73 GW in 2023 to 560 GW in 2035 and more than 1 000 GW in 2050, of which only 2% in 2050 is projected to be dedicated for hydrogen production. With faster clean energy transitions in the APS and NZE Scenario, the demand for both low-emissions electricity and hydrogen increases. Offshore wind capacity reaches 1 600 GW in 2050 in the APS, of which 15% is dedicated to hydrogen production, and 1 950 GW in the NZE Scenario, of which 20% is for hydrogen production.

Offshore wind projects can be designed to produce either hydrogen or electricity or both. The optimal choice of design varies with the surrounding energy system. In remote areas, projects devoted entirely to hydrogen production could be advantageous because it might be cheaper to transport hydrogen over long distances than it would be to transmit electricity. In areas that are close to existing grids, it might make most sense to focus on the production of electricity. In some areas, hybrid projects could prove to be the best option, if electricity market designs provide the right incentives. Hybrid projects can offer opportunities to optimise their value by selling into electricity or hydrogen markets. In the North Sea, hybrid projects are now under consideration by a variety of interested parties including national governments, private funds and consortia like the North Sea Wind Power Hub, which brings together leading transmission system operators in North Sea countries.

Delivering either electricity or hydrogen or both requires significant infrastructure investment to cover the costs of electrical equipment, subsea cables, pipes, pumps, offshore platforms and the production equipment itself. Hybrid projects would be especially complex and expensive, potentially costing tens of billions USD, and offshore hydrogen production relies on new and unproven technology. If such projects are to be developed, clear long-term planning and investment priorities will be critical, and a variety of governments, transmission system operators, developers and investors will need to work together and accept a share of the risks involved.

3.4.3 Power sector CO_2 emissions

Power sector CO_2 emissions were 15.3 Gt in 2023, up from 14.9 Gt in 2022, and accounted for 40% of the global energy-related total. Emissions would have fallen in 2023 from their 2022 level without a hydropower generation shortfall caused by droughts (IEA, 2024e). Growing demand for electricity means that emissions have risen in recent years despite decreasing carbon intensity in the power sector. Since 2010, around 70% of total power sector emissions are from coal, but the electricity mixes of both advanced economies and emerging market and developing economies now have CO_2 intensities 30-60% lower than that of coal. In the same period, the electricity mix of advanced economies has been on average one-third less carbon intensive and has been decarbonising more than three-times faster than that of emerging market and developing economies.

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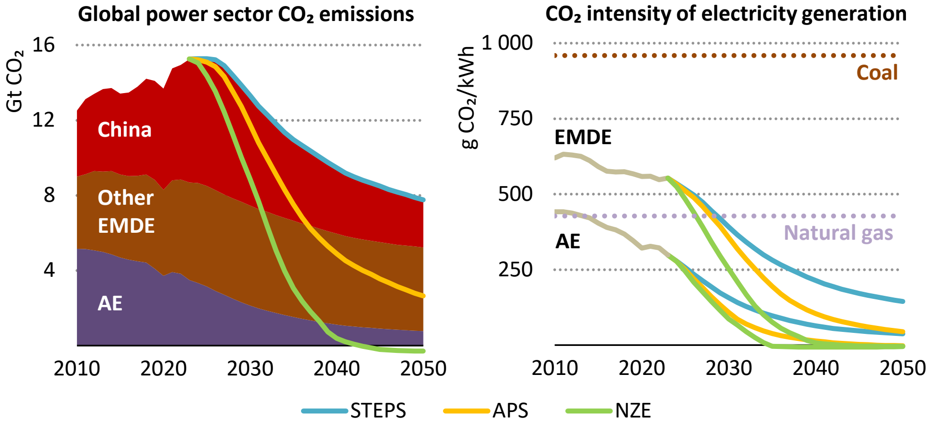
In the STEPS, emissions fall nearly 30% by 2035 and nearly 50% by 2050, getting back by 2050 to their level in 1994 (Figure 3.26). By 2035, CO_2 emissions from emerging market and developing economies are more than six-times higher than those from advanced economies (compared to 1.4-times higher in 2010), and almost half of emerging market and developing economies emissions are from China. However, power sector emissions in emerging market and developing economies peak in the mid-2020s in both the STEPS and APS. In the APS, CO_2 emissions fall 50% by 2035 and more than 80% by 2050, driven by reduced use of coal and natural gas for power generation. In the NZE Scenario, CO_2 emissions fall 80% by 2035 and reach net zero globally just before 2045. Shifting away from coal is at the heart of measures to achieve net zero emissions in power systems by 2035 in advanced economies and by 2040 in China. As coal is phased out, natural gas becomes the main source of emissions.

Figure 3.26 ▷ Global power sector CO_2 emissions and CO_2 intensity of electricity generation by region and scenario, 2010-2050



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Global power sector emissions peak in the mid-2020s and then decline by nearly 30% in the STEPS and 50% in the APS by 2035; they fall faster in all regions in the NZE Scenario

Notes: Gt CO_2 = gigatonnes of carbon dioxide; g CO_2/kWh = grammes of carbon dioxide per kilowatt-hour; EMDE = emerging market and developing economies; AE = advanced economies. In the NZE Scenario, emissions from fossil fuel combustion are counterbalanced by carbon dioxide removal through bioenergy with carbon capture and storage. CO_2 intensities for coal and natural gas are world averages today.

3.4.4 Power sector investment

Total power sector investment averaged over USD 1 trillion per year from 2019 to 2023 – including to build or refurbish all types of power plants, to expand and refurbish electricity grids and to deploy energy storage – and overtook investment in fossil fuel supply in 2020. Solar PV and wind currently account for almost 50% of the global total, and electricity grids for about one-third.

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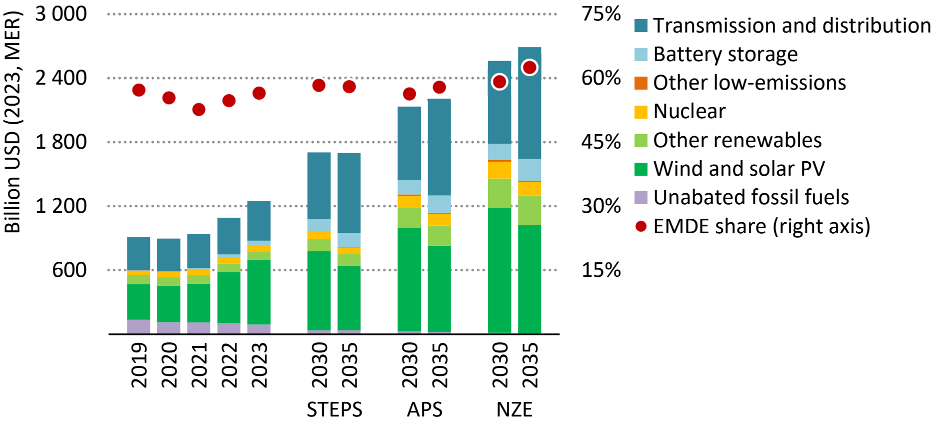
Global power sector investment rises to USD 1.7 trillion by 2030 in the STEPS (Figure 3.27). Investment in wind and solar PV increases by about one-quarter to 2030 and investment in grids by two-thirds. Battery storage investment increases three-times from the current level, reaching around USD 120 billion globally in 2030, and nuclear investment slightly increases by 5%. In the APS, investment is up to USD 2.1 trillion by 2030 as low-emissions sources of energy and storage technologies are deployed more rapidly than in the STEPS: investment in wind and solar PV increases 1.6-times from current levels, and annual investment in transmission and distribution grids rises to USD 690 billion in 2030. Beyond investment, upgrading and extending electricity grids calls for regulatory and planning changes (Box 3.6).

Figure 3.27 ⊳ Power sector investment by technology and scenario, and share in emerging market and developing economies, 2019-2035



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Global investment in the power sector increases by nearly 70% by 2035 in the STEPS, with the largest increases in electricity grids and renewables

Notes: MER = market exchange rate; EMDE = emerging market and developing economies. Other renewables include waste, bioenergy, geothermal, hydropower, concentrating solar power, marine (tide and wave) energy for electricity and heat generation. Other low-emissions includes fossil fuels with CCUS, hydrogen and ammonia.

After 2030, the level of investment in almost all low-emissions sources of electricity stabilises or falls back slightly in 2030s because so much has already been done to decarbonise power supply by this time, especially in advanced economies. However, the level of investment in grids and batteries increases to facilitate their crucial role in the increasing levels of electrification of the end-uses. In the STEPS, investment in grids nearly doubles by 2050 from its current level, while investment in batteries increases 4.6-times. In the APS, investment in grids is 2.4-times higher than today, and investment in batteries is five-times higher.

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Emerging market and developing economies account for more than 60% of growth in global power sector investment in the STEPS through to 2030 and beyond. China currently accounts for more than 60% of all emerging market and developing economies power sector investment, and its share does not drop below 40% through to 2030 in any of the three scenarios. In the APS, emerging market and developing economies more than double their average annual investment of USD 560 billion between 2019 to 2023 to USD 1.2 trillion by 2030, with an almost 80% increase by 2030 even in the STEPS. Advanced economies see a slower increase than emerging market and developing economies in the APS, but their level of investment in 2030 doubled in the APS and is about 55% above the average level in 2019-2023 in the STEPS.

Box 3.6 ▹ Can the electricity grid expand at the necessary pace?

Significant grid enhancements are required in each scenario to meet growing electricity demand and to manage the rapidly increasing deployment of renewable energy sources. New transmission lines are essential to connect large-scale wind and solar PV projects to demand centres, sometimes over long distances. Distribution lines have to be expanded to accommodate rising electricity demand and increases in distributed renewables. Increased interconnections within and between countries and regions are needed to improve electricity security and to facilitate the integration of further potential flexibility providers and distributed energy resources. From 2023 to 2030, global grid line lengths are projected to increase by approximately 15% in the STEPS and closer to 20% in the NZE Scenario.

Over the past three years, global grid investment has increased at an average annual rate of nearly 7%, to reach record highs. However, this has not prevented connection queues and grid congestion caused by delayed grid extensions. These have arisen because it can take over a decade to complete grid projects, which is much longer than is needed to complete the renewable energy projects that grid improvements are designed to serve. Electricity grid projects are highly complex and involve extensive permitting and construction processes. Comprehensive line route plans and reports must be prepared, conditions and specifications assessed, and stakeholders engaged. The process can be further complicated by local opposition to proposed line routes, tight supply chains and a shortage of qualified staff.

By 2030, transmission grid extension rates are projected to increase by 70% in the STEPS, more than 90% in APS and around 110% in the NZE Scenario (Figure 3.28). In distribution, it remains nearly the same rate in the STEPS, as advanced economies are also extending through line capacity upgrades, with a slight increase of 3% in the APS and over 10% in the NZE Scenario. Most of these increases are needed to meet rising demand and connect new customers in emerging market and developing economies, but some of the investment is needed to upgrade or replace ageing grids: this is especially the case in advanced economies, where most of the grids were built many decades ago.

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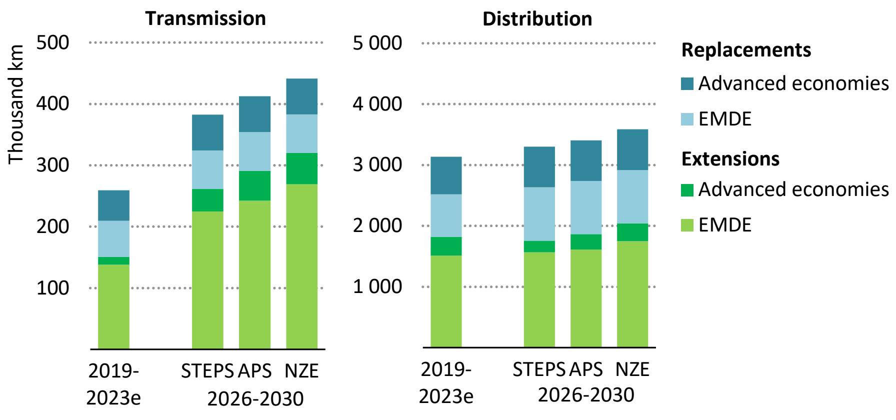
Figure 3.28 ▷ **Global average electricity grid replacements and extensions by type, region and scenario, 2019-2030**



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To effectively enable clean energy transitions, the pace of electricity grid replacements and extensions must accelerate

Notes: km = kilometres; EMDE = emerging market and developing economies. 2019-2023e: values for replacements are estimated for all historical years based on the age of infrastructure.

Long-term grid planning, incorporating forward planning in supply and demand, is essential if delays are to be avoided. Clearly defined roles and responsibilities for regulatory authorities, network operators and investors are vital, along with streamlined permitting processes and procedures. Effective and binding deadlines could be used to provide legal certainty to network operators and investors about the timely completion of approval procedures, and high priority projects could be expedited by designating "infrastructure corridors" that allow for quick initial permitting decisions. Anticipatory investment can help network operators achieve predictable and timely cost recognition and prevent further delays. Regulatory authorities could also help by developing new ways to boost innovative and digital investment, such as output-based regulations that favour efficient solutions. Many countries are developing initiatives that are designed to speed up processes and improve the current position: examples include the European Union Action Plan for Grids and the Coordinated Interagency Transmission Authorizations and Permits Program in the United States.

3.5 Fuels

Fossil fuels met just under 80% of global energy demand in 2023, a share that has fallen very gradually since 2011, when it stood at 83%. Aggregate fossil fuel demand has continued to accompany broader economic growth, but in some areas this relationship is starting to

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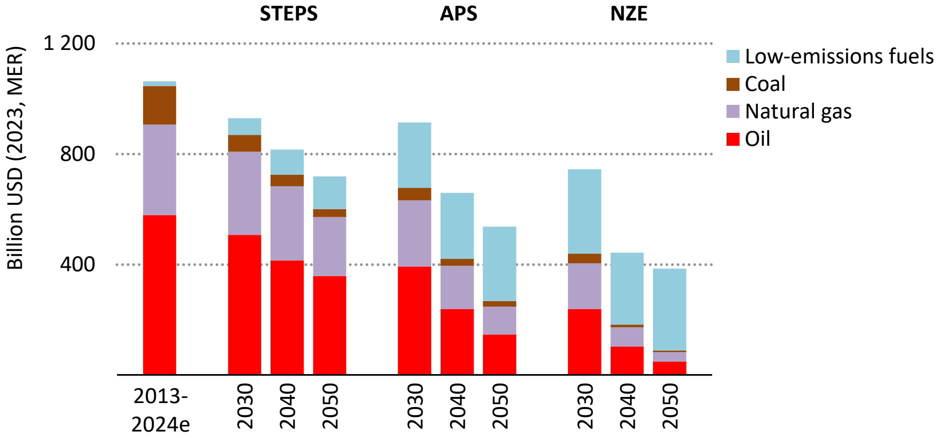
loosen. This is particularly the case in advanced economies, which have seen their economies grow by 20% over the past ten years while fossil fuel use has contracted by nearly 10%, helped by investment in clean energy technologies, rising shares of services in the economy and efficiency improvements.

In emerging market and developing economies, on the other hand, increasing energy needs have continued to push up fossil fuel use. Over the past ten years, their populations have swelled by 720 million people, they have experienced a 50% increase in economic growth and industrial output has risen by 40%. Floor space in buildings has increased by 40 000 square kilometres – enough to cover the entirety of the Netherlands – and fossil fuel consumption increased 25%. Nonetheless, per capita fossil fuel use in emerging market and developing economies remains at less than half the level of advanced economies; if emerging market and developing economies were to match this level, global fossil fuel use would be almost double what it is today.

In the STEPS, the correlation between global GDP and fossil fuel consumption seen in previous decades loosens in the years ahead, and demand for each of the fossil fuels peaks by 2030. Annual investment in fossil fuels falls from just over USD 1 trillion today to USD 650 billion in the STEPS in 2050 and drops to USD 90 billion in the NZE Scenario (Figure 3.29). Low-emissions fuels offer a route to diversification, and in the APS and NZE Scenario they become essential parts of the clean energy economy.

Figure 3.29 ▷ Average annual investment in fuel supply by type and scenario, 2013-2050



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Investment in fuels falls in all scenarios; a big rise in low-emissions fuels partly offsets the sharp drop in investment in coal, natural gas and oil

Notes: MER = market exchange rate; 2024e = estimated value for 2024. Average annual values are shown for 2013-2024e. Low-emissions fuels includes hydrogen, hydrogen-based fuels and modern bioenergy.

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3.5.1 Oil

Table 3.1 ⊳ Global liquids demand and supply by scenario (mb/d)

		STEPS			APS			NZE		
	2023	2030	2035	2050	2030	2035	2050	2030	2035	2050
Road transport	42.7	43.3	40.2	34.8	40.5	34.1	16.8	31.9	20.1	2.3
Aviation and shipping	11.6	13.0	13.5	14.5	11.0	10.1	7.5	9.3	7.0	1.8
Industry and petrochemicals	20.0	23.3	24.6	25.3	21.4	20.9	17.5	19.7	18.2	13.1
Buildings and power	11.4	9.0	7.7	6.1	8.1	6.1	3.6	6.6	3.6	0.4
Other sectors	13.3	13.1	13.1	12.5	11.8	10.9	8.4	10.8	8.9	5.3
World oil demand	**99.1**	**101.7**	**99.1**	**93.1**	**92.8**	**82.0**	**53.7**	**78.3**	**57.8**	**23.0**
Liquid biofuels	2.3	2.9	3.2	4.1	4.9	6.3	7.0	6.0	6.8	5.9
Low-emissions hydrogen-based fuels	0.0	0.0	0.1	0.6	0.3	1.4	4.6	0.7	2.0	5.6
World liquids demand	**101.4**	**104.7**	**102.4**	**97.9**	**98.0**	**89.7**	**65.4**	**85.0**	**66.6**	**34.5**
Conventional	62.7	59.4	57.0	54.3	54.9	46.6	28.9	48.6	35.7	15.3
Tight oil	9.1	11.2	11.8	10.7	10.8	10.4	7.2	8.4	6.4	1.6
NGLs	20.2	23.1	22.1	19.2	19.8	18.4	13.1	15.4	11.0	4.1
EHOB	3.9	4.6	4.6	5.1	3.9	3.6	2.7	3.2	2.5	1.3
Other	1.0	1.0	1.0	1.0	0.9	0.9	0.3	0.4	0.3	0.1
World oil production	96.9	99.2	96.5	90.3	90.4	79.9	52.1	76.0	55.9	22.4
OPEC share	*34%*	*33%*	*34%*	*40%*	*34%*	*36%*	*41%*	*35%*	*39%*	*51%*
Processing gains	2.4	2.5	2.6	2.8	2.4	2.2	1.6	2.3	1.9	0.7
World oil supply	**99.2**	**101.7**	**99.1**	**93.1**	**92.8**	**82.0**	**53.7**	**78.3**	**57.8**	**23.0**
Price (USD [2023]/barrel)	**82**	**79**	**78**	**75**	**72**	**67**	**58**	**42**	**33**	**25**

Notes: mb/d = million barrels per day; NGLs = natural gas liquids; EHOB = extra-heavy oil and bitumen; OPEC = Organization of the Petroleum Exporting Countries. Other production includes coal-to-liquids, gas-to-liquids, additives and kerogen oil. Historical supply and demand volumes differ due to changes in stocks. Liquid biofuels and low-emissions hydrogen-based liquid fuels are expressed in energy equivalent volumes of gasoline and diesel, reported in million barrels of oil equivalent per day. Methodological differences explain the deviations with the IEA Oil Market Report 2024. See Annex C for definitions. See Annex E for inputs to the IEA Global Energy and Climate Model.

Global oil markets continue to evolve and rebalance amid shifts in geographical and sectoral supply and demand. Demand in 2023 surpassed the previous peak set in 2019, increasing by nearly 2 mb/d from 2022 levels to reach 99 mb/d, of which China contributed 1.5 mb/d. Transport accounted for a large share of the global increase: demand for road passenger cars increased by nearly 600 thousand barrels per day (kb/d), while fuel use for aviation increased by 1 000 kb/d after flight activity eclipsed pre-pandemic levels. Demand for oil from petrochemicals increased by 500 kb/d in 2023, almost double the average growth over the last 5 years. All of the growth on the supply side was met by non-OPEC sources, primarily from the United States where over 40% of production comes from tight oil plays.

Demand growth is slowing noticeably in 2024 and is expected to be less than 1 mb/d for the year as a whole. This pattern of slowing growth continues in the STEPS: the trajectory for oil

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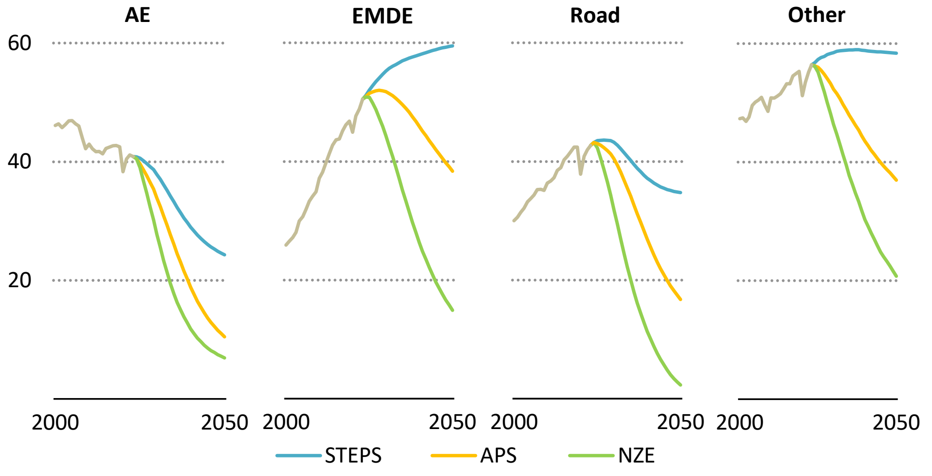
demand between 2023 and 2035 in the STEPS remains broadly unchanged from the *WEO-2023*, and, as before, demand peaks before 2030. By 2050, oil demand is around 6 mb/d lower than in 2023, driven primarily by lower levels of demand in transport.

Demand

In the STEPS, global oil demand peaks before 2030 at just less than 102 mb/d, and then falls back to 2023 levels of 99 mb/d by 2035 (Figure 3.30). Overall oil consumption is pulled down by reduced demand for oil in road transport. Surging EV sales since 2015 have already displaced around 1.0 mb/d of gasoline and diesel demand, and EVs avoid a further 12 mb/d of oil demand growth for road transport between 2023 and 2035 in the STEPS: the net result is a 2.5 mb/d contraction in oil use for road transport over this period. Fuel switching and efficiency gains reduce oil use in the buildings sector, which contracts by 1.4 mb/d. These declines are offset by a 6.2 mb/d increase in the use of oil in aviation and petrochemical production between 2023 and 2035.

Figure 3.30 ⊳ Oil demand by region, sector and scenario, 2000-2050



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Oil demand falls as EV ownership expands in advanced economies in all scenarios; oil demand is more resilient in aviation, shipping and petrochemicals in the STEPS and APS

Notes: mb/d = million barrels per day; AE = advanced economies; EMDE = emerging market and developing economies; road = road transport. Oil demand does not include biofuels demand.

In the APS, oil demand falls by 17% in 2035 relative to 2023 levels. An additional 135 million EVs are on the road by 2035 compared to the STEPS. A doubling in the plastics recycling rate and material efficiency gains in chemicals between 2023 and 2035 arrest some of the growth in petrochemical demand. In the NZE Scenario, oil demand drops to 58 mb/d by 2035, with 1 350 million EVs on the road while the plastic recycling rates increase slightly compared to the APS.

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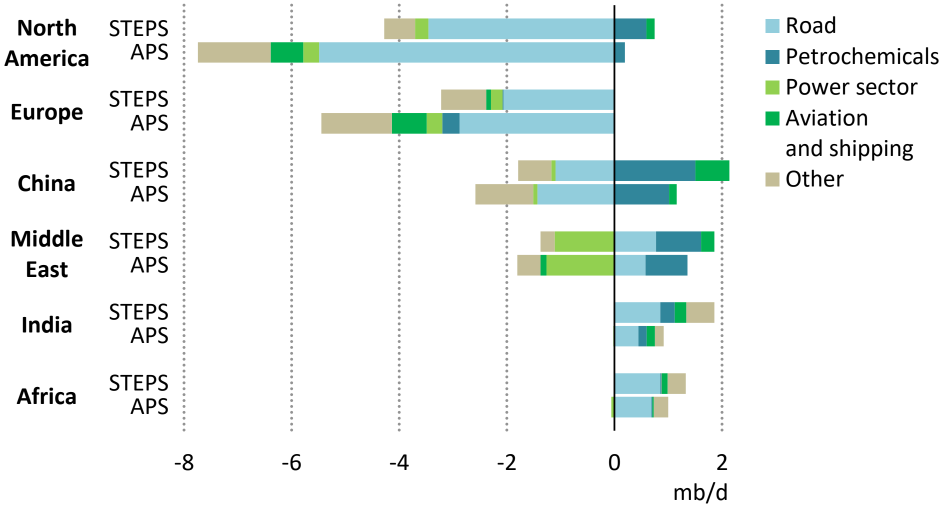
In emerging market and developing economies, oil demand growth in the STEPS slows from 1.8% a year in the 2015-2023 period to 1% a year in the 2023-2035 period. India sees the largest increase in oil demand over this period with a rise of 1.9 mb/d. Oil demand in China rises by just under 1 mb/d, with declines in road transport offset by growth of 1.5 mb/d in the petrochemicals sector (Box 3.7). China is on track to overtake the United States as the world's largest oil consuming country by 2030. In Central and South America, Africa, Middle East and Eurasia, demand continues to grow to 2050, and it accounts for around one-third of total global demand by 2050, compared with 22% today.

In advanced economies, the STEPS sees an acceleration in the decline in oil demand that has been evident since 2005 (Figure 3.31). In Europe, the share of internal combustion engine (ICE) vehicles in total car sales falls sharply: over 20% of cars sold today are battery electric or plug-in hybrids, and this increases in the STEPS to 90% by 2035. In North America, the share of EVs in total car sales grows from around 10% today to about 70% by 2035, mostly as a result of the Environmental Protection Agency (EPA) rules recently introduced in the United States and the Electric Vehicle Availability Standards in Canada. These trends accelerate in the APS and NZE Scenario: by 2035, the overall share of EVs in car sales in advanced economies grows to almost 90% in the APS and to almost 100% in the NZE Scenario.

Figure 3.31 ▷ Oil demand by selected sectors and by country/region in the Stated Policies and Announced Pledges scenarios, 2023-2035



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Oil demand for road transport falls in advanced economies and China in the decade ahead; oil use for petrochemical production increases in most regions

Notes: mb/d = million barrels per day. Other includes transport excluding road, aviation and shipping; industry excluding petrochemicals; buildings; agriculture; and non-energy use.

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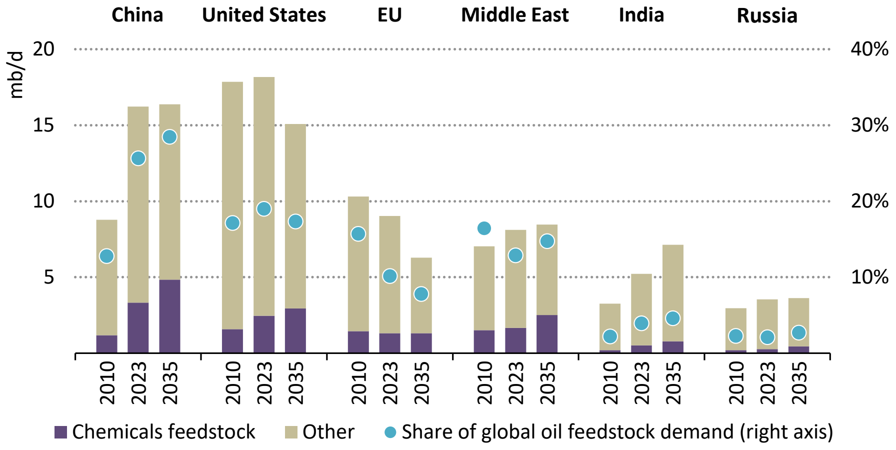
Box 3.7 ⊳ Demand for petrochemicals in China

China is the world's largest consumer of petrochemicals, and its level of consumption is continuing to rise. Rapid increase in China's clean technology manufacturing – mainly EVs, wind turbines and PV panels – is an important driver and accounts for around a quarter of the demand growth for plastics since 2019. In a bid to improve self-sufficiency, China has invested heavily in domestic production of plastics. This has helped to reduce polyolefin imports from over 30% of requirements in 2019 to around 20% in 2023, while also supporting expanding demand for plastics.

Figure 3.32 ⊳ Oil demand and global oil feedstock demand by country/region in the Stated Policies Scenario, 2010-2035



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Global oil demand peaks, yet chemical feedstock oil demand in China continues to increase and by 2035 it is larger than total oil demand in Russia

Notes: mb/d = million barrels per day; EU = European Union. Chemicals feedstock demand does not include demand for aromatics production in refineries.

The increase of petrochemicals production in China has been a key factor in recent oil market trends, displacing petrochemical output in other regions and offsetting demand reductions in other sectors (Figure 3.32). Oil demand for use as a petrochemical feedstock in China increased by over 1.5 mb/d between 2019 and 2023, which is 20% more than overall global oil demand growth in the same period. Alone the petrochemicals sector in China now uses more oil than the whole of Japan, which is the world's fifth-largest oil consumer. Almost half of the demand growth, mainly for naphtha and liquefied petroleum gas (LPG), has been met by increased refinery outputs, and the remaining demand is met by imports. The rise in domestic production of plastics reduced imports of plastics, mainly from the Middle East, Korea and United States, and an increase in imports of lower value crude oil or refined products that can be used to produce higher value chemicals, mainly from the Middle East and Russia.

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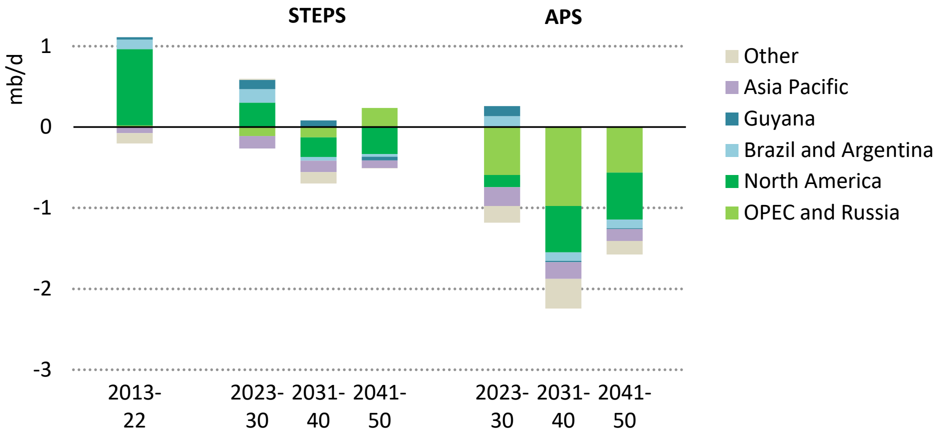
Oil demand growth in China continues to be driven by increasing petrochemicals production for the next ten years. Even as overall oil demand peaks, its use as a chemical feedstock in China continues to rise, reaching around 5 mb/d by 2035. Domestic refineries cannot entirely satisfy this growth, and so naphtha and LPG imports double to almost 2.3 mb/d over the same period. Higher recycling rates in the APS reduce demand by almost 10% in 2035 but do not halt the growth trend.

Supply

The United States has dominated recent global oil supply growth, accounting for over half of the increase in production since 2010. In the STEPS, growth in US production continues at a slower pace through the rest of the decade and contracts by around 0.25 mb/d each year on average between 2030 and 2050. Brazil, Argentina and Guyana add more than 2.5 mb/d to supply by 2035, expanding current fields and capitalising on recent discoveries. In the APS, production starts to fall across the board from about 2030: Central and South America is the only region that sees growth in production between 2023 and 2030 before declining (Figure 3.33).

Figure 3.33 ▷ Average annual change in oil production by region in the Stated Policies and Announced Pledges scenarios, 2013-2050



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Non-OPEC countries led oil supply growth over the past decade, which continues in the STEPS through the 2020s; production declines across the board after 2030 in the APS

The volume of crude production by members of OPEC and Russia reached a high point of around 47 mb/d in 2018 but has come under pressure since then as output from other countries has risen faster than demand: effective OPEC spare capacity is now around 6 mb/d. Supply is held relatively constant at a level between 42-44 mb/d in the STEPS through the

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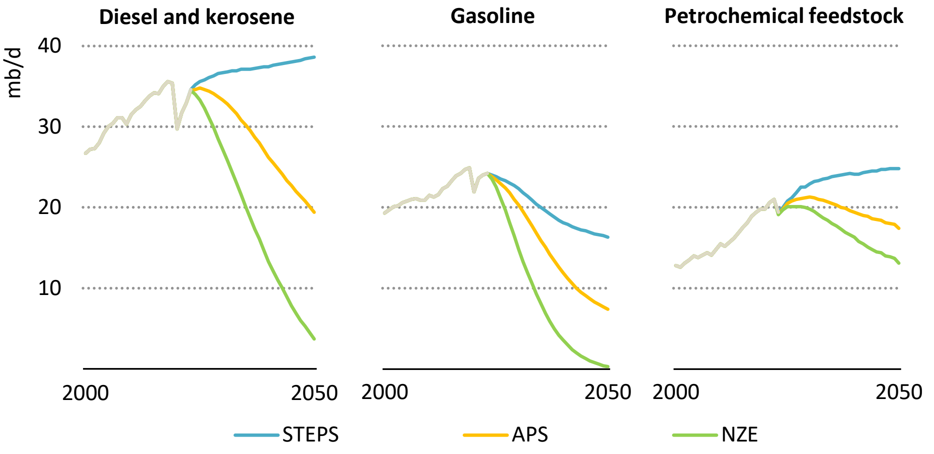
projection period. In the APS, supply from OPEC and Russia falls by close to 1 mb/d per year on average through to 2040 and by around 500 kb/d from 2040 to 2050. The overall share of OPEC in global oil supply nonetheless rises from 34% today to 41% in 2050, similar to levels reached in the STEPS, as supply from other producer countries falls faster. Russian oil production showed initial resilience against sanctions, and the ramp-up of the giant Vostok project manages to partly offset losses at mature oil fields. Production reaches a maximum level of around 11 mb/d this decade.

Refining and trade

Refineries are facing a significant adjustment period as the engine of past demand growth – road transport fuels – is projected to sputter in the years ahead. A peak in motor gasoline demand is coming into view and, in the STEPS, peak diesel demand is projected before 2030, though middle distillates are propped up by continued growth in demand for jet kerosene. Overall, oil product demand increasingly narrows toward petrochemical feedstocks, which are the only source of oil product demand growth between 2023 and 2035 apart from aviation fuels (Figure 3.34).

Figure 3.34 ▷ Demand for selected oil products by scenario, 2020-2050



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Middle distillates such as diesel and gasoline fall much more sharply in the APS and NZE Scenario than petrochemical feedstocks

This evolution in oil product demand across all scenarios creates an overhang of gasoline refining capacity and favours refineries that are closely integrated with petrochemical plants. Such facilities are primarily based in Asia and the Middle East, and also benefit from proximity to resilient sources of demand. Refiners in Europe are more exposed to the risks from changing product demand patterns, and some of them are therefore making a strategic shift into biofuels, low-emissions hydrogen and plastic recycling. In the STEPS, global refinery

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capacity sees net growth of around 2 mb/d between 2023 and 2030 before starting to decline as rising EV sales and fuel efficiency gains put pressure on refining margins. In the APS, refinery runs drop by 15 mb/d by 2035, and some 30% of today's refining capacity faces the risk of lower utilisation or closure. In the NZE Scenario, this share rises to 50% by 2035.

The Middle East remains the largest crude oil exporter in all scenarios, and the share of its exports flowing to emerging market and developing economies in Asia rises from 25% of total seaborne crude trade today to 40% by 2050 in the STEPS. As a result, the Malacca Strait between Malaysia and Indonesia becomes the world's largest chokepoint for oil and gas trade, with a higher volume of oil passing through it than the Strait of Hormuz, the chokepoint in the Persian Gulf. China remains the world's largest oil importer through to 2050 in the STEPS, and India and Southeast Asia see imports increase by around 35% by that date. By 2050, crude oil import dependency in Asia rises from about 80% today to 90% in all scenarios.

3.5.2 Natural gas

More than two years after Russia's invasion of Ukraine, global gas markets have regained a fragile equilibrium. Natural gas exports from Russia have fallen from a pre-war record of 250 bcm in 2021 to 130 bcm in 2023. Natural gas demand in the European Union in 2023 was 20% below its level in 2021, and the United States was its second-largest supplier after Norway, having delivered 60 bcm of LNG in 2023, or around half of its total LNG imports. Global natural gas demand increased by 0.5% in 2023, with a 40 bcm contraction in advanced economies, led by Europe, offset by 60 bcm of growth in emerging market and developing economies, led by China and the Middle East. A wave of new supply is also on the horizon: 270 bcm of new LNG export terminals are under construction, and will add another 50% to global LNG capacity, alongside an additional 200 bcm of annual production from upstream projects sanctioned since early 2022 that target local markets.

Natural gas demand has been revised upward in all scenarios compared with the *WEO-2023*, reflecting stronger anticipated demand for gas to meet growth in electricity demand in China as well as additional demand in the Middle East, where policies to shift away from oil in electricity generation have been reaffirmed. In the STEPS, the level of demand in 2030 has been revised up by 130 bcm compared to the *Outlook* in 2023, reaching just over 4 400 bcm before demand peaks.

Low-emissions gases – biogas, biomethane and hydrogen – are poised to see strong growth in all scenarios. By 2050, they reach nearly 400 billion cubic metre equivalent (bcme) in the STEPS, a ten-fold increase. In the NZE Scenario they reach 1.4 trillion cubic metres, meeting 60% of total gas demand in 2050.

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Table 3.2 ⊳ Global gas demand, production and trade by scenario

		STEPS			APS			NZE		
	2023	**2030**	**2035**	**2050**	**2030**	**2035**	**2050**	**2030**	**2035**	**2050**
Natural gas demand (bcm)	**4 186**	**4 430**	**4 422**	**4 377**	**4 003**	**3 493**	**2 466**	**3 617**	**2 257**	**882**
Power	1 642	1 657	1 602	1 513	1 519	1 258	786	1 537	773	136
Industry	936	1 037	1 080	1 136	941	888	674	852	711	338
Buildings	809	877	868	855	780	649	418	570	307	1
Transport	151	183	191	191	143	116	56	113	67	7
Inputs to low-emissions hydrogen	-	5	13	31	25	66	219	64	120	246
Other	647	671	668	651	593	510	302	482	279	156
of which: equipped with CCUS	*14*	*29*	*43*	*74*	*69*	*134*	*356*	*144*	*247*	*463*
Natural gas production (bcm)	**4 218**	**4 430**	**4 422**	**4 377**	**4 003**	**3 493**	**2 466**	**3 617**	**2 257**	**882**
Conventional gas	2 908	2 982	2 996	3 076	2 818	2 560	1 969	2 526	1 800	635
Unconventional gas	1 310	1 449	1 425	1 301	1 185	932	497	1 091	457	247
Natural gas trade (bcm)	**1 039**	**1 189**	**1 214**	**1 234**	**1 044**	**863**	**466**	**826**	**517**	**195**
LNG	546	690	719	830	653	597	290	539	339	145
Pipeline	493	499	495	403	391	266	176	287	179	50
Natural gas prices (USD/MBtu)										
United States	2.7	3.9	4.0	4.2	3.2	3.1	2.9	2.1	2.1	2.0
European Union	12.1	6.5	6.5	7.7	6.0	5.5	5.2	4.4	4.2	4.0
China	11.5	7.2	7.1	8.3	6.9	6.4	6.2	5.0	4.9	4.8
Japan	13.0	8.3	7.8	8.7	6.8	6.2	6.2	5.0	4.9	4.8
Low-emissions gases demand (bcm equivalent)	**36**	**78**	**125**	**362**	**175**	**375**	**1 023**	**349**	**643**	**1 397**
Hydrogen	0	18	37	128	65	210	688	172	397	1 052
Biogas	26	36	48	80	43	59	107	51	74	125
Biomethane	10	24	40	154	67	106	228	126	172	221

Notes: bcm = billion cubic metres; CCUS = carbon capture, utilisation and storage; LNG = liquefied natural gas; MBtu = million British thermal units; 1 bcm equivalent of hydrogen = 0.3 million tonnes. Low-emissions hydrogen is in gaseous form, prior to any further conversion to hydrogen-based fuels, and is produced primarily from electrolysis and steam methane reformation with CCUS. Inputs to low-emissions hydrogen includes natural gas for "merchant" hydrogen sold to end-users and not natural gas converted to hydrogen onsite by end-users for self-consumption. Other includes other non-energy use, agriculture and other energy sector. Trade reflects gross volumes traded between regions modelled in the IEA Global Energy and Climate Model. The difference between production and demand is due to stock changes.

Demand

In the STEPS, natural gas demand growth averages 0.5% per year in the 2023-2035 period, compared with a 2% average annual rate in the 2010-2023 period. Demand reaches a maximum level around 2030 and then declines very slightly through to 2050 (Figure 3.35). This trajectory is largely a consequence of accelerating deployment of renewables, efficiency gains and the electrification of end-uses. In the APS, demand begins to decline in the second-half of the 2020s and is 17% lower by 2035 than it was in 2023. In the NZE Scenario, demand falls by roughly 5% per year from 2023 to 2035, and by 6% per year on average between 2035 and 2050.

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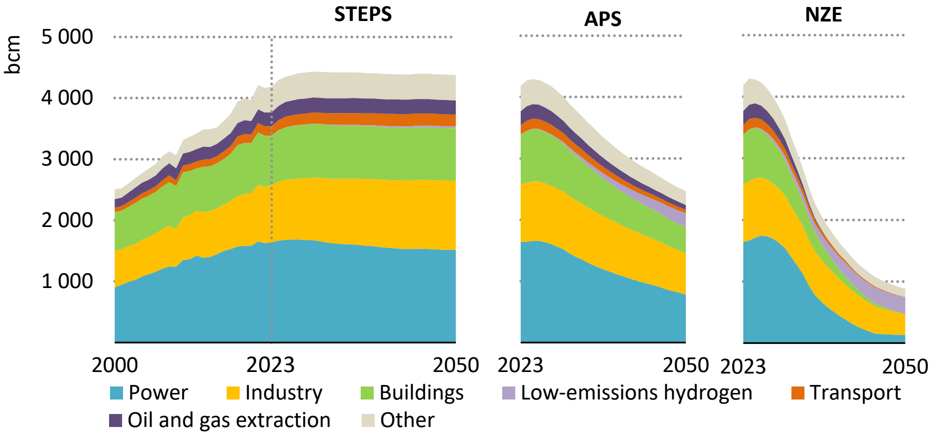
Figure 3.35 ⊳ Natural gas demand by sector and scenario, 2000-2050



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After decades of growth, natural gas demand is set to plateau by 2030 under current policy settings; demand falls 40% in the APS by 2050 and 80% in the NZE Scenario

Notes: bcm = billion cubic metres. Other includes LNG own use, transformation and distribution processes, and other own uses.

Coal-to-gas switching in the power sector in the United States in recent years is largely a consequence of cheap gas following the shale revolution, and has been responsible for over 120 bcm of natural gas demand growth between 2013 and 2022 (offset in part by 20 bcm of switching from gas to renewables over the same period). Rapid advances in renewables and efficiency gains in all scenarios leave little space for further coal-to-gas switching. However, the increase that has already taken place, together with increases in the use of natural gas in industry and own use in the LNG sector, means that the United States has been responsible for 30% of global natural gas demand growth during this period, an amount similar to China.

Growth in electricity demand opens some space for natural gas use in the power sector in emerging market and developing economies, where it increases by 190 bcm between 2023 and 2035 in the STEPS. However, this is more than offset by a reduction of 230 bcm in natural gas use in the power sector in advanced economies over the same period. Industry is the second-largest source of demand growth in emerging market and developing economies, recording a 150 bcm gain over the same period: this is only slightly offset by a 5 bcm contraction in natural gas use in industry in advanced economies. In the APS, natural gas demand growth in emerging market and developing economies is significantly reduced by faster deployment of renewables and more rapid efficiency gains across the board, together with scaling up the use of low-emissions fuels in industry (Figure 3.36). (Sensitivity analysis of the outlook for natural gas in the STEPS is included in Chapter 4 and the conditions under which gas demand could continue to grow post-2030 are discussed in Chapter 1.)

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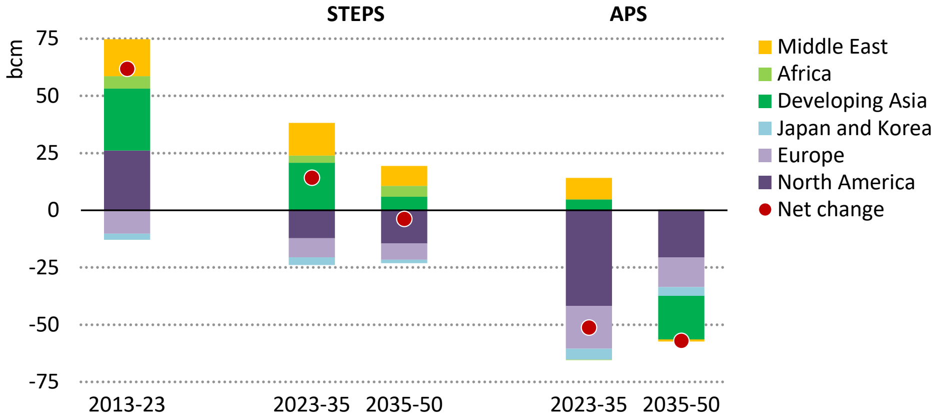
Figure 3.36 ▷ Change in average annual natural gas demand by selected region and scenario, 2013-2050



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Meeting current net zero emissions pledges would bring gas demand down more sharply in advanced economies and limit the scope for growth in EMDE

Note: Developing Asia includes China, India, Southeast Asia and Other Asia.

Supply and trade

The STEPS sees a net increase of 200 bcm of gas production between 2023 and 2035, with supply increases of around 500 bcm in markets with growing supply offsetting a drop of around 300 bcm elsewhere (Figure 3.37).

Even though its production peaks around 2030, the United States maintains its position as the world's largest natural gas producing country through to 2050. The Middle East as a whole – led by Qatar, Saudi Arabia and Iran – sees the largest growth in supply in the STEPS: its share of rises from 17% in 2023 to almost 30% in 2050. Russian gas production fails to stage a meaningful recovery from a nadir in 2023. Sanctions exacerbate the difficulty to diversify export outlets after the loss of the European market and the absence of a material increase in domestic demand means that Russian gas production in 2035 remains around 20% below pre-Ukraine invasion levels. In the APS and NZE Scenario, export outlets dry up further, and Russian gas production in 2035 falls to an average of 30-50% below pre-invasion levels.

After years spent developing the Vaca Muerta shale formation, Argentina is poised to sharply increase its natural gas production: it rises by 35 bcm in the STEPS to a level 80% higher than current production by 2035. Gas production also rises modestly in Brazil, but it declines in other countries in Central and South America in the STEPS, resulting in a 10 bcm net increase for the region between 2023 and 2035. In the APS and NZE Scenario this net increase in gas production in the region is erased by declining demand.

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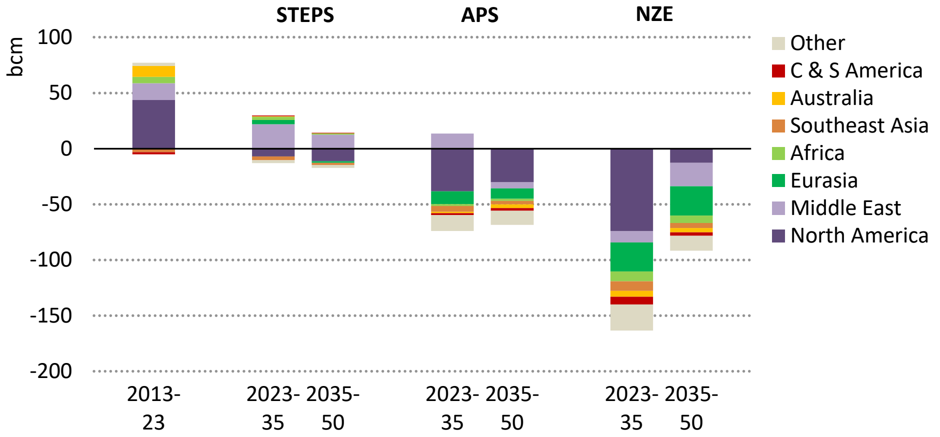
Figure 3.37 ⊳ Average annual change in natural gas production by region and scenario, 2013-2050



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Natural gas production slows in most regions compared to the previous decade; production in North America sees the largest relative change between scenarios

Note: C & S America = Central and South America.

Mature fields and slow upstream investment activity in North Africa bring overall natural gas production down by 15 bcm by 2035 in the STEPS, which puts a strain on its ability to meet domestic demand and export commitments concurrently. The story is different in sub-Saharan Africa, where there are robust increases in production in emerging producers such as Mauritania, Senegal and Mozambique, as well as in established producers such as Nigeria. In aggregate, Africa increases production to 15% above 2023 levels in the STEPS by 2035. In the APS, this falls by 8% compared with 2023. Roughly 25% of total gas production in 2035 is exported in both scenarios.

Global natural gas trade increasingly pivots toward emerging markets in Asia. Most of the increase comes in the form of LNG: the share of imports met by long-distance pipeline trade falls from almost 50% in 2023 to 40% by 2035 in the STEPS, and falls further in APS and the NZE Scenario. The largest growth market for gas imports is China, which imports an additional 80 bcm in 2035 in the STEPS compared with today: 40% of this additional growth is met by pipeline, and the remainder by LNG. India is the second-largest source of incremental import demand.

Natural gas demand in the European Union falls to 260 bcm by 2035 – a third below levels prior to Russia's invasion of Ukraine – and it falls more rapidly than domestic production, meaning that imports drop from a peak of 370 bcm in 2021 to below 250 bcm by 2035 in the STEPS. Japan's gas imports fall by 40% between 2023 and 2035 as a consequence of nuclear restarts and renewables growth. Korea's gas imports fall by almost 10% over the same period (Figure 3.38).

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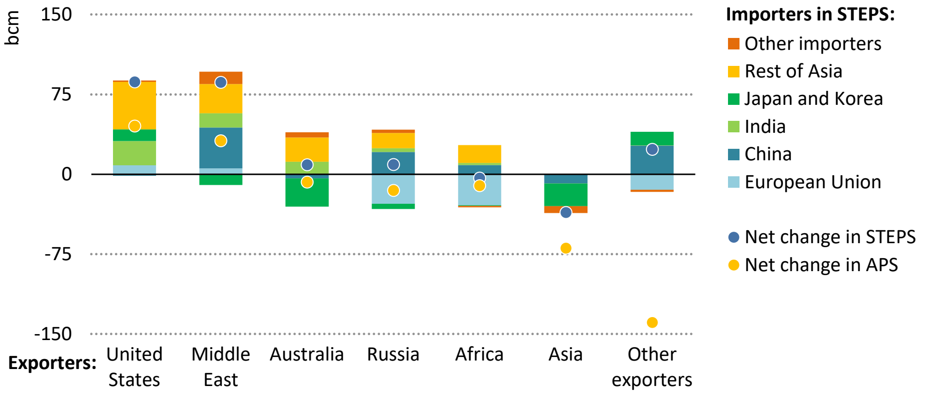
Figure 3.38 ▷ Change in long-distance natural gas trade by region and scenario, 2023-2035



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Russia's invasion of Ukraine has redrawn the map of global gas flows; the United States solidifies its position as the largest exporter, while overall trade pivots toward emerging Asia

In the STEPS, LNG demand increases by more than 2.5% per year over the 2023-2035 period, which is faster than overall natural gas demand but far less rapid than the average 6% per year LNG growth rate between 2013 and 2022. Around 270 bcm of new LNG supply is currently under construction, and this will lead to a near-doubling of capacity in the United States and Qatar, which are set to dominate supply in 2035, together accounting for around 50% of global LNG trade in the STEPS by this date. This increased supply concentration is likely to put a spotlight on possible security of supply risks that might arise from extreme weather in the Gulf of Mexico and from disruption in the Middle East.

Due to an upward adjustment to projected natural gas demand growth to 2030, LNG demand growth in the STEPS is higher than in the *WEO-2023*, reaching more than 700 bcm by 2035. However, this pace of growth does not keep pace with export capacity additions. As a result, a 130 bcm surplus emerges by 2030, bringing prices down in key importing regions like the European Union, China and Japan to a range between USD 6.5- 8.5 per million British thermal units (MBtu). This makes it difficult for some exporters to fully recover their long-run marginal cost of supply during this period.

This LNG surplus narrows in subsequent years as LNG demand growth continues in the 2030s, and a supply gap emerges in 2040. By 2050, around 175 bcm of additional LNG export capacity is required in the STEPS to cover both demand growth and retiring capacity. This additional supply mainly comes from the Middle East, East Africa and North America. In the APS, projects currently under construction are sufficient to meet LNG demand: this peaks at 650 bcm in 2030, and no supply gap emerges. In the NZE Scenario, demand can be met in aggregate from projects existing today, without any need for additional LNG from projects

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currently under construction: this has a profound effect on gas prices in importing regions, which fall to around USD 5/MBtu by 2030.

Russia does not manage to replace the gas export volumes lost to Europe. Given ample supply in China to meet demand in all scenarios, we do not assume that the Power of Siberia 2 pipeline comes online. As a result, Russia's exports to China reach a maximum level of 60 bcm per year in the STEPS through to 2050. With sanctions compounding the difficulty of increasing LNG export capacity, Russian LNG production peaks at just under 50 bcm in 2030, which is far below the government target level of 150 bcm by 2030.

3.5.3 Coal

Table 3.3 ⊳ Global coal demand, production and trade by scenario (Mtce)

		STEPS			APS			NZE		
	2023	**2030**	**2035**	**2050**	**2030**	**2035**	**2050**	**2030**	**2035**	**2050**
World coal demand	**5 986**	**5 307**	**4 453**	**3 191**	**4 702**	**3 231**	**1 370**	**3 440**	**1 743**	**501**
Power	3 916	3 349	2 609	1 612	2 944	1 800	686	2 015	738	228
Industry	1 606	1 581	1 539	1 367	1 396	1 175	608	1 199	864	219
Other sectors	464	377	305	213	362	257	76	226	140	54
of which abated with CCUS	*0%*	*0%*	*0%*	*1%*	*0%*	*4%*	*25%*	*2%*	*13%*	*77%*
Advanced economies	878	502	357	219	336	196	75	249	122	53
Emerging market and developing economies	5 108	4 806	4 096	2 973	4 365	3 035	1 295	3 191	1 620	447
World coal production	**6 278**	**5 308**	**4 454**	**3 191**	**4 702**	**3 231**	**1 370**	**3 441**	**1 743**	**501**
Steam coal	5 079	4 262	3 479	2 398	3 743	2 423	985	2 619	1 192	409
Coking coal	970	911	861	711	851	724	346	759	533	89
Peat and lignite	229	135	114	82	107	84	39	62	18	3
Advanced economies	1 041	628	519	412	451	332	127	310	198	36
Emerging market and developing economies	5 237	4 680	3 934	2 779	4 251	2 899	1 243	3 131	1 544	465
World coal trade	**1 144**	**965**	**877**	**712**	**797**	**629**	**307**	**612**	**368**	**97**

Notes: Mtce = million tonnes of coal equivalent; NZE = NZE Scenario; CCUS = carbon capture, utilisation and storage. The difference between production and demand is due to stock changes.

Global coal demand has been volatile in recent years. It dropped sharply during the Covid-19 pandemic, but it rebounded during the subsequent recovery, increased further after the Russian invasion of Ukraine, and rose to a record high in 2023 on the back of strong growth in China and India.

Demand

Coal demand is projected to fall in the years ahead in all scenarios, but the timing and the speed of its decline is closely tied to the strength of climate action. In the STEPS, demand drops by around 25% by 2035 from 2023 levels, with rapid reductions in advanced economies and modest declines in emerging market and developing economies. The fall in consumption

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after 2035 is more widespread, with coal use about 45% lower in 2050 than in 2023. In the APS, demand falls more quickly: it is already about 45% lower than in 2023 by 2035, and 75% lower by 2050. In the NZE Scenario, global demand plunges by around 70% by 2035 and over 90% by 2050.

China remains the largest consumer of coal, accounting for over half of global coal demand in 2035 in each scenario, but surging growth in renewables and slowly declining demand in industry lead coal use in China to fall over the next few years. India is the second-largest coal consumer and is the main driver of future demand growth: its coal use increases in power to 2030 and in industry to 2050 in the STEPS, and its energy-related CO_2 emissions continue to rise before peaking around 2035. Demand increases steadily in a number of countries in Southeast Asia. Almost everywhere else, however, the STEPS sees coal demand head downwards.

Advanced economies have historically consumed more coal per capita than emerging market and developing economies, but this has changed in recent years as they have retired coal plants or run them less frequently, while many emerging market and developing economies have installed new plants and used coal to meet rising energy needs. In 2023, 26 GW of coal-fired generation capacity were retired globally, 88% of them in advanced economies, while 65 GW were added, almost all in emerging market and developing economies: China accounted for 47 GW (73%) of these global capacity additions.

The power sector currently accounts for 65% of world coal demand, and it continues to be the largest coal user in the STEPS and APS through to 2050. In the NZE Scenario, however, the speed at which renewables and energy efficiency progress in the power sector means that the industry sector overtakes it as the largest coal user by 2035. In this scenario, there is a risk that recently commissioned coal assets fail to recover their investment. By 2050, coal use in the NZE Scenario drops to below 10% of today's level, and over 75% of its emissions are captured with the use of CCUS.

Supply and trade

Global coal production reached a new record in 2023, driven by growth in China, India and Indonesia. Over 30 new mines opened, 25 in China and four in India (Global Energy Monitor, 2024). China accounted for around 55% of global coal supply. India nearly overtook Indonesia as the second-largest coal producer following two years of record increases in production, and it plans to double coal output by 2030. Despite raising production, China continued to increase coal imports in 2023, while Indonesia and Mongolia raised exports.

In the STEPS, coal production peaks around 2025 and then falls by nearly 30% to 2035, dropping by 50% in advanced economies and 25% in emerging market and developing economies. It then continues to fall through to 2050. The supply of steam coal, mainly used in the power sector along with lignite, drops by close to 55% to 2050; the production of coking coal, mostly used in steel production, falls by about 25%. In the APS, global production falls by around 50% to 2035 and by nearly 80% to 2050. China, in line with its pledge that its total CO_2 emissions will peak before 2030, accounts for most of this decrease, reducing its

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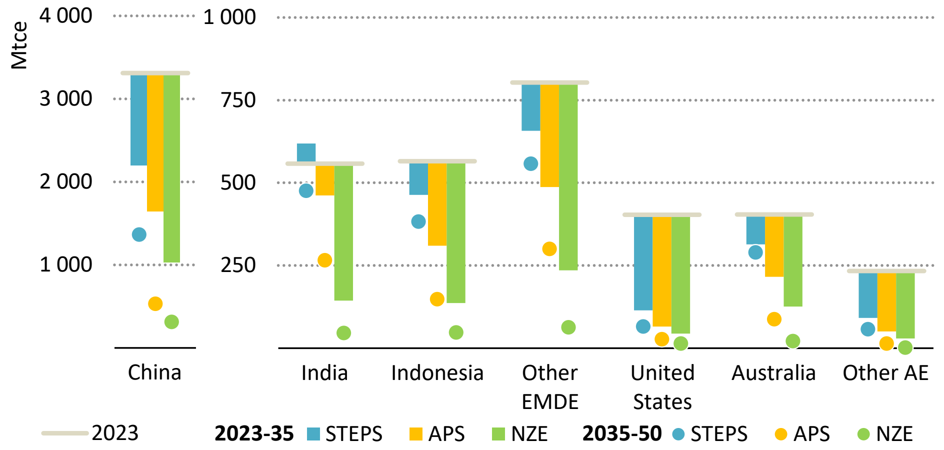
production by over 1 600 Mtce by 2035 and nearly 2 800 Mtce by 2050; this reduction is larger than that of all other economies combined. In the NZE Scenario, global coal supply declines by around 70% to 2035 and by over 90% to 2050 (Figure 3.39).

Figure 3.39 ⊳ Change in coal production by county/region and scenario, 2023-2050



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China accounts for the biggest reductions in coal production in all scenarios; India is the only major coal producer to increase output to 2035 in the STEPS

Note: Mtce = million tonnes of coal equivalent; EMDE = emerging market and developing economies; AE = advanced economies.

Global coal exports approached historical records in 2023, driven mainly by increased activity in the Asia Pacific region, which accounts for 80% of total imports. Indonesia and Australia were responsible for over half of global exports in 2023, with Indonesia solidifying its position as the largest exporting country. Australia provides 45% of global coking coal exports, and Indonesia around 40% of steam coal exports. China is the largest single importing country: it draws in around 30% of the global total, and these imports meet 10% of its domestic demand. India, Japan and Korea together account for roughly a further 35% of global imports.

In the STEPS, coal trade falls around 25% by 2035 and 40% by 2050 as China's market shrinks and India increases domestic production. Demand for high quality steam coal in advanced economies faces a tighter market as Russia's exports diminish. In the APS, coal use falls faster, causing trade to drop by around 45% to 2035 and nearly 75% to 2050. India overtakes China as the largest single importer of coal before 2030, while Indonesia and Australia remain the major exporters, and imports of coking coal to Europe, Japan and other advanced economies decline to around one-fifth of 2023 levels by 2050. In the NZE Scenario, the transition away from coal is fast, and trade falls to just under 10% of 2023 levels by 2050.

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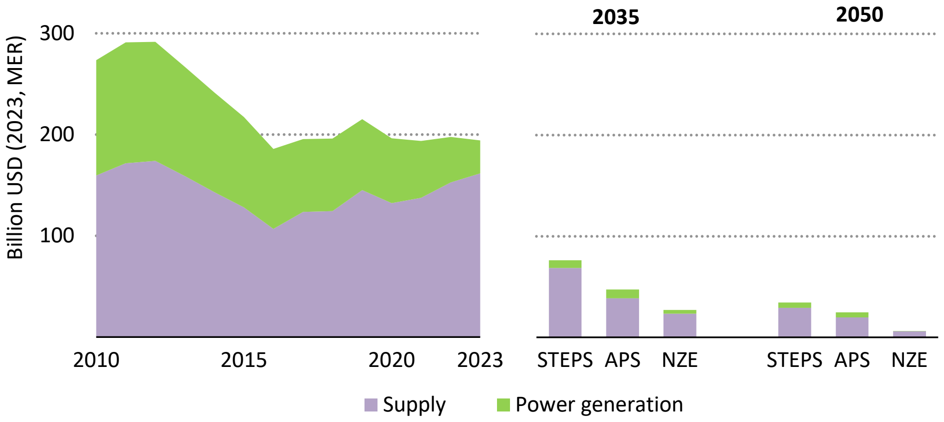
Investment

Coal prices surged amid supply shortages in 2021 and were followed by even higher prices in 2022, leading major coal consumers like China and India to scale up investment in domestic production. This led to an increase of over 5% in investment in global coal supply in 2023 (Figure 3.40). Emerging market and developing economies accounted for around 90% of all coal investment in 2023, with China being by far the largest single coal investor across all sectors. Investment in advanced economies has been slowly dwindling and continues to fall in all scenarios, with the highest absolute decrease to 2050 taking place in Australia.

Figure 3.40 ▷ Investment in coal supply and coal-fired generation, 2010-2050



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Investment trends confirm coal's declining role in new electricity generation, but also highlight the long-lived nature of coal power plants and the steel industry

Investment in coal supply and coal-fired generation totalled some USD 195 billion in 2023. Investment in the STEPS responds to falling demand by dropping to 60% below its 2023 level by 2035 and 80% below it by 2050. Around 60% of this remaining investment is concentrated in China, India and Southeast Asia. In the APS, investment falls by around 75% by 2035 and 85% by 2050. In the NZE Scenario, investment falls to less than 5% of 2023 levels by 2050 and is mostly geared to supply facilities equipped with CCUS.

3.5.4 Modern bioenergy

Global bioenergy consumption was around 60 EJ in 2023. The use of biomass such as wood, charcoal and other solid bioenergy in traditional cooking stoves accounted for about one-third and modern bioenergy for the remainder. In the industry sector, modern solid biomass is mainly used where process residues are available, such as food or paper production. It can also be employed in the power sector as a dispatchable source of renewable electricity, or in improved cookstoves to replace the traditional use of solid biomass. Transport biofuels, primarily ethanol and biodiesel, can be used across different

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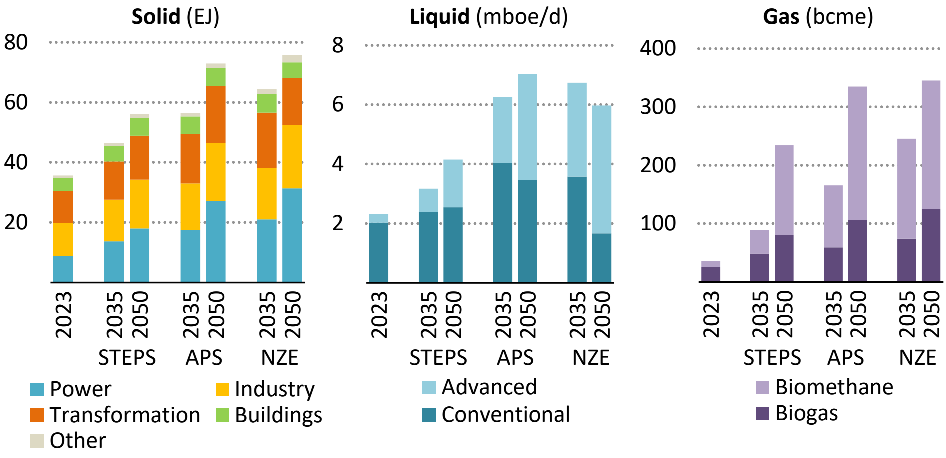
transport modes but can have long-term advantages in areas where electrification is challenging, such as shipping and aviation. Biogas is used as a local source of dispatchable heat and power, or when upgraded, can be converted to biomethane for use as a drop-in replacement for natural gas.

Modern bioenergy is versatile, but its sustainability credentials have come under scrutiny. Currently, around 20% of its supply comes from cropland dedicated to conventional biofuel production, and therefore is potentially competing with food production. The remaining 80% of supply is from organic waste streams, and forest and wood residues. Questions have been raised about this type of feedstock development on the grounds that it can have negative effects on biodiversity and greenhouse gas emissions. Clear sustainability criteria and tools such as life cycle greenhouse gas performance standards are essential to ensure that the future development of bioenergy resources commands widespread public acceptance.

Modern bioenergy demand worldwide increases from 42 EJ today to 56 EJ by 2035 and to more than 70 EJ by 2050 in the STEPS (Figure 3.41). In the APS and NZE Scenario, production rises to almost 100 EJ by 2050, with the majority of feedstocks derived from sustainable sources such as forestry and agricultural residues, recycled organic material and other organic waste streams. The shift to these feedstocks is driven by regulations that differentiate feedstocks based on their life cycle emissions and provide enhanced financial support to projects with relatively low-emissions intensities.

Figure 3.41 ⊳ Modern bioenergy demand by type and scenario, 2023-2050



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Modern bioenergy use rises to 100 EJ by 2050 in the APS and NZE Scenario, which is at the bottom-end of the range of the assessed sustainable potential

Notes: EJ = exajoule; mboe/d = million barrels of oil equivalent per day; bcme = billion cubic metres equivalent. Other includes renewable waste.

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Modern solid bioenergy

Solid bioenergy accounts for around 85% of total modern bioenergy demand. This share declines in all scenarios to around three-quarters by 2050. In the STEPS, modern solid bioenergy demand reaches 45 EJ by 2035 and 55 EJ by 2050, with notable demand growth from the power sector in China and industry in India. The APS and NZE Scenario both project higher growth, to 75 EJ by 2050. The use of solid biomass for power generation is the single largest source of demand for bioenergy in these two scenarios. This is primarily the result of a large requirement for dispatchable power in a world in which electricity accounts for around half of total final consumption. The largest source of growth is the power sector in China, where consumption grows from 3 EJ today to 7 EJ in 2050 in the APS.

Liquid biofuels

Demand for liquid biofuels rose by around 7% in 2023 to reach 2.3 million barrels of oil equivalent per day (mboe/d). In the STEPS, demand increases to 3.2 mboe/d in 2035 and to 4.1 mboe/d in 2050, mainly due to an increase in sustainable aviation fuel (SAF) demand from almost zero today to over 0.8 mboe/d. In the APS, liquid biofuels rise to 6.3 mboe/d by 2035 and 7 mboe/d by 2050, with over half of the increase above the level in the STEPS from the scaling up of SAF and most of the rest from increased biodiesel demand. In the NZE Scenario, the use of liquid biofuels expands more rapidly than in the other scenarios, reaching 6.5 mboe/d by the early 2030s, with SAF making up around 20% of total demand. Demand plateaus in the NZE Scenario after 2035 and is below APS levels by 2040 as electrification takes over many end-uses faster and more thoroughly than in the APS.

In the STEPS, liquid biofuel demand expands by around three-quarters between 2023 and 2035 in emerging market and developing economies but falls by 10% in advanced economies. By 2050, Brazil, Indonesia and India, which are each able to leverage a wide pool of potential feedstocks, together account for half of liquid biofuel demand, compared with 30% today. In the APS, growth is more evenly distributed as countries with net zero emissions pledges use a wide range of feedstocks to develop their bioenergy resources: by 2050, demand for liquid bioenergy rises by 40% in advanced economies and more than triples in emerging market and developing economies. In the NZE Scenario, demand more than doubles in emerging market and developing economies by 2050.

Biogas and biomethane

In the STEPS, combined biogas and biomethane demand more than doubles by 2035 to reach 90 bcme. In all scenarios, the share of biomethane in total biogases demand increases by 2050, driven largely by the value attached to its use as a dispatchable source of energy and as a drop-in substitute for natural gas. The cost gap between natural gas and biomethane currently averages around USD 10/MBtu in key gas-consuming regions, but this narrows to USD 4/MBtu in the APS reflecting CO_2 pricing, policy support and economies of scale. In the STEPS, advanced economies see their share of total global demand decline from about 50% today to just 21% in 2050. Demand in China meanwhile rises considerably, reaching nearly 100 bcme by 2050 and accounting for 40% of global demand. In the APS and NZE Scenario,

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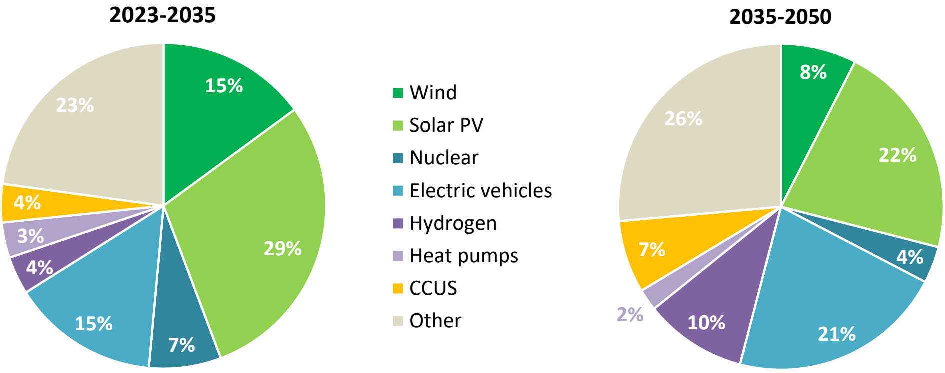
total biomethane demand amounts to around 220 bcme by 2050, compared with about 150 bcme in the STEPS.

3.6 Key clean energy technologies

Clean energy is experiencing rapid growth as deployment of several key technologies accelerates on the foundation of policy support and sustained cost reductions. Since 2019, clean energy growth has outpaced that of fossil fuels by a ratio of two-to-one. The production of low-emissions electricity has expanded by almost 2 000 TWh, around 20%, despite disruption in hydropower from droughts and unscheduled downtime at some nuclear power plants. In contrast, fossil fuel-based electricity generation increased by 910 TWh, around 5%, which is less than the growth of solar PV alone – 930 TWh since 2019 – and on a par with the increase in wind power output. Global investment in clean energy over this period rose by almost 50%, about 10% per year on average, and is set to reach almost USD 2 trillion in 2024. However, investment needs to increase to approximately USD 4.5 trillion per year by 2030 to deliver what is required in the NZE Scenario, and clean energy deployment needs to broaden: at present it is heavily concentrated in advanced economies and China (IEA, 2024a).

Figure 3.42 ▷ Clean energy technology contribution to energy combustion CO_2 emissions reduction in the APS, 2023-2050



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Deployment of seven key clean energy technologies accounts for about three-quarters of CO_2 emissions reductions from today through to 2050

Note: Other includes energy efficiency improvements, other fuel switching such as electrification or switching to biomass, and behaviour changes.

The momentum behind clean energy technologies is shifting the outlook for emissions even under current policy settings. In the STEPS, CO_2 emissions are projected to be 6.5 Gt lower in 2030 than in our 2015 pre-Paris Baseline Scenario (Figure 3.42). In the APS, the deployment of seven key clean energy technologies – solar PV, wind power, nuclear, electric vehicles, heat pumps, low-emissions hydrogen and carbon capture – accounts for about three-

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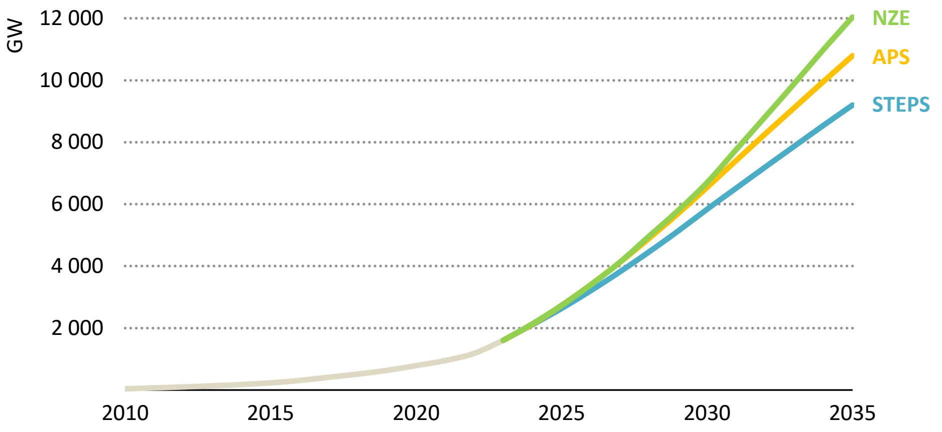
quarters of energy-related CO_2 emissions reductions between 2023 and 2035 and beyond. Scaling up of these technologies is also the main enabling factor for the decline in fossil fuel demand this decade in the NZE Scenario.

3.6.1 Solar PV

Solar PV capacity additions increased by over 80% in 2023 to reach a new record of 425 GW. Solar PV deployment increased 2.5-times in China, which was responsible for over 60% of all capacity additions. Rapid expansion of manufacturing in China resulted in a 50% reduction in PV module costs since December 2022, which improved the competitiveness of solar PV and boosted its uptake. Advanced economies accounted for most of the remaining growth in 2023, with capacity additions of nearly 60 GW in the European Union and over 30 GW in the United States. In the rest of the world, solar PV capacity additions in 2023 were over 70 GW.

Solar PV capacity additions expand by almost 60% in the STEPS by 2035, double in the APS and increase 2.5-fold in the NZE Scenario (Figure 3.43). Today, solar PV generates just over 5% of total electricity generation, but it is set to increase its share to 17% in 2030, and thus to play a crucial role in helping to meet the COP28 pledge of tripling renewable capacity by 2030. By 2035, solar PV overtakes coal-fired and gas-fired generation to become the main source of electricity, providing 25% of total generation in the STEPS, 30% in the APS and 35% in the NZE Scenario. The rapid rise of solar PV increases the need for power system flexibility to ensure electricity security (see Chapter 5).

Figure 3.43 ▹ Solar PV capacity by scenario, 2010-2035



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Solar PV capacity additions increase dramatically by 2030 in each scenario, and by far become the fastest growing source of electricity over the next decade

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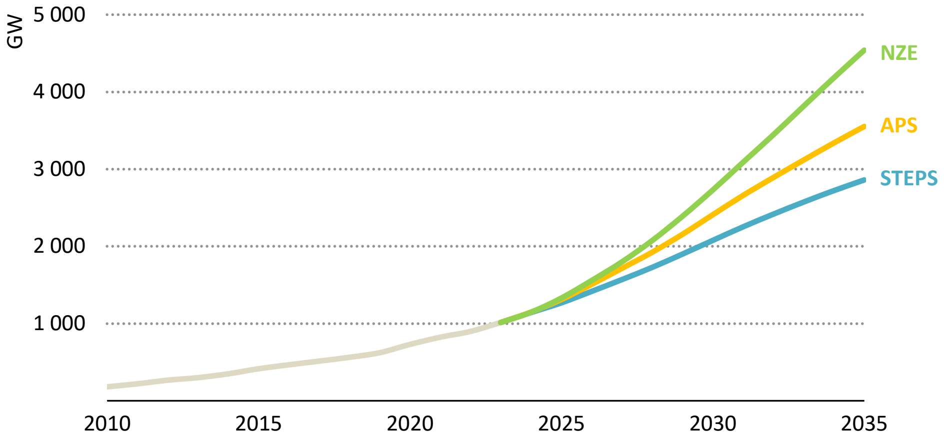
3.6.2 Wind

Worldwide wind power capacity additions increased over 50% to 116 GW in 2023, surpassing the previous record high in 2020 (Figure 3.44). Onshore wind projects accounted for 107 GW of the additions, 92% of the total. By far, China increased capacity more than any other country, adding 76 GW of wind capacity, 66% of the total. Expansion in advanced economies was much lower, with only 15 GW of wind capacity additions in the European Union, on a par with 2022, and just above 6 GW in the United States, down from over 14 GW in 2020 and 2021. However, capacity additions in the United States and the European Union are projected to increase significantly in the coming years in part reflecting the long-term policy support provided by the US Inflation Reduction Act and to recent European Union policies to address the challenges posed by slow and complex permitting procedures. Issues such as the cost of financing, revenue uncertainty and delays in grid connections continue to constrain more rapid deployment, especially in emerging market and developing economies other than China.

Figure 3.44 ▷ Wind power capacity by scenario, 2010-2035



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Global wind capacity additions were up more than 50% in 2023, passing the 2020 high, and accelerate further in all scenarios

With 1 000 GW of installed capacity generating over 2 300 TWh, wind power is the largest source of variable renewable electricity today. Over 60 countries have set deployment targets for wind as part of their climate pledges. It has a central role in efforts to fulfil the COP28 pledge of tripling renewable capacity by 2030. Wind capacity additions increase in all scenarios. Wind becomes the second-largest source of electricity by capacity in the STEPS by 2035, passing 2 800 GW of installed capacity and 7 500 TWh of generation. More rapid electrification and accelerated low-emissions power deployment see these numbers increase even faster with installed wind capacity rising to over 3 500 GW in the APS and over 4 500 GW in the NZE Scenario by 2035.

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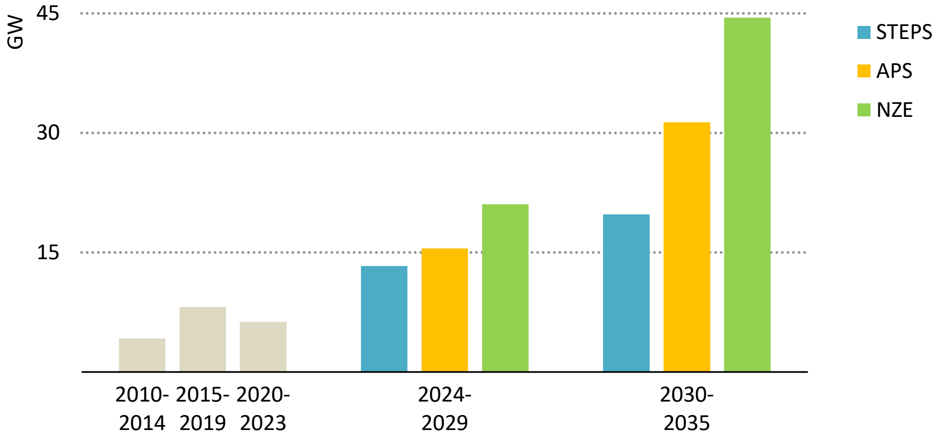
3.6.3 Nuclear

In countries open to the technology, nuclear power can be an important source of low-emissions electricity. It currently provides 9% of global electricity. It can offer baseload power, enhance grid stability and flexibility, and optimise grid capacity utilisation, making it a valuable part of a portfolio of low-emissions technologies designed to achieve net zero emissions by 2050.

In 2023, five new nuclear reactors with a combined capacity of 5.5 GW began operations in Belarus, China, Korea, Slovak Republic and United States. Combined with the 1.6 GW of existing reactors that were restarted after suspended operations, this more than offset the 6.3 GW of nuclear capacity retirements in 2023, resulting in a net increase of operational nuclear capacity. Through the first nine months of 2024, 4.5 GW of new nuclear capacity has been connected to the grid from new nuclear reactors in China, India, United Arab Emirates and United States. Over the same period, construction started on seven other reactors: five in China, and one each in Egypt and Russia. As of October 2024, there were 62 reactors with around 75 GW of capacity under construction, which would increase worldwide nuclear capacity by nearly 20% when connected to electricity systems.

Figure 3.45 ▹ Annual average nuclear power capacity additions by scenario, 2010-2035



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Nuclear capacity additions accelerate in all scenarios, with China accounting for 40% of global additions in the STEPS by 2035 and nearly 50% in the NZE Scenario

Nuclear capacity and generation are set to increase in each scenario, albeit at a slower pace than several other low-emissions power technologies (Figure 3.45). Emerging market and developing economies drive this growth, notably China, which accounts for 40% of global nuclear capacity additions in the STEPS by 2035 and almost 50% in the NZE Scenario. These

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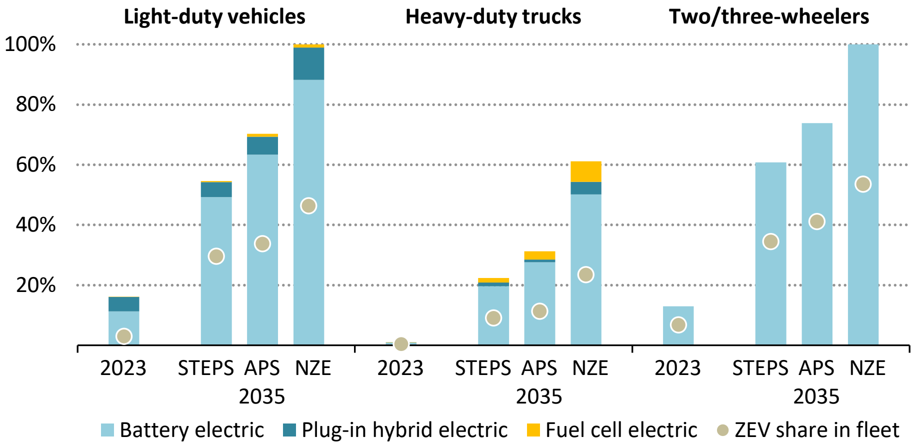
projected additions mean that China is on track to have the largest nuclear power capacity in the world by around 2030 in each scenario.

Small modular reactors are under development in several advanced economies, including Canada, France, Japan, Korea, United Kingdom and United States. China and Russia are also developing them. If they can be brought successfully to market at reasonable costs, they could provide new opportunities for nuclear power in more markets around the world.

3.6.4 Electric vehicles

While electric cars currently account for around 20% of new car sales, they represent less than 5% of the total number of cars on the road. Tight margins, high inflation, the phase-out of purchase incentives in some countries, and a lack of public charging infrastructure have raised questions about how fast EV uptake can be increased. However, global sales data remain robust. In 2023, global electric car sales, including battery electric and plug-in hybrids, reached about 14 million units. Sales are expected to grow this year to around 17 million, representing more than one-in-five cars sold. In the first-half of 2024, electric car sales increased by around 25% compared to the same period in 2023, driven largely by strong performance in China, which accounted for 60% of global sales. In August 2024 alone, electric car sales in China exceeded 1 million, and sales in 2024 as a whole are set to exceed 10 million. By the end of 2024, EVs are expected to account for nearly half of all cars sold in China.

Figure 3.46 ▷ Global market share of zero-emissions vehicles by type and scenario, and share in stock, 2023-2035



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Battery EVs remain the dominant technology for light vehicles, while hydrogen makes inroads beyond 2030 mainly for long-haul road transport

Note: ZEV = zero-emissions vehicle.

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In the STEPS, the share of electric car sales rises to over 55% by 2035 (Figure 3.46). Key drivers of this growth include the rapid expansion of the Chinese EV market, newly implemented EPA regulations in the United States, CO_2 emissions standards in the European Union, and the launch of new EV models in markets such as India, Southeast Asia and Latin America. Continued reductions in battery costs also play a part, with global average battery cell prices to drop below USD 80/kWh during the first nine months of 2024, sustaining the optimism (Benchmark Minerals, 2024).

Significant investment over the past five years has led to battery manufacturing capacity far exceeding current demand. In 2023, global EV battery manufacturing capacity was around 2.2 TWh, while demand was approximately 750 gigawatt-hours (GWh). Yet, the current excess capacity may not last very long: battery demand is set to rise very quickly, increasing more than fourfold by 2030 in the STEPS, fivefold in the APS and sevenfold in the NZE Scenario. However, manufacturing capacity appears capable of keeping pace: committed and existing battery manufacturing capacities together are close to what is needed by 2030 in the NZE Scenario.

Electric cars are becoming more affordable as competition intensifies, especially in China. Around 60% of electric cars sold in China today are cheaper than their average internal combustion engine (ICE) equivalent, but electric cars generally remain more expensive than their ICE equivalents in Europe and the United States, though much depends on the particular country and car segment (IEA, 2024f). Mass market adoption of EVs requires the introduction of more affordable models to the market. Many automakers plan to launch cheaper electric models in Europe and the United States. Declining battery prices should also improve affordability.

3.6.5 Heat pumps

Heat pumps today account for 12% of sales of residential heating equipment worldwide. They have already overtaken sales of fossil fuel-based heating systems in some markets such as France and the United States. By 2035, their market share is set to almost double in the STEPS, reaching approximately 30% in the APS and 40% in the NZE Scenario (Figure 3.47).

However, in 2023 global heat pump sales marked a 3% decline, a shift after two consecutive years of double-digit growth driven by the energy crisis. Sales rose by 12% in China, but it was the only major market to buck the trend. Several factors, with varying regional impact, contributed to the global slowdown, including a decrease in natural gas prices from their 2022 peaks, policy and subsidy changes, less new building construction, and broad consumer aversion to large ticket items amid high interest rates and inflation. The decline in heat pump sales in 2023 also reflects a broader downturn in heating equipment sales in some regions.

Wide deployment of heat pumps in a variety of applications can help meet climate targets. Despite the slight decline in sales in 2023, there are reasons to expect a pick-up in the years to come. Heat pumps are becoming increasingly competitive with gas boilers in key markets over their lifetimes. When considering both cooling and heating, heat pumps already

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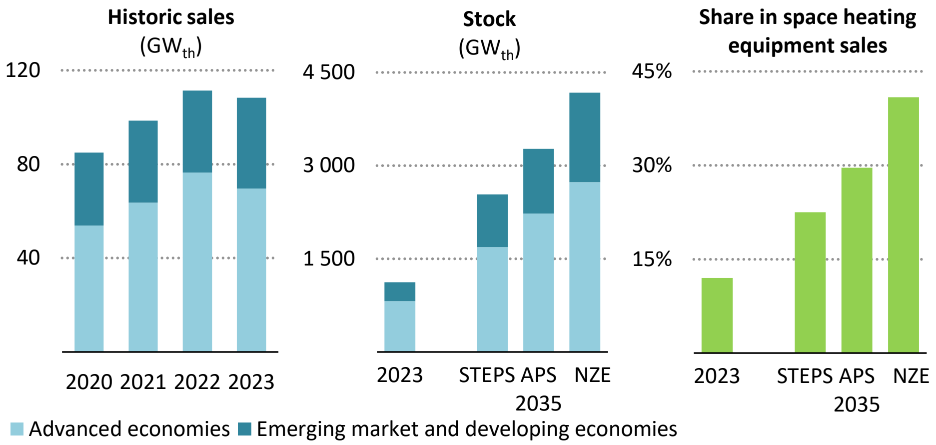
represent one of the most cost-effective options, even in markets where natural gas prices are relatively low, such as the United States. Additionally, there are numerous recent investment announcements and upcoming funding support measures, such as the Inflation Reduction Act in the United States, which aim to develop local manufacturing capabilities and to lower costs.

Despite the progress being made and the projections of rising sales, upfront costs often remain high, particularly for low-income and middle-income households, and the design of electricity tariffs and energy taxes still disadvantages heat pumps compared to fossil fuel boilers in some countries. Maintaining policy stability and heat pump subsidies over the long term, and reforming electricity and gas tariffs in the context of declining gas prices will be critical to provide market actors with visibility while sustaining the rapid manufacturing capacity expansions seen in recent years. Growing sales are going to require more and more skilled installers, which is another issue for governments to consider.

Figure 3.47 ▷ Global heat pump sales and stock by scenario, 2020-2035



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Global heat pump sales dropped 3% in 2023, marking a shift after two consecutive years of double-digit growth, but their market share is set to almost double by 2035 in the STEPS

Note: GW$_{th}$ = gigawatts thermal.

3.6.6 Hydrogen

Global hydrogen production reached 97 Mt in 2023, an increase of almost 2.5% compared to 2022. Production remains predominantly reliant on unabated fossil fuels (Figure 3.48). Hydrogen produced from natural gas without CCUS accounted for 63% of the global total; coal without CCUS, primarily in China, was responsible for 20%; and by-product hydrogen[5]

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[5] By-product hydrogen from the chlor-alkali industry is not included.

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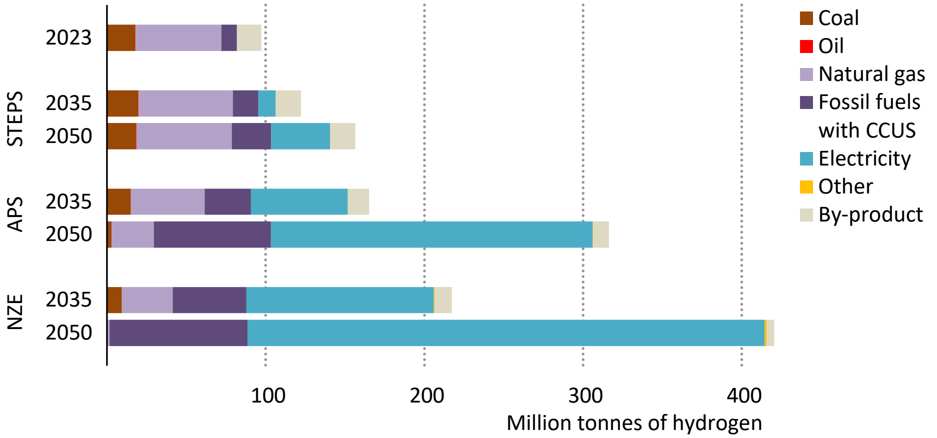
for a further 16%. Low-emissions hydrogen production in 2023 was below 1 million tonnes hydrogen (Mt H_2) and was primarily derived from fossil fuels with CCUS technologies; production from water electrolysis was below 100 thousand tonnes hydrogen (kt H_2) and it is primarily located in China.

Figure 3.48 ▷ **Global hydrogen production by technology and scenario, 2023-2050**



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Low-emissions hydrogen production increases rapidly in the APS, more than tripling from 2035 to 2050, but it remains two-thirds of the level required in the NZE Scenario by 2050

In 2023, worldwide installed capacity of water electrolysers for dedicated hydrogen production reached 1.4 GW, and the capacity added in 2023 nearly matched the cumulative global installed capacity up to 2022. China, which accounted for less than 10% of the global installed capacity in 2020, was responsible for more than four-fifths of the capacity that came online in 2023, including the world's largest electrolyser project, the 260 MW Kuqa plant by Sinopec. Projected low-emissions hydrogen production from announced projects could reach 49 Mt H_2 by 2030. Excluding those in very early stages of development, production could exceed 26 Mt H_2 by 2030 and could meet what is required in the APS in 2030 for low-emissions hydrogen production. However, this 26 Mt H_2 would represent only 40% of the total low-emissions hydrogen production needed in the NZE Scenario in 2030. If projects at early stages are included, the 49 Mt H_2 by 2030 represent three-quarters of projected needs in the NZE scenario. The largest part of the remaining gap in this scenario consists of low-emissions hydrogen produced from electrolysis, while production from fossil fuels with CCUS is already closer to the projected value in the NZE Scenario.

By 2050, low-emissions hydrogen production in the APS accounts for 82% of global hydrogen production, thanks to its use in heavy industry, transport, production of hydrogen-based fuels and electricity generation. In the NZE Scenario, low-emissions hydrogen production

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accounts for 70% of all hydrogen production by 2035, which rises to more than 95% by 2050. Low-emissions hydrogen produced from fossil fuels with CCUS technologies accounts for over 20% of total hydrogen production both in the APS and in the NZE Scenario by 2050, capturing over 585 Mt CO_2 in the APS and around 615 Mt CO_2 in the NZE Scenario. Global electrolyser production accounts for 65% of total hydrogen production in the APS and almost 80% in the NZE Scenario by 2050, requiring the installation of 2 000 GW of electrolyser capacity in the APS and 3 000 GW in the NZE Scenario.

Renewable energy capacity will need to increase significantly to meet electricity demand that arises from low-emissions hydrogen production. By 2050, the installed capacity of renewables for hydrogen production reaches 3 000 GW in the APS and nearly 5 000 GW in the NZE Scenario, with almost 80% of this capacity coming from solar PV. The dedicated renewables generation for hydrogen production accounts for more than 10% of global electricity generation in APS by 2050 and 15% in NZE. Global hydrogen and hydrogen-based fuel trade increases in 2050 to almost 60 million tonnes of hydrogen equivalent (Mt H_2-eq) in the APS and almost 75 Mt H_2-eq in the NZE Scenario, representing around 20% of overall low-emissions hydrogen demand in both scenarios. This requires the development of extensive infrastructure for the storage and transport of both hydrogen and ammonia, even though some elements of the existing infrastructure for fossil fuels could be utilised.

3.6.7 Carbon capture, utilisation and storage

Carbon capture, utilisation and storage (CCUS) is currently applied at around 45 facilities worldwide with a capture capacity of roughly 50 Mt CO_2 per year. While expansion of operational capacity has been slow in recent years, announced projects indicate potential strong growth on the horizon. Realisation of all the projects announced worldwide, which could be completed by 2030, would total 435 Mt CO_2 of capture capacity and around 615 Mt CO_2 of storage capacity per year. However, this is far from assured as only 20% of the announced capture capacity and 15% of the announced storage capacity have reached a final investment decision or are already in operation (IEA, 2024g).

For the next decade, the list of announced projects falls short of what is needed to capture 1.3 Gt CO_2 globally by 2035 in line with the APS, and still further below the 2.5 Gt CO_2 required in the NZE (Figure 3.49). To get closer to NDC and net zero emissions targets, new projects are needed to reduce emissions from fossil fuel-fired power plants and in hard-to-abate industrial processes. In both the APS and NZE Scenario, CCUS technology is also employed to produce low-emissions hydrogen from natural gas, accounting for 10-15% of total emissions captured annually by 2050. The use of atmospheric carbon dioxide removal increases especially in the NZE Scenario, to reach 1.2 Gt CO_2 by 2050, or a fifth of all captured emissions.

In the power sector, carbon capture technologies offer the ability to significantly reduce CO_2 emissions from coal-fired power plants, which emitted 11.3 Gt CO_2 in 2023, or almost 30% of global energy-related CO_2 emissions. With around 9 000 coal-fired units in operation

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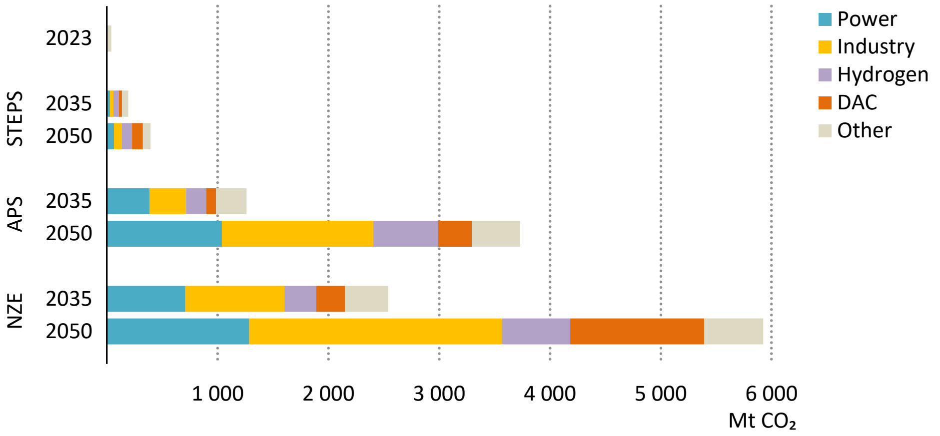
today, many of which have potentially long lifetimes ahead, CCUS could have a role to reduce their emissions to keep climate targets within reach. In the STEPS, carbon capture in the power sector makes limited progress since few projects have reached the stage of final investment decision, and there are few concrete policy targets. In the APS and NZE Scenario, however, carbon capture expands rapidly to 2035 and beyond, to reach around 1 050 Mt CO_2 in the APS and 1 300 Mt CO_2 in the NZE Scenario by 2050. This supports the emissions reductions for coal plants achieved in these scenarios, along with repurposing them for flexibility, retrofitting them to use low-emissions ammonia or retiring them early (IEA, 2022).

Figure 3.49 ▷ Global annual CO_2 emissions captured by sector and scenario, 2023-2050



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Carbon capture is applied at 45 facilities today; further progress has been slow in recent years, but it could play a major role to cut emissions in the power and industry sectors

Note: DAC = direct air capture; Mt CO_2 = million tonnes of carbon dioxide.

In the industry sector, there is currently a large gap between project announcements and the required rates of emissions capture in the APS by 2035. About 4.5 Mt of capture capacity operates in industry today, and a further 39 Mt of planned capacity has progressed to the feasibility study stage or beyond. However, even if all planned capacity were realised, it would fall well short of the 330 Mt CO_2/year captured in the APS by 2035, half of which the APS projects to be deployed in the cement sub-sector, and much of the rest from the production of chemicals and steel. Due to project announcements and policies such as the US Inflation Reduction Act, the Canadian CCUS Investment Tax Credit, and the EU Emissions Trading System, two-thirds of the deployment in 2030 in the APS is in advanced economies. These innovative projects and supporting policies demonstrate the feasibility and improve the competitiveness of carbon capture technologies. Beyond 2030, however, two-thirds of CCUS deployment in the industry sector by 2035 is projected to be in emerging market and developing economies, where energy-intensive industries are concentrated.

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Chapter 4

Exploring uncertainties in the *Outlook*

Considering potential variations from the STEPS

SUMMARY

- While the Stated Policies Scenario (STEPS) provides the direction of travel for the energy system based on today's policy settings, a wide range of factors influence the energy sector and there are many uncertainties. In this chapter we explore the possible impact of several uncertainties on the outlook in the STEPS.
- We do this by analysing the issues and building sensitivity cases around some of the most important and topical uncertainties affecting the energy sector. This includes how variations in the pace of growth of electric vehicles (EVs) and in the use of plug-in hybrids might impact energy demand. We also consider variations in the assumed pace of renewables deployment and assess potential responses to liquefied natural gas oversupply. And we consider uncertainties about how the development of data centres and artificial intelligence, the pace of appliance efficiency improvements, and more frequent and intense heat waves might affect electricity demand.
- Oil demand could be 2-3% higher or lower in 2035 than in the STEPS in the sensitivity cases. EV sales were the largest uncertainty analysed: a slower uptake of EVs could raise oil demand by 1.2 million barrels per day (mb/d) in 2030, mainly in the United States and Europe, and by more than 2 mb/d by 2035. By contrast, enhanced utilisation of EV manufacturing capacity could lead to more EVs being sold in emerging market and developing economies outside China, reducing oil demand by 1.8 mb/d in 2035.
- Natural gas demand could be affected by a liquefied natural gas surplus of around 130 billion cubic metres (bcm) in 2030 in the STEPS. Fully absorbed, this would lift global gas demand by up to 3% in 2035. The gas could help accelerate coal-to-gas switching in industry, but it could also delay the deployment of wind power and heat pumps. Conversely, natural gas demand could be 4% lower in 2035 from slower electricity demand growth and faster solar PV uptake.
- Electricity demand could move up or down in our sensitivity cases by up to 1 700 TWh to 2035, or about 5%. In the high case, natural gas- and coal-fired power would adjust up or down as needed in the near term, while renewables would play a bigger role after 2030. In the low case, electricity demand would still rise rapidly.
- Our analysis indicates that, even combining all the high cases, global peaks for oil, natural gas and coal demand would still occur within a few years of those for STEPS, albeit at higher absolute levels: up 1.7 mb/d for oil, 140 bcm for natural gas, and 37 million tonnes of coal equivalent for coal. Taking all the uncertainties together, CO_2 emissions could be up to 1.0% higher than in the STEPS in 2035, or as much as 3.6% lower, and in all cases would peak within a few years of the STEPS.

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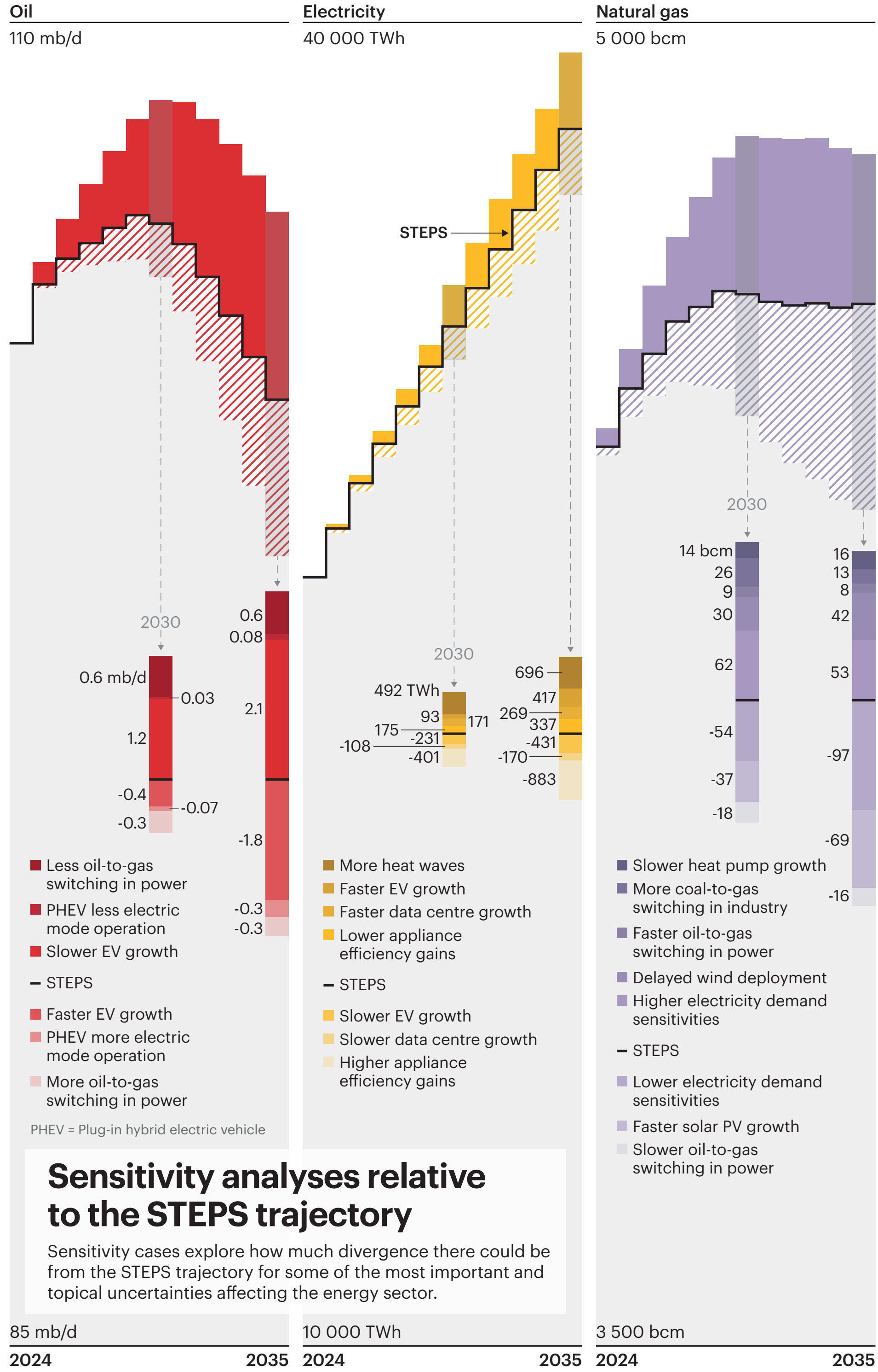
Sensitivity analyses relative to the STEPS trajectory

Sensitivity cases explore how much divergence there could be from the STEPS trajectory for some of the most important and topical uncertainties affecting the energy sector.



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4.1 Introduction

The Stated Policies Scenario (STEPS) is based on analysis of current policy settings and regulations. It aims to provide an understanding of where prevailing regional and global energy trends are leading us. However, the energy sector is influenced by a wide range of factors that make for uncertainty, as discussed in Chapter 2. These factors range from shifting geopolitics to changing policies and customer behaviour, and from fast-evolving climate impacts to changing markets and new technologies such as artificial intelligence (AI).

In this chapter we explore several key uncertainties, using a set of sensitivity cases to investigate how outputs could diverge from the STEPS trajectory. We focus our analysis of uncertainties on the STEPS because it is the scenario which provides a sense of the prevailing direction of travel for the energy sector. The sensitivity cases do not change the broad policy backdrop that underpins and drives the STEPS, or the economic and demographic assumptions that are reflected in the STEPS. Rather, they assess how varying some of the assumptions about deployment rates in the STEPS might affect the energy demand outlook by fuel, sector and region, focusing in particular on electric vehicles (EVs), renewables deployment, the liquefied natural gas (LNG) surplus and electricity demand.

Each uncertainty is explored through the framework of the Global Energy and Climate (GEC) Model, which allows us to quantify impacts, and to combine different impacts to provide a better understanding of a plausible range of outcomes for demand by energy source, type and associated carbon dioxide (CO_2) emissions. When carrying this out, we consider the implications of each uncertainty for all fuels, including coal and renewables, as well as for CO_2 emissions. We focus on their direct impacts and avoid making assumptions about consequential synergistic or counterbalancing effects in other areas of services demand. To isolate the impact of the factors analysed, we have assumed for our sensitivity cases that the price environment is consistent with the trajectories in the STEPS.

There are many uncertainties that bear on the energy outlook. Those we have selected are all important in terms of their potential impacts and are currently the subject of much debate. We have chosen not to look at the impacts of specific geopolitical events or changes to trade patterns that could occur, or to make assumptions about specific policy changes, but rather to focus on potential shifts in deployment rates, whatever the cause, with the aim of shedding light on the direction and scale of the impacts they might have.

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4.2 Exploring the uncertainties

All aspects of energy are subject to a wide range of uncertainties, and so are our scenarios. The uncertainties we explore in detail in this chapter are by no means comprehensive, but they are all important and topical. A central goal of sensitivity analysis is to explore the possible impact of changes to modelling results. The analysis presented in this chapter is intended to provide insight into what those impacts might be, and thus to help improve understanding of the energy system. We focus on four main areas: EVs, renewables deployment, the LNG surplus and electricity demand.

Electric vehicles

The electric vehicle (EV) market is expanding rapidly, leading to a move away from oil to electricity in road transport. Growth has been especially rapid in recent years: EV sales more than tripled between 2018 and 2023, with China alone accounting for over half of the increase. However, there are uncertainties about the future pace of growth in the EV market. In the STEPS, our projections of EV trends and sales take account of factors such as consumer response, advances in technology and policy support. The sensitivity cases consider some of the uncertainties that could affect these parameters.

Our EV category includes plug-in hybrid electric vehicles (PHEV), which have a powertrain that enables use of two energy sources, and we consider the impact of variations in that usage.

Renewables deployment

Renewables account for a growing proportion of electricity generation, and their deployment is set to continue to increase rapidly. Growth is driven primarily by wind and solar photovoltaics (PV), which together increased by 16% year-on-year in 2023, with over half of that expansion taking place in China. The rapid pace of renewables growth brings both risks and opportunities. Risks could arise from pressures in supply chains or difficulties in permitting, notably for wind; opportunities could arise from further large reductions in costs of the kind that have benefited solar PV in the past, which could lead to an acceleration of renewables deployment.

In addition, developments such as a switch from oil to gas in power generation in the Middle East, for example, could have knock-on implications for the renewables sector.

LNG supply

A wave of new LNG export capacity is under construction, which has the potential to create a surplus of supply in global gas markets. Downside pressure on natural gas prices could arise from the additional supply, which could make LNG use more attractive for industry, incentivising coal-to-gas switching.

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Lower natural gas prices also reduce the attractiveness to consumers for switching from gas boilers to heat pumps, which could potentially delay the uptake of this more efficient form of heating.

Electricity demand

The growth in demand for electricity use in data centres and artificial intelligence (AI) has garnered a lot of attention recently. Growth will no doubt continue, but there are uncertainties over its pace, which will be influenced by factors such as market trends, algorithm developments and improvements in the efficiency of hardware and software.

Appliances and air conditioners account for a rising proportion of demand in emerging market and developing economies, with increasing levels of ownership reflecting economic growth and a rapidly expanding stock of buildings. This is exemplified by the 5% growth in energy demand for appliances in 2023, with more than half of this growth in China. Appliances tend to be less efficient in emerging market and developing economies than in advanced economies, reflecting in part a strong second-hand market and more limited energy efficiency measures. The pace at which the efficiency of appliances improves and the extent to which levels of ownership increase together represent a significant uncertainty in electricity demand projections.

Climate change is already leading to an increasing number of extreme weather events. This includes heat waves which increase electricity demand in the short term by driving up immediate cooling needs and in the longer term by pushing up the level of ownership of air conditioners. The extent to which heat waves occur in the years ahead and the way that responses to them affect electricity demand is another uncertainty.

Uncertainties impact multiple energy sources

Each uncertainty has an impact across more than one fuel type, reflecting the interconnected nature of the energy system.

Most of the uncertainties we explore touch on the generation and/or demand of electricity. A variety of fuels contribute to power generation, and changes that affect one of these fuels have implications for others in the mix. For example, while EVs displace demand for oil, they also increase demand for electricity which could be generated using coal, natural gas, oil or a renewable energy source: the specific mix depends on location and timing.

Some of the uncertainties explored do not directly impact electricity demand, but they still have implications for multiple primary energy sources. For example, changes from using coal to natural gas in industry, or from using oil to natural gas for power generation in the Middle East. Here again much depends on location and timing.

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4.3 Sensitivity analyses relative to the STEPS trajectory

A summary of our sensitivity cases to explore uncertainties is in Table 4.1. Each case is a conceivable variation on the STEPS. Quantitative impacts on the key energy sources of oil, natural gas and electricity are presented in the following sections.

Table 4.1 ▷ Overview of sensitivity cases

Uncertainty	High demand case	Low demand case	Impacted fuels
Electric vehicles			
Pace of EV growth	**Slower EV growth** Slower rollout, mainly in North America and Europe.	**Faster EV growth** Enhanced utilisation of EV manufacturing capacity leading to increased sales primarily in EMDE markets outside China.	Oil, natural gas, electricity, coal
PHEV electric mode operation	**Less electric mode operation** Lower electric propulsion mode use by PHEVs.	**More electric mode operation** Higher electric propulsion mode use by PHEVs.	Oil, natural gas, electricity, coal
Renewables			
Pace of renewables deployment	**Delayed wind deployment** Wind capacity expansion faces difficulties.	**Faster solar PV growth** Solar PV capacity expansion more than expected.	Natural gas, electricity, coal
Middle East power generation	**Less power oil-to-gas switching** Delay in shift from oil-fired power generation.	**More power oil-to-gas switching** Faster shift away from oil-fired power generation.	Oil, natural gas
LNG oversupply			
Coal-to-gas switching	**Increased industry coal-to-gas switching** Industry demand in China and Southeast Asia take up some LNG oversupply.		Natural gas, coal
Heat pump uptake	**Slower heat pump growth** European Union and China take up some LNG oversupply which leads to slower rates of heat pump installation.		Natural gas, electricity
Electricity demand			
Data centres/AI	**Faster data centre growth** Stronger energy demand growth.	**Slower data centre growth** Weaker energy demand growth.	Natural gas, electricity, coal
Efficiency improvements	**Lower appliance efficiency gains** Slower efficiency improvements in EMDE.	**Higher appliance efficiency gains** Faster efficiency improvements in EMDE.	Natural gas, electricity, coal
Heat waves	**More frequent, intense and longer duration heat waves** Drives up cooling and air conditioner ownership, especially in EMDE.		Natural gas, electricity, coal

Note: EMDE = emerging market and developing economies; EV = electric vehicle; PHEV = plug-in hybrid electric vehicles; AI = artificial intelligence.

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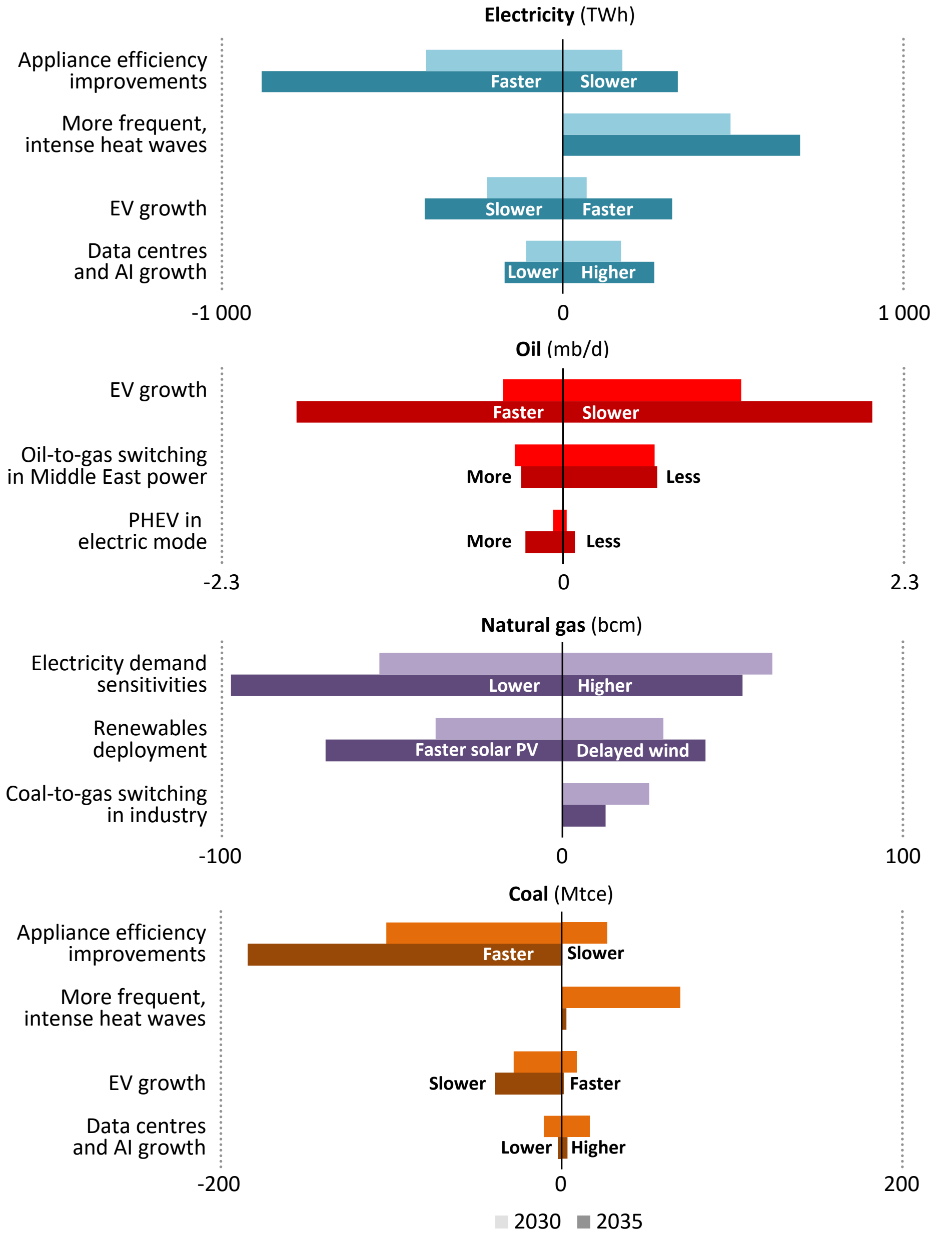
Figure 4.1 ⊳ Demand changes by fuel for selected sensitivity cases



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Overall impacts affect up to 5% of total demand for electricity and up to 4% for both oil and natural gas in 2035; related effects on coal demand are up to 5% in 2030 before diminishing

Note: TWh = terawatt-hours; mb/d = million barrels per day; bcm = billion cubic metres; Mtce = million tonnes of coal equivalent; PHEV = plug-in hybrid electric vehicles; EV = electric vehicle; AI = artificial intelligence.

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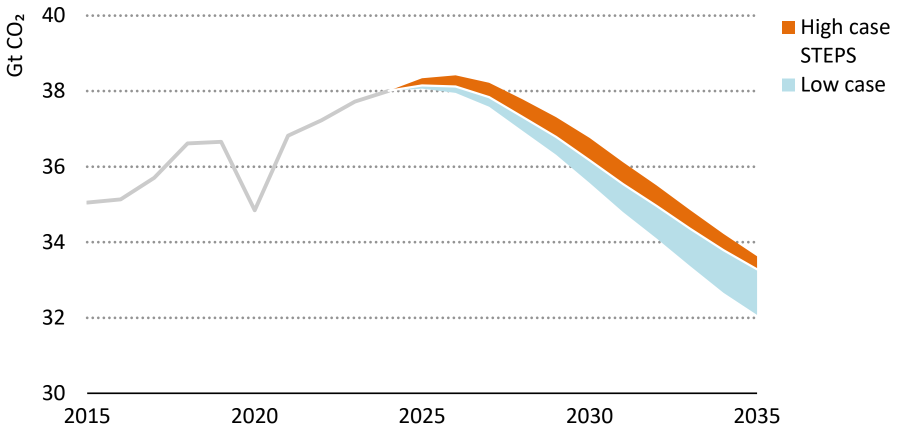
Our oil and gas sensitivity analysis suggest potential variations could alter total demand for oil by as much as 3%, and gas by as much as 4% by 2035 relative to the STEPS (Figure 4.1). Variations in electricity demand for our selected sensitivity elements reach almost 5% in 2035 compared to the STEPS, with related impacts on coal that reach 5% of total demand in 2030 before diminishing.

Combining all the sensitivity components and interactions into *high* and *low cases* indicates that CO_2 emissions peak within a few years of the STEPS (Figure 4.2). In the high case, emissions are 1.6% higher in 2030 and 1% higher in 2035 than in the STEPS. In the low case, emissions are down 1.6% in 2030 and 3.6% in 2035. These variations add up to 5 gigatonnes (Gt) to cumulative energy sector emissions over the period to 2035, or reduce them by as much as 7 Gt. Across our sensitivity analysis, overall CO_2 emissions are affected less than the demand for each fuel as a result of the balancing effects that take place between fuels when combining sensitivities. For example, while emissions from oil use are reduced in the faster EV growth sensitivity, this is counteracted, albeit to a lesser extent, by slightly higher power sector emissions due to increased electricity demand.

Figure 4.2 ▹ **Energy-related CO_2 emissions in the STEPS and collectively for the sensitivity cases, 2015-2035**



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Even with combining all the sensitivities, CO_2 emissions still peak in the mid-2020s; the high and low cases deviate less than 4% from the STEPS by 2035

Note: Gt CO_2 = gigatonnes of carbon dioxide.

The changes from the STEPS presented by the sensitivity analysis here for oil, natural gas and coal are three- to ten-times less than those between the STEPS and the Announced Pledges Scenario (APS) in 2030, and six- to thirty-times less than those between the STEPS and the Net Zero Emissions by 2050 (NZE) Scenario for the same year.

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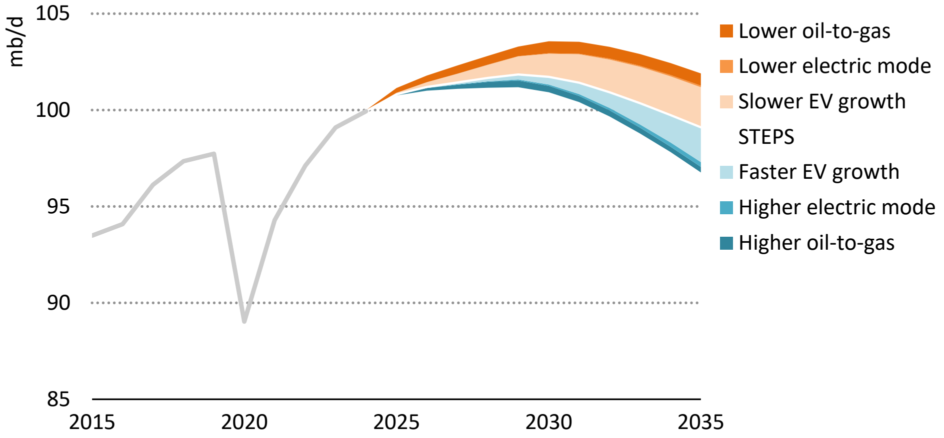
4.4 Uncertainties in oil demand

Oil demand peaks by 2030 in the STEPS after increasing by about 2.6 million barrels per day (mb/d) from 2023 to 2030. Within this decade, rising sales of EVs and improvements in fuel efficiency lead to petrochemicals taking over from road transport as the main contributor to oil demand growth. The pace of EV sales and the role of PHEVs are two key uncertainties for the oil outlook, and the degree of oil-to-gas switching in the power sector in countries in the Middle East is a third. Exploring and combining these sensitivities, we find that global oil demand peaks within a few years of that for the STEPS in the high demand case with an additional 1.7 mb/d of oil use, and in the low case with 0.7 mb/d less use of oil (Figure 4.3). By 2035, oil demand across the sensitivities ranges from 97 mb/d to 102 mb/d.

Figure 4.3 ▷ Global oil demand in the STEPS and key sensitivities, 2015-2035



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Selected oil sensitivity cases point to changes in oil demand of up to 2.8 mb/d by 2035, with the strongest influence being the rate of EV uptake

Notes: Electric mode refers to the use of plug-in hybrid electric vehicles in electric motor mode. Oil-to-gas switching in power generation is relevant to the Middle East.

4.4.1 Electric vehicle pace of growth

EVs are one of the key factors tempering future oil demand. Annual electric car sales rise from 14 million today to over 40 million in 2030 and nearly 60 million in 2035 in the STEPS. This shift to EVs displaces over 6 mb/d of oil demand by 2030 and 13 mb/d in 2035, with most of the savings deriving from passenger cars. However, the amount of oil displaced depends heavily on how quickly EV sales continue to increase.

Electric car sales were up by around 25% year-on-year in the first half of 2024, with China accounting for about 80% of this increase. Some regions like Asia show robust growth, and North America has seen a rise of nearly 13%. But sales are rising more slowly in other parts

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of the world for various reasons. For example, some EV subsidies in the European Union have been phased out, and more stringent CO_2 emissions standards are not due to take effect until 2025 (see Chapter 1). A wide range of factors will affect the future rate of EV uptake, including policy support, fuel and emissions standards, the extent to which more affordable EV models become available, the rollout of charging infrastructure, consumer preferences and company strategies.

The market share of new electric passenger cars sold in the STEPS reaches about 45% by 2030. In the *Slower EV growth case*, this figure decreases by close to ten percentage points. In the *Faster EV growth case*, it increases by close to five percentage points, and the impact becomes more pronounced beyond 2030, particularly in emerging market and developing economies outside China as they significantly expand their car fleets: as a result, the market share of electric cars reaches two-thirds by 2035 in the *Faster EV growth case*, compared with just over 55% in the STEPS during the same period.

Slower EV growth, higher oil demand

Certain regions are at higher risk of slowdown in EV sales than others, especially those with strong policies or ambitious goals that may be delayed, cancelled or fail to be met. The risks are particularly acute as markets transition from early adoption of EVs to a phase in which EVs account for the majority of sales.

In the United States, for instance, there is uncertainty about the future evolution of greenhouse gas emission standards, and the path that is taken will have significant implications for future EV demand. Any slowdown in the United States, which accounts for about 85% of the entire North American car market, could have ripple effects throughout the region. In the European Union, a review of its CO_2 standards in 2026 will assess progress toward achieving 2035 targets, and its outcome is likely to have implications for the speed of EV adoption in EU member countries. Elsewhere, some advanced economies in Asia are facing challenges to increase their EV market share to levels that are comparable to those in other advanced economy markets, while recently announced EV targets in Australia may require additional support measures. Even in China – the largest EV market – PHEVs now account for over 30% of total electric car sales, suggesting that consumers still have concerns about range anxiety arising from a perceived lack of adequate charging infrastructure.

In this sensitivity case, we assume that these various risks lead to electric car sales being around 10% lower than in the STEPS by 2035. Electric car sales in the United States are close to 10% lower than in the STEPS, and sales in the European Union are 5% lower. Most of the rest of the reduction is in China, where sales are assumed to be around 7% lower than in the STEPS. As a result of these changes, oil demand is around 2 mb/d higher in 2035 than in the STEPS, with the United States and China being key sources of variations (Figure 4.4). This does not affect the timing of peak oil demand projected in the STEPS: the peak still comes by the end of the decade, but at a level of around 103 mb/d rather than below 102 mb/d as projected in the STEPS.

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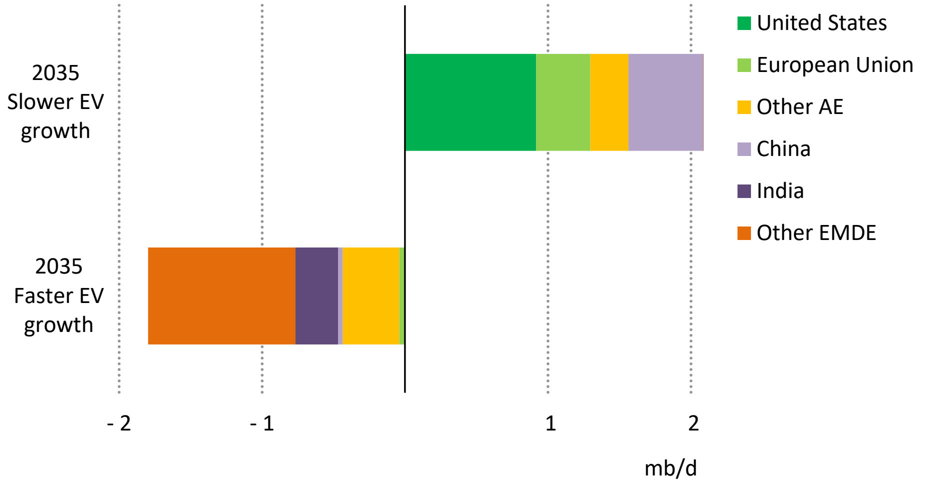
Figure 4.4 ⊳ **Variations in oil demand related to rate of EV uptake in selected regions relative to the STEPS, 2023-2035**



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Slower EV uptake increases oil demand by 2 mb/d in 2035, of which 60% is from the United States and European Union; faster EV uptake mostly reduces oil demand in other EMDE

Note: AE = advanced economies; EMDE = emerging market and developing economies.

Faster EV growth, lower oil demand

Emerging market and developing economies outside China offer an opportunity to accelerate EV uptake. Spare Chinese EV manufacturing capacity could feed into growing demand in these economies, especially those with established trade routes to China, and they could introduce further domestic measures to support this growth.

Car production utilisation rates, encompassing both internal combustion engine (ICE) vehicles and EVs, in China are low, at around 50% of total manufacturing capacity. Typical car plants in other regions operate at about 70% capacity on average. While car production utilisation rates in China could exceed 90% for a few large EV manufacturers, there is excess capacity available that could produce 5 million more EVs annually. This could feed demand from emerging market and developing economies as they mature. Plans to scale up domestic EV production in parts of Asia and Latin America could also meet growing demand.

In this sensitivity case, we increased global electric car sales by an additional 11 million in 2035, on top of the over 55 million electric car sales that already feature in the STEPS (Figure 4.5). We assumed that these additional sales would mostly be in emerging market and developing economies outside China. This leads to a reduction in oil demand of 1.8 mb/d in 2035. The reduction does not affect the date when of peak global oil demand is reached in the STEPS: the peak still comes by the end of this decade, albeit at a level approximately 0.3 mb/d lower than in the STEPS.

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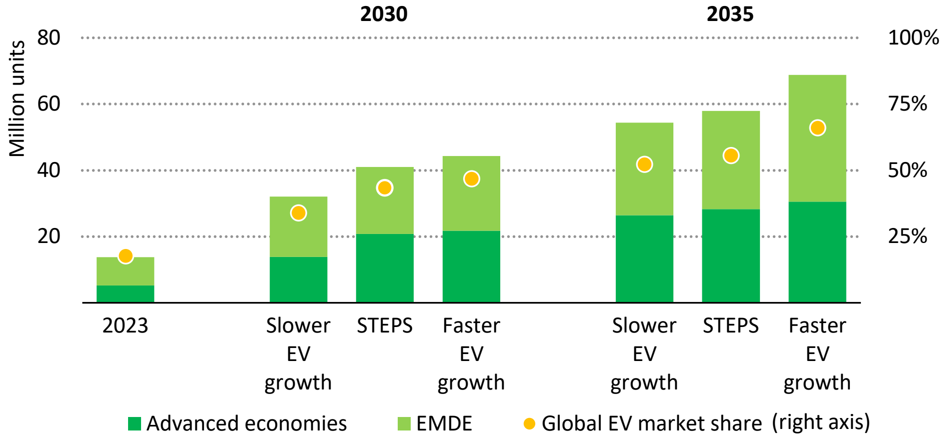
Figure 4.5 ⊳ **Global electric car sales and their market share by sensitivity case and in the STEPS, 2030 and 2035**



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Faster EV uptake could add over 3 million more electric car sales than in the STEPS by 2030 and the impact strengthens as the EV market expands to 2035

Note: EMDE = emerging market and developing economies.

4.4.2 PHEV in electric mode operation

The share of plug-in hybrid electric vehicles in total electric car sales has fluctuated between 25% and 40% since 2015. There has been significant recent growth in PHEV sales, particularly in China, where they increased by 80% in 2023 – a far bigger increase than by battery electric cars, which saw sales rise by over 20%. There are several underlying reasons, the most important of which is that PHEV powertrains largely overcome range anxiety by combining the benefits of both conventional engines and EVs. The trend in China is also attributed in part to the introduction of new PHEV models, given that the market was previously dominated by battery electric models.

Despite playing a strong role in the EV mix in the short term, sales of PHEVs are likely to drop rapidly after 2030 as an increasing number of more affordable battery electric models becomes available and as advances in battery technology and the rollout of charging infrastructure alleviate range anxiety. However, the critical factor for PHEVs is how consumers operate them. Studies have shown that electric mode use typically accounts for between 20% and 40% of the annual mileage (ICCT, 2022). Incentives such as access to low-emissions zones for PHEVs operating solely in electric mode, along with government efforts to ensure affordable electricity prices, could boost the use of electric mode in PHEVs.

Employing electric mode usage as a factor, we constructed two sensitivity cases with different oil demand trends: a *more electric mode operation case* which increases the current levels of electric propulsion by over 30 percentage points by 2035, and a *less electric mode*

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operation case which holds the proportion of PHEV electric propulsion at current levels. In the case where electric mode use stagnates, PHEVs lead to an increase in oil demand by around 100 thousand barrels per day (kb/d) by 2035; in the case where electric propulsion increases, oil demand declines by 250 kb/d over the same period.

4.4.3 Oil-to-gas switching in the Middle East power sector

Oil remains an important part of the electricity mix in the Middle East. The region currently consumes around 1.7 mb/d of oil every year in the power sector alone, equivalent to the total oil demand of Indonesia. Around 340 terawatt-hours (TWh) were generated by oil-fired power plants in 2023, providing 25% of total electricity supply in the region. The largest user of oil-fired power in the Middle East is Saudi Arabia, generating nearly half of the total in 2022: it is home to the world's largest oil-fired plant, which consumes around 200 kb/d on peak days. Other major users of oil-fired power are Iran (over 20% of the regional total) Kuwait (18%), Iraq (8%), Syria (5%) and Lebanon (1%).

There is much uncertainty, however, about the amount of oil that will be used in the electricity sector in the Middle East over the next decade. While electricity demand is projected to rise rapidly, the largest users of oil in power are making efforts to shift away from oil to natural gas and renewable energy sources. For instance, the Vision 2030 programme in Saudi Arabia aims to phase out oil for power generation by 2030, though specific plans to achieve this objective have not yet been established. High dependence on oil in the power sector is a point of concern to many countries in the region, and consideration is being given to how to reduce its use. For example, in Iraq, where there has been recent progress in switching to natural gas and where there are ambitions to increase the availability of natural gas for power through the elimination of flaring before 2030.

Taking into consideration these policies and factors, Middle East oil demand in the power sector declines by about 900 kb/d to 2030 in the STEPS, while natural gas demand in the power sector increases by over 40 billion cubic metres (bcm) and renewable electricity generation increases sixfold. In a case where transitions away from oil are delayed in Saudi Arabia, Iraq and other countries in the region, oil use in the power sector could decline by less than it does in the STEPS, and in consequence oil demand could be some 500 kb/d higher in 2030 than in the STEPS. On the other hand, in a case where transitions away from oil proceed more quickly than in the STEPS, including through more rapid switching to natural gas and renewables, oil use in the power sector could be further reduced by around 250 kb/d in 2030 compared to the STEPS.[1]

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[1] The competition between natural gas and renewables in the Middle East is also an important uncertainty, but outside the scope of this analysis.

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Box 4.1 ⊳ Shipping chokepoints

International navigation accounts for 4% of global oil demand. Some international shipping routes pass through chokepoints, which are narrow waterways that connect larger bodies of water. These chokepoints pose a risk of disruption to shipping routes, whether caused by a natural disaster, accident, geopolitical conflict or piracy acts. Examples include the Strait of Malacca, the Danish Straits and the Strait of Gibraltar.

Two key global chokepoints are the Suez Canal and Panama Canal, where security concerns, geopolitics, weather and operational issues have all recently had impacts.

The Panama Canal saw capacity restrictions throughout much of 2023 caused by a drought that reduced water levels. The average number of ships permitted to pass was about 10% lower than typical levels.

The Suez Canal has seen more dramatic impacts. It was temporarily blocked for six days in 2021. Since December 2023, security risks from Houthi activity in the vicinity of the Bab al-Mandab Strait have reduced the number of cargo and tanker ships passing through the canal by about 50%. The alternative route around Africa via the Cape of Good Hope involves a significantly longer journey. For example, the journey from Singapore to Rotterdam by sea would be over 40% longer if ships could not pass through the Red Sea. This has implications for both activity and energy demand.

If all international ships were to avoid or lose access to the Suez Canal, the longer distances they would have to travel would mean an increase of nearly 10% in tonne-kilometres travelled. Additional energy requirements for the more circuitous route might well be compounded by some operators increasing shipping speeds to meet delivery deadlines. We estimate that the net effect could increase oil demand in shipping by around 330 kb/d during 2024.

4.5 Uncertainties in natural gas demand

While global natural gas demand increases by about 250 bcm from 2023 to a peak of 4 400 bcm in the late-2020s in the STEPS, global gas markets remain well supplied. A wave of new LNG supply coming to market, together with other factors, applies downward pressure on the price of LNG exports in the STEPS (see Chapter 1). The response to these price reductions is uncertain and could lead to global natural gas demand increasing faster than projected in the STEPS in order to clear available supply. We find that the LNG surplus of around 130 bcm in 2030 in the STEPS could lead to higher demand for natural gas, with some of it being used for electricity generation, heating and industry. This would displace the fuels that would otherwise have been used, such as oil in power, coal in industry and electricity in buildings, including heat pumps.[2] In addition, we analyse the implications for

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[2] If the LNG prices were very low, lower than in the STEPS, then it could also lead to significant amounts of coal-to-gas switching in the power sector (see Chapter 1).

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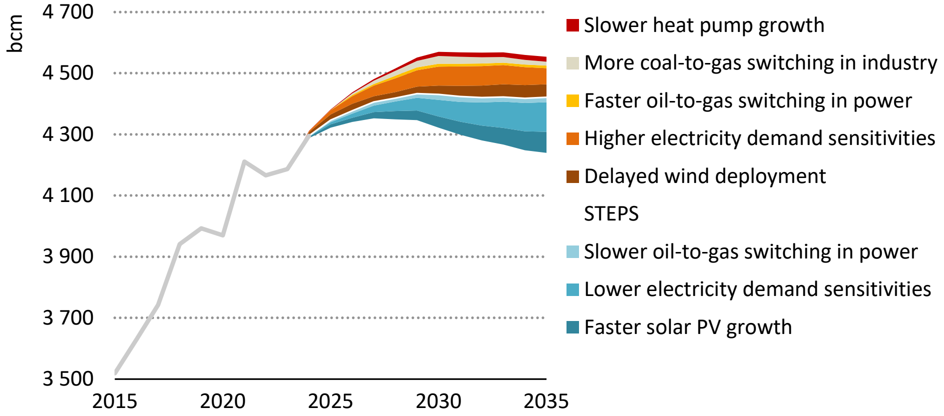
natural gas demand related to uncertainties in the pace of renewables deployment and electricity demand growth.

Combining these uncertainties, we find that the effects would see a peak within a few years of that for the STEPS (Figure 4.6), although there are circumstances that could see growth beyond this range (see Box 1.6 in Chapter 1). On the other hand, faster solar PV deployment and lower electricity demand growth could see an earlier peak in natural gas demand and a more significant decline to 2030 and 2035.

Figure 4.6 ▷ Global natural gas demand in the STEPS and key sensitivities, 2015-2035



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Surplus LNG absorbed by increased gas use mainly in power and industry could add 3% to gas demand by 2030; nevertheless, peak natural gas demand would still be around 2030

Note: bcm = billion cubic metres.

4.5.1 LNG oversupply

In the STEPS, LNG demand increases by 145 bcm between 2023 and 2030, while export capacity expands by around 270 bcm, loosening global gas markets (Figure 4.7). This puts downward pressure on natural gas prices, which in the STEPS average around USD 6.5 per million British thermal units (MBtu) in the European Union in 2030, USD 7/MBtu in China and around USD 8/MBtu in Japan. This is almost half the levels seen in the European Union in 2023, and about 35% lower in China and Japan. Existing LNG export capacity and new capacity under construction is sufficient to meet projected demand in the STEPS until 2040. This suggests that no further projects are required in the near term to satisfy demand for LNG.

Compared with previous waves of LNG supply growth, there are now fewer buyers that are obliged to take volumes of gas on long-term take-or-pay contracts. Around one-third of the capacity under construction is as-yet uncontracted, meaning these additional volumes will

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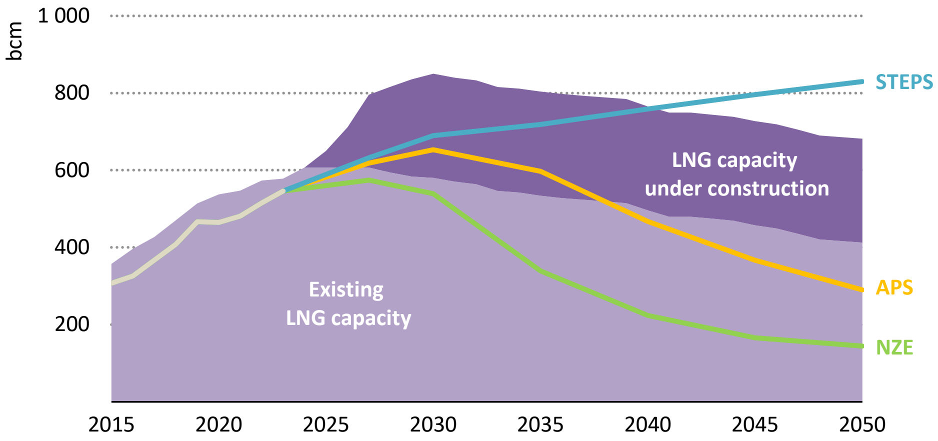
be made available on the spot market from suppliers or portfolio players with equity stakes in the terminals. With the increasing liquidity and flexibility of global LNG supply, there is a high degree of uncertainty about which markets and sectors have the capacity to absorb these additional volumes of gas. This is compounded by uncertainties about production: in some cases, this might fall faster than anticipated, e.g. Bangladesh or Thailand, and in others it might surprise on the upside, for example in China.

Figure 4.7 ▷ LNG trade by scenario relative to existing and under construction export capacity to 2050



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There is additional surplus of around 130 bcm of LNG by 2030 in the STEPS based on current project announcements; this surplus declines after 2030 as LNG capacity reduces

Note: LNG capacity is derated to 90% of nameplate capacity to account for maintenance, outages and upstream supply availability.

On the import side, there is significant LNG regasification capacity of around 1 500 bcm today – more than double the amount of export capacity – and a further 200 bcm is being built. Around 40% of the new capacity is being built in China. Europe is also increasing its ability to import LNG and by 2030 its regasification capacity is set to reach 370 bcm per year, which is 50% higher than it was before Russia invaded Ukraine. Overall, there are relatively few infrastructure-related constraints to increasing LNG use, barring some bottlenecks to reach new centres of gas demand in India.

We explored a sensitivity case where the LNG surplus and the resulting downward pressure on prices in the STEPS stimulates additional demand above the level in the STEPS of around 75 bcm by 2030. This additional demand raises overall LNG capacity utilisation from 80% in the STEPS in 2030 to 90%, closer to current levels of around 95%. Most of the incremental volume comes from existing projects in the United States, with the remainder supplied principally by Canada, Qatar and exporters in Nigeria and Mozambique. The upward

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adjustment to demand pulls forward the date at which new LNG export capacity is needed. Whereas in the STEPS, current projects are able to meet demand to 2040, in this sensitivity case a supply gap opens in the mid-2030s and around 60 bcm of new capacity is required by 2040.

There are several potential sources of this incremental supply, but many face challenges. Current projects in East Africa have been delayed by security concerns, while difficulties developing upstream resources have tempered export capacity growth in West Africa and Australia. Russian LNG supply growth is meanwhile hobbled by sanctions, while possible projects in other countries with export ambitions, such as Saudi Arabia, are at a very early stage of development. On the other hand, Qatar and the United States, which dominate today's pipeline of new projects, look well-placed to develop more capacity in the long term. Canada and Argentina are also in a strong position to ramp up gas exports now that they are completing planned infrastructure to transport gas from inland fields to coastal terminals.

4.5.2 Higher natural gas demand uncertainties

The power sector is the largest user of natural gas, consuming about 40% of the total in 2023. Any changes in power sector demand for natural gas could therefore have a significant effect on overall natural gas demand. Two of the most important potential changes that could raise natural gas use in the power sector are an acceleration in the pace of electricity demand growth (section 4.6) and delays or reductions in expansion of renewables. We find that changes of this kind, together with increased oil-to-gas switching in the Middle East, could raise natural gas demand in the power sector by 100 bcm in 2030. The majority of that increase would be in gas-importing countries, which together would take up a significant portion of the LNG surplus. In our analysis, the effects are largest in China, the European Union and Southeast Asia, though there are also smaller effects in many other countries (Figure 4.8). Among exporting countries, these uncertainties would affect natural gas demand in the power sector the most in the United States, followed by countries in the Middle East.

There are of course many other uncertainties in the power sector. For example, there could be significant policy changes, such as additional measures in some countries to accelerate transitions away from coal-fired power, or a change of position on nuclear power. There could also be more coal-to-gas switching in the power sector than projected in the STEPS if gas prices were to fall to levels below those projected. However, we have had to be selective in choosing uncertainties for consideration, and these fall outside the scope of this analysis.

In the power sector, uncertainties concerning the pace of expansion for wind power are especially relevant for gas demand. In the STEPS, global wind power is projected to increase rapidly and to double by 2030: these projections reflect policy support for wind power in over 60 countries, widespread resource availability and proven low-cost technology. The link between wind power and natural gas use in the power sector is particularly important in the European Union and the United States, regions where the wind industry has recently faced

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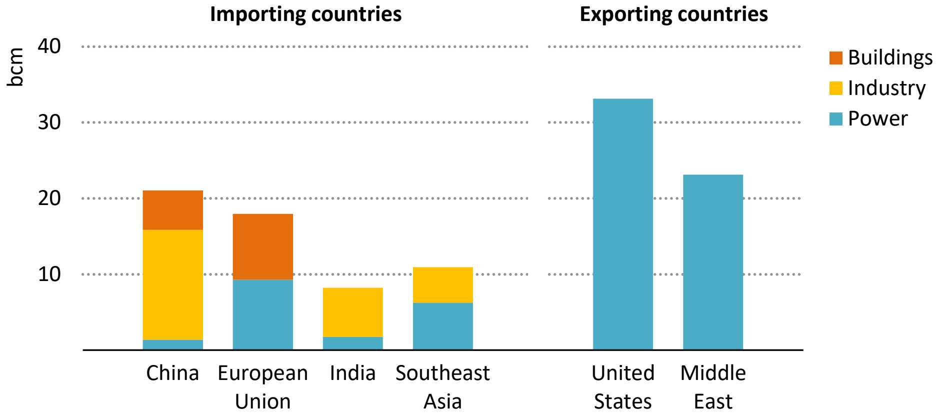
challenges, creating some uncertainty about the pace at which deployment is likely to be scaled up in the coming years. The main challenges are from supply chain issues, permitting and licensing hold-ups, grid connection queues, and with tightening profit margins due to fixed price contracts and increases in equipment costs. Onshore wind development is most affected by the challenges arising from permitting, licensing and grid queues, and offshore wind by those arising in the supply chain and related financial challenges. A number of US offshore projects were cancelled or delayed in 2023, which are already reflected in the STEPS, but the challenges for offshore wind could last longer than projected. There has also been a reduction in the level of participation in recent wind power auctions in the European Union.

Figure 4.8 ▹ **Additional natural gas demand potential from sensitivity cases based on the STEPS, 2030**



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Uncertainties for natural gas are dominated by the power sector, but uncertainties are also significant in industry and buildings in gas-importing countries

Such uncertainties could reduce expansion of wind power to 2035 by almost 20% in the United States, and almost 15% in the European Union, cutting installed wind capacity in 2035 by nearly 80 gigawatts (GW) (Figure 4.9). The impact of delayed deployment of wind power in the United States would be an extra 23 bcm of natural gas demand in 2030 and over 30 bcm in 2035, while in the European Union it would lead to an extra 7 bcm of gas demand in 2030 and 9 bcm in 2035. The solar industry faces some of the same challenges, including grid connection queues and permitting and licensing problems in some instances, but its supply chains are in a stronger state.

Additional growth for electricity demand could also raise the level of natural gas demand in the power sector. In advanced economies, a faster rise in electricity demand that outstripped the growth of renewables would be likely to prompt turning to natural gas to fill the gap. In emerging market and developing economies, where coal is the primary source of electricity, a faster than expected increase in electricity demand would lead to additional use of coal,

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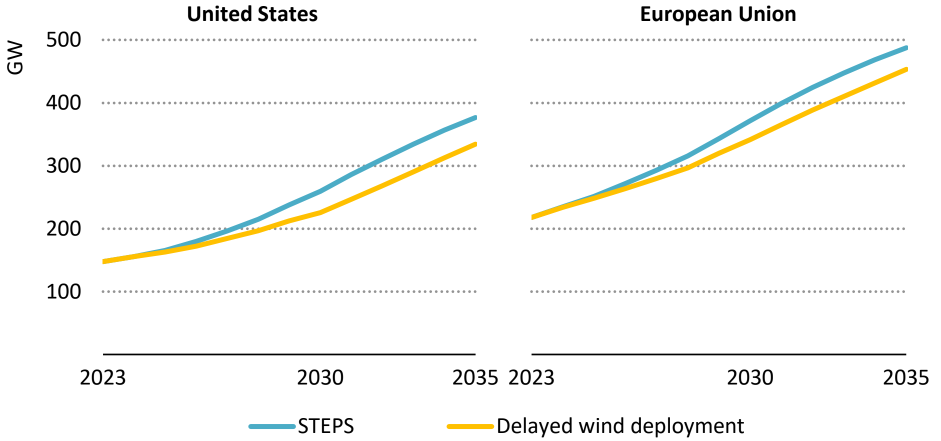
but it would also mean a search for additional natural gas in many instances, particularly in Southeast Asia. As discussed, the extent of oil-to-gas switching in the Middle East is another major uncertainty.

Figure 4.9 ▷ Wind power capacity expansion in the STEPS and delayed wind deployment case, 2023-2035



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Whether due to permitting, licensing, grid connection or other issues, even modest delays in wind power deployment could have a real impact on natural gas demand

We have also assessed the potential for a larger response from the industry sector to lower natural gas price resulting from the LNG surplus. Lower prices could lead to faster displacement of coal and oil boilers by natural gas in China, India and Southeast Asia without changing the rate of electrification. In non-energy-intensive industry, where most of this displacement occurs, the average rate of replacement for natural gas boilers increases to 2.3% per year in the sensitivity case compared with 0.6% in the STEPS by 2030. This results in gas demand increasing by 23 bcm in 2030 compared to the STEPS, displacing 13 million tonnes of coal equivalent (Mtce) of coal demand and 0.3 mb/d of oil demand. We assume that distribution infrastructure is able to meet this additional demand, though that may be challenging in some cases, notably in India and Southeast Asia.

Lower natural gas prices in the years ahead could also lead to larger increases in demand for natural gas for ammonia production as a result of existing coal-based production plants in China and Southeast Asia being converted to gas faster than projected in the STEPS, though the effect on gas demand is much smaller than that arising from the displacement of oil and gas boilers in industry. In the sensitivity case, this switch results in additional gas demand of around 3 bcm for ammonia production by 2030, which displaces another 4 Mtce of coal demand.

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Lower natural gas prices could also have a larger impact on the buildings sector by delaying moves away from gas-fired heating to heat pumps. Heat pump growth slowed in 2023 as the market consolidated after a significant surge in 2022 which was probably driven by the energy crisis. Growth is expected to pick up again. The STEPS projects growth in the stock of heat pumps by two-thirds by 2030. However, China and the European Union, which account for more than 40% of the current global heat pump stock, remain particularly vulnerable to the risk that the lower gas prices in the STEPS could further slow the pace of gas boiler replacements. In the sensitivity case, heat pump sales could be reduced by 20% in the European Union and China, resulting in a 10% reduction in stock by 2030 compared with the STEPS: this increases gas demand by 14 bcm, displacing 50 TWh of electricity by 2030.

4.5.3 Lower natural gas demand uncertainties

Solar PV deployment is a major success story in global clean energy transitions. Installed solar capacity has roughly doubled every three years since 2015, and this increase has been accompanied by similar expansion in solar PV manufacturing capacity. Existing solar PV module manufacturing capacities are more than sufficient to produce over 900 GW of solar PV modules, which is the level of capacity additions required in the NZE Scenario by 2030; announcements of planned new capacity would increase this to almost 1 400 GW, or more than 50% above the NZE Scenario level, assuming that these plans proceed. Existing overcapacity has contributed to a 90% reduction in solar PV costs since 2010, but it has also put at risk the competitiveness of the industry, with the STEPS projecting a utilisation rate for solar module manufacturing of just 50% by 2030.

If manufacturing overcapacity persists, there is potential for a larger response to the low solar PV costs projected in the STEPS, with even faster solar PV growth, especially in emerging market and developing economies, despite challenging financing conditions. In this sensitivity case, we assess to what extent such an acceleration might displace fossil fuel power plants, and what the impact of would be.[3] We project that solar PV capacity additions might increase by 60 GW in 2030 compared to the STEPS, which would mean an average 55% utilisation rate for manufacturing capacity. This would reduce natural gas-fired power generation by 180 TWh in 2030 and about 330 TWh in 2035, saving close to 40 bcm and almost 70 bcm of natural gas respectively, alongside reductions for coal-fired power. In the modelling, two-thirds of the reductions in natural gas use by 2035 are in China and Southeast Asia, where solar PV manufacturing capacity is concentrated, and the other third in countries in Africa. Faster solar PV deployment would also cut coal-fired power in many regions. The combined effect of these changes would bring an additional 280 million tonnes of carbon dioxide (Mt CO_2) emissions reductions in 2035 compared with the STEPS.

Uncertainties concerning the pace of electricity demand growth could vary the level of natural gas demand in the power sector. Global electricity demand could be reduced by as much as 2%, in turn reducing the global demand for natural gas by around 50 bcm in 2030

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[3] We carried out a similar analysis in the high solar PV case in the *World Energy Outlook* 2023.

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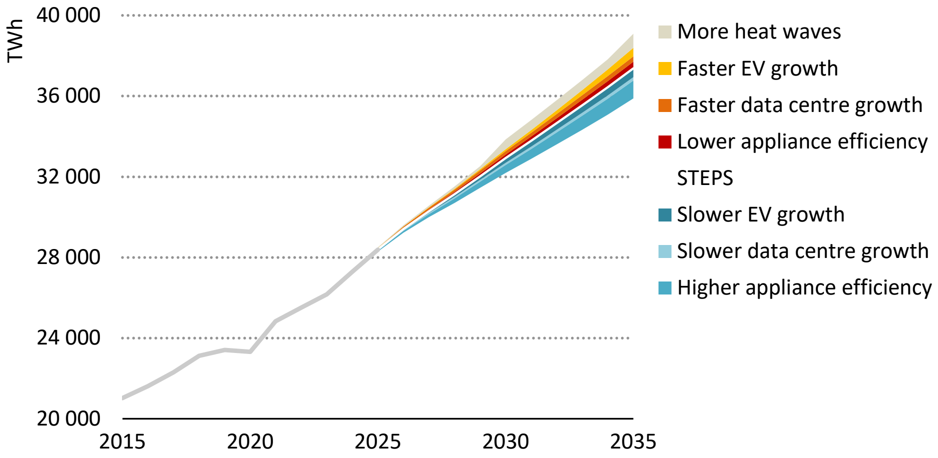
(section 4.6.4). About two-thirds of this demand reduction would likely take place in emerging market and developing economies, where the uncertainties for electricity demand growth are largest, and would principally affect India and Southeast Asia, with more modest impacts in the Middle East, Africa and China. While advanced economies are more reliant on gas-fired power, the uncertainties they face about electricity demand growth are more circumscribed. The sensitivity case nevertheless sees a decline in demand for natural gas of around 30 bcm compared with the STEPS as a result of uncertainties about the speed of growth in electricity demand for EVs, appliances and data centres. This principally affects the United States, which sees demand fall by almost 17 bcm compared with the STEPS, with most of the rest of the reduction in the European Union.

4.6 Uncertainties in electricity demand

Electricity demand in the STEPS increases at an annual average rate of 3% from 2023 to 2035. Many of the key drivers relate to emerging market and developing economies, where rising populations and incomes result in higher levels of demand as more buildings are constructed and as more people buy and use appliances and air conditioners. Demand for cooling has already led to a rapid rise in the sale and use of air conditioners, which is expected to continue. Heat waves are likely to become more frequent and intense with climate change, increasing both the demand for and costs of cooling (see Box 5.4 in Chapter 5). Data centres are another cause of rising electricity demand, linked in part to expanding use of AI.

Figure 4.10 ▻ Global electricity demand in the STEPS and key sensitivities, 2015-2035



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Electricity demand increases strongly in the STEPS, but several plausible uncertainties could push demand growth close to 15% above that of the STEPS level

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With these drivers in mind, we evaluated key uncertainties related to data centre demand, appliance efficiency and heat waves, together with EV growth (section 4.4.1). Our sensitivity case finds that, in aggregate, the average annual growth rate from 2023 to 2035 moves up to 3.4% in the high case and down to 2.7% in the low case. While shifts of this size would be important, they would not deflect the continuing and inexorable rise of electricity demand. Meeting higher electricity demand has near-term implications in our sensitivity case for both gas-fired and coal-fired power, particularly the latter, which in the modelling would see demand rise by 4% at the global level in 2030 (Figure 4.10).

4.6.1 Data centres

In early 2024, over 11 000 data centres were registered worldwide. The number of servers installed increased around 4% per year between 2010 and 2020, but data centre electricity demand broadly plateaued as increasing information technology (IT) demands were mitigated by efficiency improvements in cooling and by workloads moving to larger and more efficient cloud data centres. In recent years, however, electricity consumption has picked up as efficiency improvements have been outpaced by surging demand for data centre services.

Data centre electricity consumption was estimated in 2022 to be in the range of 240 to 340 TWh, around 1% to 1.3% of total electricity consumption (excluding data networks and crypto mining). Although AI currently accounts for a relatively small share of global data centre electricity consumption, it is emerging as a new driver of growth. Investment in AI and new data centres is booming. The global venture capital sector has invested over USD 225 billion in AI startups over the past five years, compared to USD 143 billion over the same period in startups operating across all aspects of the clean energy sector. Driven in part by data centres and AI, capital spending by US technology giants Alphabet (Google), Meta (Facebook), Amazon and Microsoft reached around USD 150 billion in 2023, up by more than a factor of two on the 2019 level and equivalent to around 0.5% of US gross domestic product. Interest is not confined to advanced economies, with China, India and other emerging market and developing economies also seeing robust growth in data centres.

A substantial increase in electricity consumption from data centres appears inevitable (IEA, 2024). However, several factors make projections challenging. First, the supply chain is highly concentrated around a few bottlenecks, particularly for the chips that handle AI and other compute-intensive workloads. Taiwan Semiconductor, which holds more than a 90% share of the market for AI related chips, has announced investments to meet expected demand for their most advanced chips, and plans to open new factories in 2026, but it is currently limited to existing infrastructure. Average lead times for new chip fabrication plants are 3-5 years. Second, efficiency gains are hard to model. They have recently been substantial: NVIDIA's Blackwell Platform cut energy consumption by around 75% compared to the previous generation of graphics processing unit (GPU) chips. In addition, there is potential for algorithmic optimisation to reduce future computational load. However, more efficient chips may also increase demand due to the rebound effect, and energy efficiency improvements appear unlikely to fully offset the growing service demands due in part to AI. Third, any or all

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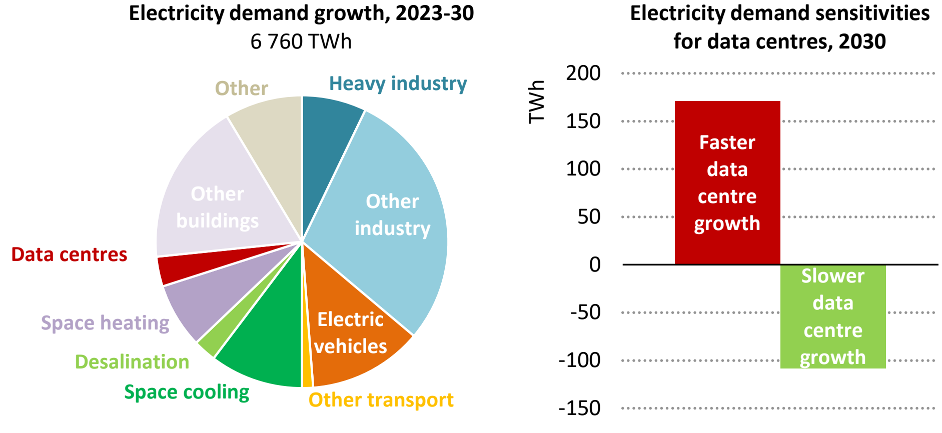
of the electricity network, generation capacity and permitting processes may constrain the rate of data centre expansion.

There are also policy-related uncertainties. On one hand, governments have enacted industrial and localisation policies to support development of domestic value chains for chips and data centres. On the other hand, trade restrictions on key physical components, e.g. certain chips and chip tools, at the global level, or data centre construction limits at the local level, could slow developments.

Furthermore, data availability presents substantial challenges for analysts to assess the outlook for data centre electricity demand, in contrast to other more traditional parts of the energy system, where data collection processes are more standardised.

The evolution of demand for data centres and AI services is thus highly uncertain. Major investment in AI startups and computing resources are being made, but the nature, speed and scale of end-use adoption is still unclear. For these reasons, projections should be made with caution, using a scenario-based approach and putting results in the context of the broader energy sector.

Figure 4.11 ▹ Electricity demand growth by end-use in the STEPS, 2023-2030, and data centre sensitivity cases



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Data centres account for a small share of global electricity demand growth to 2030, and plausible high and low sensitivities do not change the outlook fundamentally

Note: Other includes electricity demand from agriculture. Electricity demand does not include any own use for generation, nor transmission or distribution losses.

Total electricity demand across all sectors is set to increase by around 6 760 TWh by 2030 in the STEPS, equivalent to more than the electricity demand of the European Union and the United States combined in 2023. The main drivers of this increase are the electrification of transport, industrial processes and space heating, and rising demand for appliances and

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cooling equipment. In the STEPS, about 80% of additional electricity demand for 2023-2030 is in emerging market and developing economies. Data centre demand grows strongly but provides a relatively small contribution to overall electricity demand growth (Figure 4.11).

Driven by the rising demand for both AI and more conventional data centre services, global server capacity is expected to more than double by 2030. After a decade of substantial technical efficiency improvements and on the back of an increase in more energy-intensive data centre workloads, notably for AI, the rate of technical efficiency gains is expected to flatten (Masanet, 2020) (Uptime Institute, 2023). Consequently, global data centre electricity demand is anticipated to increase significantly by the end of this decade, with the scale dependent on technological advances in IT equipment and hardware deployment. In the base case, data centres account for less than 10% of total electricity demand growth at the global level, which is roughly on a par with demand growth for desalination, and less than a third of the demand growth for both EVs and space cooling in the buildings sector.

Therefore, growth of electricity demand for data centres is projected to be rapid, but the level looks set to remain relatively small in the context of overall global demand growth. Nevertheless, data centre operators are now among the most active clean electricity purchasers as clean electricity supply becomes central to their sustainability strategies (BNEF, 2024). The top ten corporate buyers of clean energy power purchase agreements (PPAs) in 2023 included Amazon, Meta, Alphabet and Microsoft. Between 2023 and 2030, total data centre demand growth is projected to be just below 50% of the annual global increase in low-emissions sources of electricity over the last five years, so meeting this demand growth sustainably is feasible. However, data centres are very spatially concentrated, and constraints on generation and grid capacity may be more severe at the local level (Figure 4.12).

The clustering of data centres is driven by the benefits of proximity to infrastructure such as fibre optic cables and power resources; to customers, particularly those with a need for near-real time access to data, like financial services companies; and to existing business ecosystems and talent pools. Location decisions are also driven by incentives and regulation, and by climatic considerations: cooler places have lower cooling needs. Spatial concentration is already creating tensions, with several jurisdictions issuing moratoria on further data centre development or taking steps to restrict it.

Overall, significant electricity demand increase from data centres is inevitable, but the extent of growth is uncertain. In any likely scenario, however, data centres look set to remain a relatively small driver of overall electricity demand growth at the global level in the decade to come. Nonetheless, constraints at the local level may be significant. To ensure that the outlook for data centre demand growth is better understood and that actual growth is met sustainably, policy makers, the energy industry and the technology sector need to work more closely together to enhance data sharing, strengthen regulatory dialogue, improve efficiencies, scale up low-emissions electricity supply and mitigate local bottlenecks.

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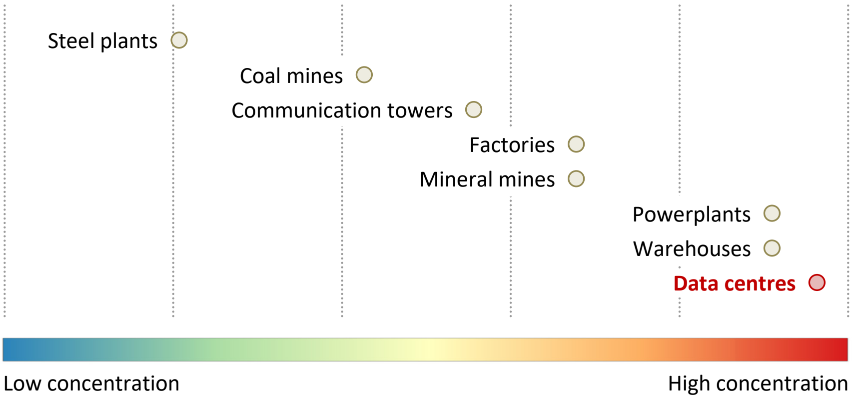
Figure 4.12 ▷ Spatial concentration of selected types of facilities, United States



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Data centres have an exceptionally high spatial concentration, which has significant implications for local power grids, given their substantial power requirements

Notes: The concentration is calculated as the inverse of the linearised Nearest Neighbour Index, which is a mathematical representation of how clustered or dispersed each category is, calculated via the ratio of the observed mean distance to the expected mean distance. Power plants include both conventional facilities as well as renewable energy systems.

4.6.2 Heat waves

Global temperatures are rising as the climate changes, and 2023 was the warmest year on record. In addition to climatological shifts and their impact on the average global surface temperature, there has been an increased prevalence of extreme temperatures in the form of more intense, frequent and persistent heat waves, some of which have led to notable temperature records. Recent examples include highs of almost 50 degrees Celsius (°C) over three days in western Canada (2021), highs exceeding 40 °C in the United Kingdom (2022), and extended heat waves over much of India during May/June 2024 and parts of China in August 2024.

One consequence of more intense, frequent and longer heat waves is expected to be an increase in ownership of air conditioners. Consumers buy units to stay cool in high temperatures and to be prepared for expected future heatwaves. For example, heat waves in India during 2024 are understood to have prompted a doubling of air conditioner sales. As conditions get hotter, air conditioners are used more often, and they also have to work harder to keep buildings and people cool. Space cooling is already one of the fastest growing sources of electricity demand and it plays a significant role in increasing the level of peak demand for electricity (see Chapter 5). The combination of increased use and ownership is cumulative and accelerates electricity demand growth. The energy demand curve also shifts with higher peak consumption levels that could jeopardise system security.

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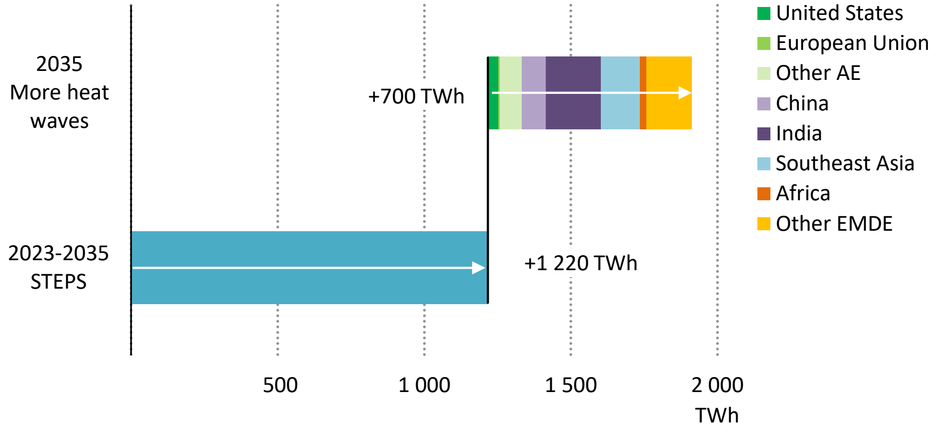
For the sensitivity case, we considered a world where more frequent, more intense and longer heat waves mean that levels of cooling demand in aggregate are higher than in the STEPS. It concentrates on what cooling from high temperatures would mean for electricity demand. We assessed heat waves by considering the historic distribution of cooling degree days and assuming more periods in the higher, hotter end of the spread. In addition, we factored in an accelerated pace of air conditioner ownership acquisition. The results indicate that electricity demand would be around 500 TWh higher in 2030 in this sensitivity case, compared to the STEPS, and almost 700 TWh higher in 2035, which is around 20% of total cooling demand in the buildings sector in that year in the STEPS (Figure 4.13).

Figure 4.13 ▹ Cooling demand in the buildings sector due to variations in heat waves relative to growth in the STEPS, 2023-2035



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More frequent heat waves could increase cooling demand growth by 55% more than in the STEPS by 2035, mostly in emerging market and developing economies

Note: AE = advanced economies; EMDE = emerging market and developing economies.

More than 80% of the electricity demand increase compared to the STEPS occurs in emerging market and developing economies, notably India, China and Southeast Asia, due to their climate and their relatively low air conditioner ownership rates, and cooling demand increases by an average of 25% compared to the STEPS. In advanced economies, cooling demand increases by just over 10% since air conditioner ownership is already near saturation levels in regions in which it is needed. We find that average air conditioner ownership rates would be 16% higher in 2035, a level not seen until after 2040 in the STEPS, which drives 70% of the demand increase. In most regions, this demand increase has to be met by additional dispatchable generation because cooling demand is concentrated in a few months of the year. Since this type of generation is heavily reliant on fossil fuels, gas and coal consumption would each increase by 2% by 2030, resulting in 270 Mt of additional CO_2 emissions.

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4.6.3 Appliance efficiency in emerging market and developing economies

Acquisition and use of an expanding array of electrical appliances and cooling equipment is a key driver of rising electricity consumption in fast-growing emerging market and developing economies in the STEPS (see Chapter 3). Energy consumption in the buildings sector from space cooling and appliances is set to increase in the STEPS by 35% to 2030 and 60% by 2035. This is primarily driven by growth in population and floorspace, increased ownership of appliances and improved living standards.

Energy efficiency improvements, supported by strong policy measures, can help to moderate this growth which is reflected in the STEPS. Rates of efficiency improvements, however, have varied widely in the past across emerging market and developing economies as a result of differing policies and standards together with uneven implementation, and the scope for efficiency improvements is at risk of being severely curtailed by the continued sale of obsolete and inefficient air conditioners and other appliances in some emerging market and developing economies. Without appropriate standards, regulation and effective enforcement, consumers could be locked into old, inefficient technologies for many years. The difficulty of assessing the scale of future energy efficiency improvements against this background creates potential uncertainties for the STEPS projections which we have analysed in the following cases.

Low appliance efficiency, high demand case

Markets with strong minimum energy performance standards (MEPS) only cover a limited share of global demand for cooling appliances. This provides incentives for appliance manufacturers to maintain distinct product ranges for those countries with MEPS and those without, or to specialise in less efficient products with cheaper upfront costs. Our high demand case assumes that, for the end-uses considered, weak or delayed efficiency policies reduce the rate of efficiency improvement by one-third. The effect of this is to increase electricity demand in the buildings sector in emerging market and developing economies by 170 TWh by 2030 and 340 TWh by 2035, compared to the STEPS, which is equivalent to 3% to 5% of cooling and appliances demand. The impact is amplified over time by economic growth and increased appliance ownership. There are wide regional disparities, with India seeing the largest impact from poor air conditioner efficiency at about 30% of the total increase in electricity demand (Figure 4.14).

High appliance efficiency, low demand case

In the low demand case, the number of markets with strong MEPS expands to reach critical mass, so that international companies choose to comply with standards across all their global operations in order to avoid the costs of maintaining separate product ranges for markets with MEPS and those without, and manufacturers specialising in inefficient goods are gradually squeezed out. As a result, more efficient appliances are rolled out worldwide. Our low demand case assumes that widespread MEPS and efficiency labelling lead to efficiency levels equivalent to those in the APS. This results in electricity demand 400 TWh lower in 2030 than in the STEPS, and almost 900 TWh lower by 2035, equating to 13% of cooling and

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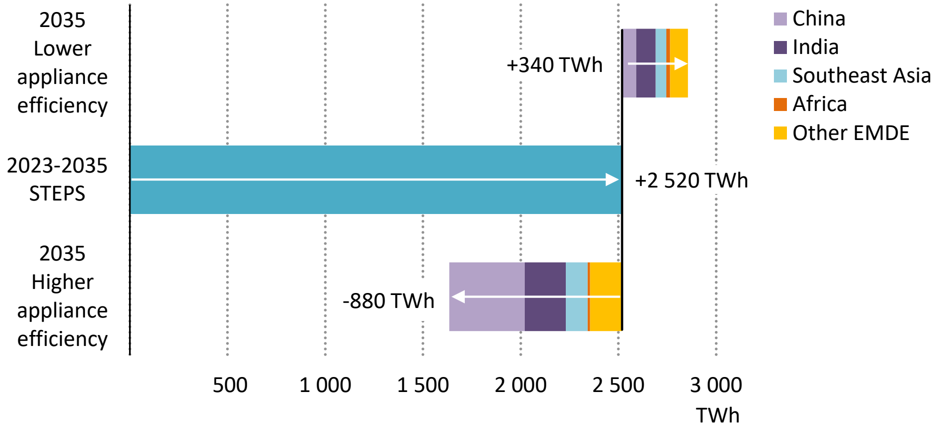
appliances demand in the buildings sector. Highly efficient standards benefit China the most, due to its economic development and high growth in ownership rates, and it accounts for almost 45% of the demand reduction.

Figure 4.14 ▷ Sensitivity cases on appliance efficiencies in EMDE electricity demand relative to the growth in the STEPS, 2023-2035



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More energy-efficient appliances in emerging market and developing economies could shave one-third off the increase in electricity consumption in the STEPS to 2035

Note: EMDE = emerging market and developing economies.

4.6.4 Implications of changes in electricity demand

Meeting higher or lower electricity demand growth than projected in the STEPS has implications for the supply of electricity that vary by region related to the available fleet of power plants. The operations of existing power plants could be varied in many cases to meet higher or lower electricity demand, though new construction could be needed to meet higher electricity demand that persists, while lower demand could lead to earlier retirements of some power plants.

Meeting higher electricity demand

In the short term, faster electricity demand growth would be met largely by operating existing power plants more often, in particular coal- and natural gas-fired power plants. In advanced economies, this would generally mean higher levels of natural gas-fired power. In some cases, higher demand may also require new power capacity to ensure that peak demand can be met. In the STEPS, the average capacity factor of natural gas-fired power plants in advanced economies declines from 36% in 2023 to 31% in 2030 and 26% in 2035. If they had to meet the higher demand seen in the sensitivity case, the average capacity factor for gas-fired power plants would still decline over time, but it would do so at a slower rate.

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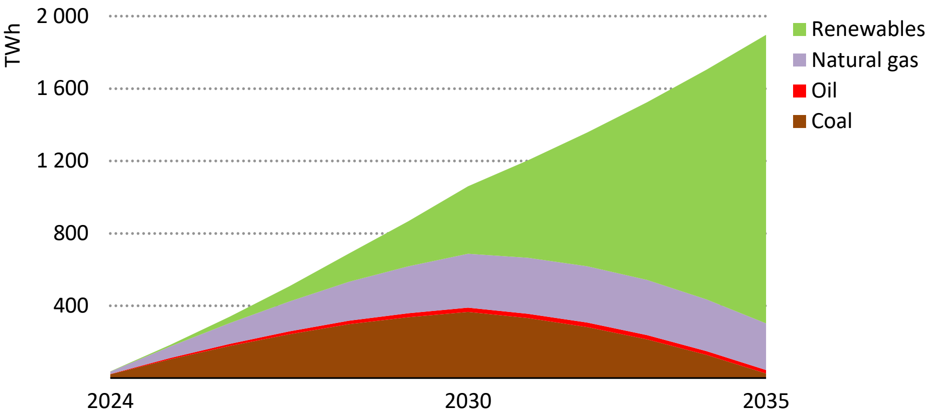
In emerging market and developing economies, the large fleet of coal-fired power plants is capable of significantly increasing output to meet higher levels of demand. However, even with the additional electricity demand growth explored here, the average capacity factor of coal-fired power in emerging market and developing economies still declines from 2023 to 2030, even though coal-fired power generation is 4% higher in 2030 than in the STEPS.

In the longer term, new renewables capacity could be built by the late 2020s and early 2030s to meet nearly 85% of higher electricity demand. As solar PV and wind are already the cheapest new sources of electricity in most regions today, it is likely that they would be deployed to meet persistently higher levels of electricity demand, thus mitigating the additional total output from coal- and natural gas-fired power plants (Figure 4.15).

Figure 4.15 ▷ Increase in global electricity supply to meet the high cases by energy source, 2024-2035



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Additional output from coal and natural gas power plants meets demand in the near term, while renewables scale up to meet most additional demand by 2035

Meeting lower electricity demand

Lower growth in electricity demand would drive faster reductions of fossil fuels to 2030 and beyond. Natural gas-fired power in 2030 is 4% lower in this sensitivity case than in the STEPS, and coal-fired power is 4.5% lower, while oil use in the power sector is largely unchanged. Collectively, the changes in fossil fuel-fired power would reduce CO_2 emissions by 520 Mt in 2030.

Renewables, nuclear power and other low-emissions sources are largely unchanged by lower electricity demand growth. Many countries have targets to increase installed capacity or the low-emissions share of generation based on specific electricity demand expectations. Where electricity demand growth turns out to be lower, we project that most of those countries are likely to choose to overshoot their share targets rather than to seek to slow deployment of renewables.

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Security, affordability and sustainability

Finding the right balance

SUMMARY

- Policy makers need to balance goals related to energy security, affordability and sustainability. Some policy choices can simultaneously boost all three, but many require trade-offs. A critical challenge is to minimise the trade-offs and to help avoid a narrow focus on one that unwittingly compromises the others.
- Fuel security remains a vital element of energy security. Disruption in a major producing region or at today's trade chokepoints, including the Straits of Hormuz and Malacca, could lead to severe price volatility. Maintaining reliable fuel infrastructure and the systems they depend on is essential to support security in energy transitions and facilitate the scaling up of low-emissions fuels.
- Electricity security is high on the agenda as increasing demand and more variable generation sources highlight the importance of secure, resilient and flexible power systems. Batteries are rapidly scaling up to provide short-term flexibility; demand response can provide short-term and some seasonal flexibility while also helping to keep costs down; thermal power and hydropower are the main sources of seasonal flexibility today and are set to remain so through to 2050.
- The security of clean energy supply chains and of critical minerals supply is of pivotal importance to clean energy transitions. Clean energy manufacturing capacities are well above deployment levels today, but facilities are highly concentrated geographically. Critical minerals supply is also highly concentrated, and there is risk of future gaps between prospective supply and demand for copper and lithium.
- Issues of affordability and fairness are at the centre of the energy debate today. Clean energy transitions can help reduce household bills, but this depends on a sharp increase in investment and on support for those that cannot afford the higher upfront costs of some clean energy technologies. Today, almost 750 million people lack access to electricity and 2 billion people lack access to clean cooking: significantly accelerated action is needed to achieve universal energy access by 2030.
- Climate change and poor air quality entail severe risks to lives and livelihoods. In the STEPS, the temperature rise reaches 2.4 °C by 2100 while in the NZE Scenario it peaks at less than 1.6 °C and then falls to less than 1.5 °C in 2100. Action to reduce CO_2 emissions to net zero as soon as possible and rapidly cut methane emissions is essential to reduce climate change risks. Together with action on other pollutants, this also brings dramatic improvements in air quality.
- Boosting clean energy investment is vital for just, orderly and equitable transitions. Clean energy investment rises from around USD 2 trillion today to nearly USD 3 trillion in the STEPS in 2035 and to USD 5 trillion in the NZE Scenario.

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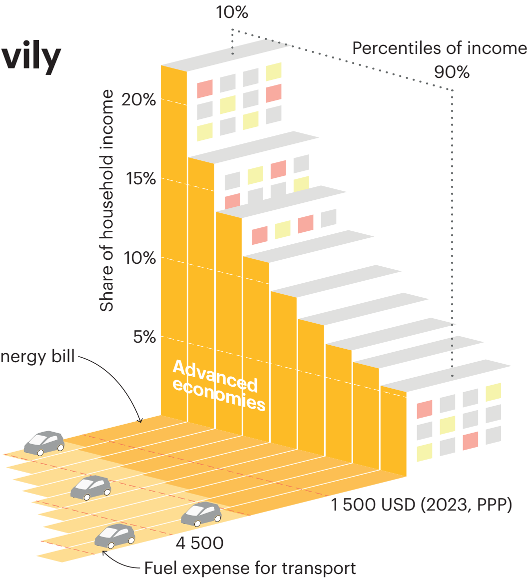
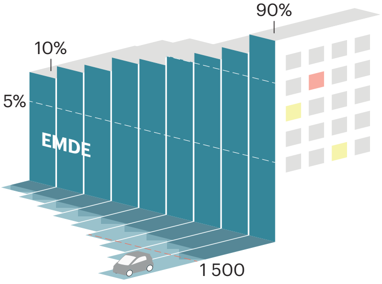
Household energy expenditure weighs heavily on the poor

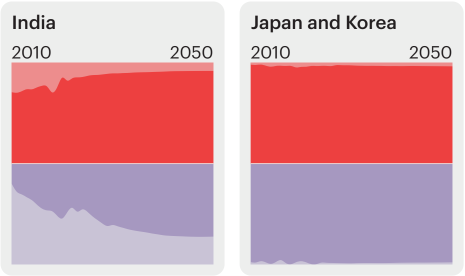
The poorest households in advanced economies spend nearly one quarter of their disposable income on energy; in emerging market and developing economies (EMDE), many poor households lack access to modern energy or do not own appliances or vehicles.

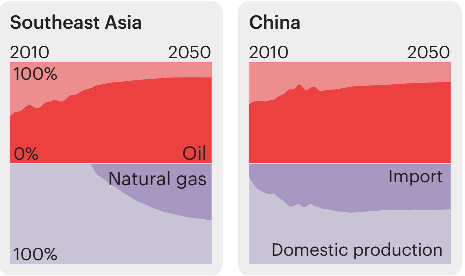




Oil and gas import dependency

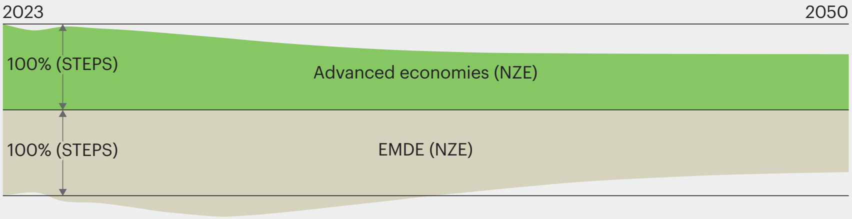
Oil and gas import dependency rises in Asia in the STEPS, with particularly steep increases in Southeast Asia.





Household expenditure on energy bills and clean energy

Household expenditure is lower in the NZE Scenario than in the STEPS in advanced economies; it is higher in the near term in emerging market and developing economies, but soon falls.



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5.1 Introduction

Each of our scenarios has different implications for security, affordability and sustainability. These are the elements examined in detail in this chapter. The three objectives are rarely in perfect alignment, and policy makers often face choices and trade-offs between them. But neither are they necessarily in opposition to one another and there are many policy choices that can simultaneously attain all three. What can be said with some confidence is that the way policies are designed is key to striking a balance between these objectives.

Energy security is the focus of the first part of this chapter. Energy security means having uninterrupted energy available at an affordable price. That in turn means ensuring reliable sources of supply and designing and maintaining infrastructure and systems that are resilient against physical and cyber threats. Alongside traditional risks to fuel security, issues could arise during energy transitions, not least in the power sector, given increasing electricity demand and a shift to more variable generation, and in clean energy supply chains, given concerns about market concentration and an excessive reliance on a small number of suppliers. Each scenario has some distinctive risks. The trajectories that we map may in some ways understate the difficulties that lie ahead. Our scenarios depict smooth, orderly processes, in which markets, investment, technologies and policies evolve in a consistent way. This is not how the energy system operates in practice. The future is likely to be characterised by competing interests, market imbalances, stop-and-go policies and bouts of volatility and turbulence, just as the past has been.

People-centred aspects of energy transitions are the focus in the second section. Public acceptance is a critical factor for the pace and consistency of energy transitions. In this context, the impact of transitions on energy affordability, on jobs and livelihoods, and on the ability to access energy services is particularly important. This section provides an overview of how energy transitions are affecting people, and how they are affected by people's choices. It covers energy access and affordability, energy employment and changing consumer behaviours, highlighting how these people-centred aspects look today, and how they could evolve in the years ahead.

Efforts to tackle climate change is the focus of the third section. It details emissions of carbon dioxide (CO_2) and methane associated with each scenario and looks at the extent to which they could exacerbate climate change. In addition to the implications of each scenario for the rise in global average temperatures, it considers the substantial variations in outcomes for air quality and the consequent effects on public health.

The indispensable role of investment in safeguarding all the elements discussed in earlier sections wraps up this chapter. It examines recent trends in capital flows to the energy sector, looks at sources of investment and financing, and assesses their adequacy in relation to the requirements of the scenarios.

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5.2 Energy security

Energy security is a "foundational and central mission" for the International Energy Agency (IEA), in the words of the communiqué adopted by ministers at the IEA 50th anniversary meeting in 2024. The concept of energy security has evolved over the years since the IEA was created in response to the first oil shock in the 1970s. Assessing energy security now requires a comprehensive approach that encompasses not only traditional risks but also risks that could emerge because of the impacts of climate change and the momentum behind clean energy transitions.

The IEA response to recent turbulence in energy markets provides an illustration of the multiple issues in play. In 2022, following Russia's full-scale invasion of Ukraine, the IEA undertook the two largest-ever co-ordinated emergency oil stock releases in its history to help prevent shortfalls in global supplies. At the same time, within days of the Russian invasion, the IEA released a ten-point plan showing how the European Union could rapidly reduce its reliance on natural gas supplies from Russia, including by accelerating deployment of clean energy technologies.

Although the crisis had a very specific cause, it highlighted the general risk of excessive reliance on a single source of energy from a single producer, and the benefits that diversity can bring for energy security. With this principle in mind, the IEA has also been paying close attention to the resilience and diversity of clean energy supply chains, including security risks affecting the supply of critical minerals that are essential for many clean energy technologies.

Traditional risks to oil and gas security show few signs of abating and continue to be a central preoccupation for the IEA, even as these risks evolve during energy transitions. As the world moves towards a more renewables-rich energy system, some aspects of energy security will improve, but new hazards are also emerging. For example, a more digitalised and electrified world means that cybersecurity and electricity security have become critical concerns for policy makers around the world.

Lasting energy security is not just about increasing the supply of power and fuels, and ensuring that adequate and resilient infrastructure and systems are in place. It is also about using energy more efficiently. Better materials and insulation, newer technologies and more efficient appliances significantly reduce the energy needed to heat, cool and light our homes and workplaces.

In addition, it is about minimising CO_2 and methane emissions. It is sometimes claimed that policy makers need to choose between energy security and climate action. There are indeed some potential trade-offs, which we discuss in this section. But failure to act on emissions increases the risks to energy security, not least because the physical consequences of a changing climate pose a threat to the reliability of the global energy infrastructure and trade flows. A comprehensive approach to energy security needs to include major reductions in the energy-related emissions that are creating risks to energy supplies, as well as efforts to make energy systems more climate resilient.

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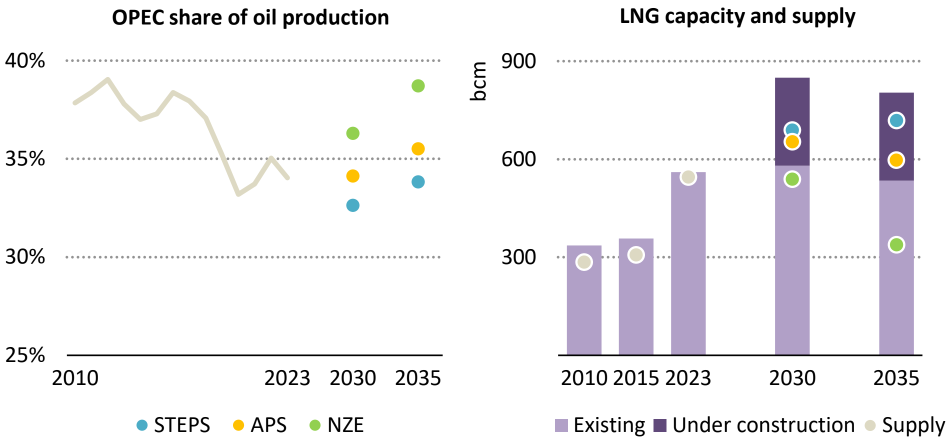
5.2.1 Fuel security

Adequacy of oil and gas supply and investment

The position of oil and natural gas markets today is very different from just a few years ago. Before the Covid-19 pandemic, global spare crude oil production capacity, excluding Iran and Russia, averaged less than 3 million barrels per day (mb/d); today it stands at close to 6 mb/d. During the global energy crisis, after gas exports to Europe from Russia were cut, natural gas markets were so tight that a 2022 explosion and fire at a liquefied natural gas (LNG) terminal in Texas with 20 billion cubic metres (bcm) capacity, close to 20% of US LNG capacity, caused wholesale natural gas prices to jump in much of Europe by more than 10% and in the United Kingdom by more than 20%. Although the European natural gas market remains fragile, markets are now less tight, around 270 bcm of new LNG capacity is set to become available in the next few years, increasing global available liquefaction capacity by close to 50% by 2030 (Figure 5.1).

Figure 5.1 ⊳ OPEC market share and LNG utilisation by scenario



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New non-OPEC oil production and the upcoming wave of new LNG supplies should help buffer against the risk of price shocks, but there is no room for complacency

Notes: bcm = billion cubic metres; STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario; NZE = Net Zero Emissions by 2050 Scenario. LNG capacities are available capacity, which are 90% of nameplate capacity.

Previous editions of the *World Energy Outlook (WEO)* warned of a risk of underinvestment in oil and natural gas in a Stated Policies Scenario-like trajectory for demand, noting a gap between the amounts being invested in oil and gas and the future requirements of this scenario. This risk appears to have receded. Oil and gas investment has risen by around 30% since 2021, while estimates of future investment have come down as projected oil and gas

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demand levels have moderated. However, there is no room for complacency: unexpected outages or other events could drastically change the supply-demand balance.

In the Stated Policies Scenario (STEPS) in this *WEO,* oil and natural gas demand both peak before 2030 and decline slowly thereafter. Investment in both new and existing fields is needed in the STEPS to avoid volatile markets and prices, but the level of investment in oil and gas supply in 2024 (USD 860 billion) is around 20% more than what is invested in 2035 in this scenario. Increases in oil production in a number of non-OPEC producers, including the United States, Brazil, Argentina and Guyana, push the Organization of the Petroleum Exporting Countries (OPEC) share of the market down to around 33% in 2030, a level not seen since the late 1980s. After 2030, the OPEC share of the oil market starts to rise again.

In the Announced Pledges Scenario (APS) and Net Zero Emissions by 2050 (NZE) Scenario, oil and natural gas demand peak earlier and then fall at a much faster rate. Investment in oil and gas in the APS in 2035 amounts to some USD 490 billion, which is around 40% lower than today, and in the NZE Scenario it is USD 250 billion, which is 70% lower. In these scenarios, many new projects face major commercial risks, and some may fail to recover their upfront costs. If all LNG projects under construction are developed, the global average utilisation rates of LNG plants would fall from around 95% of capacity today to 75% by 2035 in the APS and to less than 45% in the NZE Scenario, much lower than the 90% utilisation rate in the STEPS.

Balancing investment in fossil fuels and clean energy

There is sometimes a debate about whether the emphasis should be placed on demand-side or supply-side actions in pushing forwards towards net zero emissions. In practice, rapid and sustained progress towards net zero emissions depends on tackling both supply and demand in an integrated way. In the APS and the NZE Scenario, reductions in fossil fuel investment are synchronised with reductions in demand, notably through efficiency gains, and with rapid scaling up of investment in clean energy. This approach offers the prospect of rapid progress while minimising price volatility and security risks. For example, the nearly 75% reduction in investment in fossil fuel production in the NZE Scenario between 2023 and 2035 is only consistent with maintaining reliable energy supplies on the assumption of a 2.5-fold increase in clean energy investment over the same period (Figure 5.2). This scenario requires policies that focus both on scaling up the supply and demand of clean energy and on scaling back the supply and demand of fossil fuels.

Policies and measures focussing on reducing fossil fuel demand and supply play a particularly important role in ensuring that the energy transition is achieved in a just, orderly and equitable way. Examples include policies that focus on the early retirement or conversion of fossil fuel assets, such as coal-fired power plants or long-lived industrial facilities, or that focus on providing clear signals to markets about the desired direction of travel, such as bans on the sale of fossil fuel equipment. Inclusive dialogue between industry, labour, communities and governments – including between producer and consumer countries – are also essential to help inform coherent energy investment planning and to maximise

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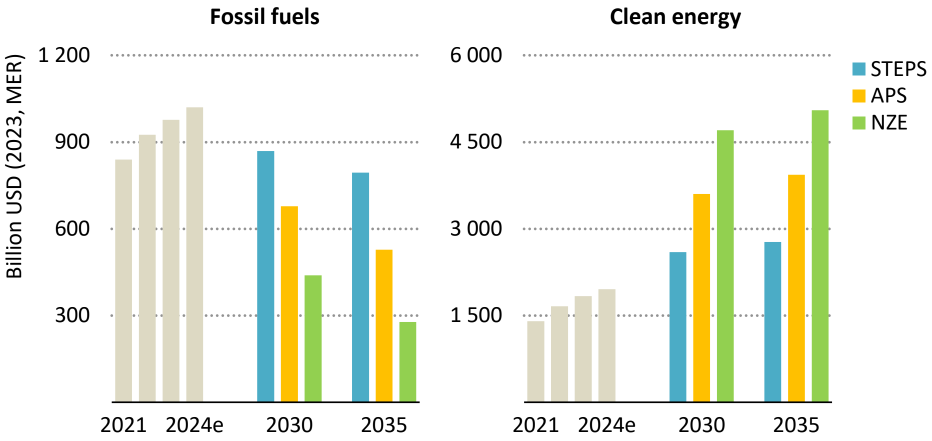
opportunities for socio-economic development from the transition. Supply-focussed fossil fuel policies include those that reduce the emissions intensity of oil and gas supply or put in place arrangements for the safe and responsible decommissioning of fossil fuel infrastructure when it is no longer needed. These policies also have a part to play in avoiding the unplanned, chaotic or premature retirement of existing fossil fuel infrastructure where this could have negative consequences for the reliability of the overall system.

Figure 5.2 ▹ Annual investment in fossil fuels and clean energy by scenario, 2021-2035



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Cutting investment in fossil fuels ahead of scaling up investment in clean energy would push up prices and undermine just, orderly and equitable clean energy transitions

Note: MER = market exchange rate; 2024e = estimated value for 2024.

Resilient and reliable fuel supply chains and infrastructure

Ample spare crude oil capacity and the upcoming wave of new LNG supplies provide buffers against the risk of sharp price shocks, but the security of fuel supplies is far from guaranteed, not least because the effectiveness of this capacity to address any shortfalls that may arise hinges on the ability of alternative sources of supply to reach an affected country or region quickly. Without both resilient and reliable sources of energy and infrastructure to transport supply to customers, local or regional disruptions remain a distinct possibility in the face of risks from geopolitical tensions, technical failures and extreme weather events. These impacts are likely to be felt more acutely in import-dependent countries. For example, for importers in Asia – including Japan, Korea, and developing Asia – oil and gas import dependency increases in aggregate in all scenarios, while the share of oil and gas in total energy demand falls. In the STEPS, oil import dependency for these countries rises from 80% today to close to 90% in 2050, and gas import dependency increases from 40% today to 60%

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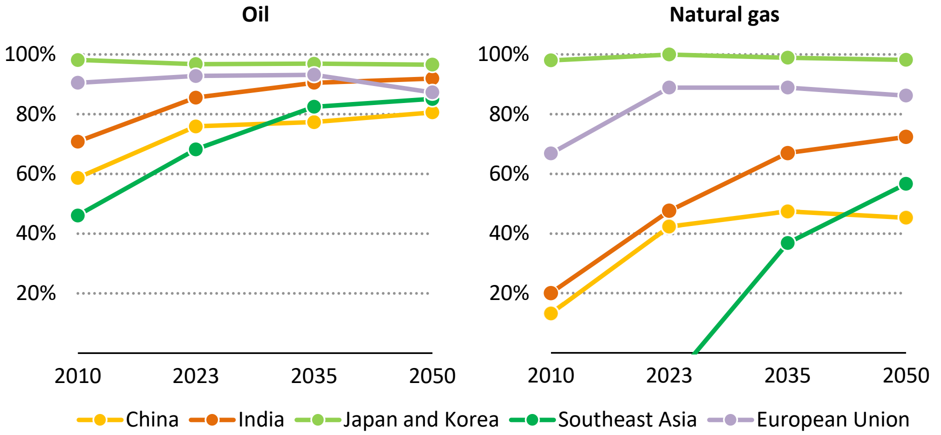
by 2050 (Figure 5.3). Petrochemical demand in Asia as a whole is one of the key drivers of oil demand and imports (see Chapters 3 and 6).

The Middle East is the world's largest oil exporter today and this remains the case in all scenarios. It is also responsible for around one-third of the increase in LNG supplies in the STEPS to 2035. The Middle East-Asia route is therefore set to remain an essential artery for seaborne trade in oil and gas. As a result, consumers in Asia are exposed to the risk that geopolitical events in the Middle East or accidents near major trade chokepoints could lead to physical shortages of supply, as well as price volatility.

Figure 5.3 ▷ Oil and natural gas import dependency in selected countries/regions in the STEPS, 2010-2050



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Oil and gas import dependency in Asia continues to rise, with particularly steep increases in Southeast Asia

Key maritime trade routes remain vital to the well-being of global oil and gas markets, but they depend on safe passage through places such as the Strait of Hormuz and the Strait of Malacca. Today some 80% of crude oil imported into East Asian countries passes through the Strait of Malacca, and more than half of it flows through the Strait of Hormuz. The Strait of Malacca is mounting in importance, and oil and gas volumes flowing through it are set to increase from 24 mb/d and 70 bcm today to 28 mb/d and 140 bcm in 2050 in the STEPS, cementing its position as the largest chokepoint for global oil and LNG trade (Figure 5.4). The complete closure of the Strait of Hormuz, while unlikely, would block off around 20 mb/d of crude oil and oil products, or around 20% of global oil supply, together with the vast majority of OPEC spare production capacity. Around 20% of global LNG trade also flows through the Strait of Hormuz, and any action that blocked this would similarly be highly damaging for natural gas markets.

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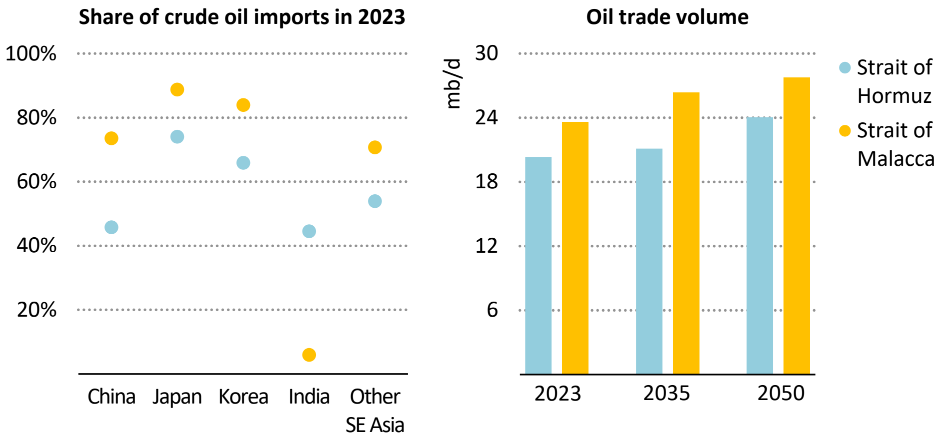
For producer economies, energy transitions create a powerful incentive to accelerate the pace of economic and energy sector reforms while at the same time reducing a major source of revenue that could finance these reforms. Just ten established producer economies in the Middle East, Africa and Latin America currently produce more than 30 mb/d of oil and nearly 800 bcm of natural gas annually, and their income from oil and gas sales in 2035 falls by 30% in the APS and by 70% in the NZE Scenario from the average annual level seen between 2010 and 2023. The consequences of reductions in oil and gas revenue of the kind seen in these scenarios would fall most heavily on producers, but they could affect consumers as well. If a major producer were to struggle to withstand the strains placed on its fiscal balances, there is a risk that this might at some point affect its political and economic stability, which could in turn disrupt supplies and lead to higher and more volatile prices globally. The downward spiral in Venezuela's oil and gas sector in recent years illustrates that this is more than a theoretical possibility.

Figure 5.4 ⊳ **Asian crude oil imports through chokepoints and oil trade volume via major chokepoints in the STEPS**



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Around 80% of crude oil trade to Asian countries flows through the Strait of Malacca, the largest chokepoint for global oil and gas trade

Note: md/d = million barrels per day; Other SE Asia = Southeast Asia excluding Indonesia.

The Middle East, a major fuel supplier to the global market, is particularly vulnerable to climate events, underscoring its need for more climate resilient energy infrastructure (Box 5.1). However, the increase in frequency and severity of climate hazards such as floods, cyclones, droughts and extreme heat waves pose serious risks to energy infrastructure and threaten reliable energy supplies in all parts of the world. For example, Hurricane Ida temporarily disrupted 95% of oil and gas production in the Gulf of Mexico in the United States in 2021 and shut down many oil refining and petrochemical facilities for weeks. In the same

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year, exceptionally cold weather in Texas shut down some natural gas and power supplies, causing blackouts and hardship for consumers. There are also increasing risks from violent storms that could impact LNG plants and refineries, which are often located in coastal areas, and from water shortages in dry regions, which can disrupt fuel supply operations.

Box 5.1 ⊳ Climate resilience in the Middle East

The Middle East is facing a higher temperature rise than the global average, along with more erratic precipitation patterns. Between 1980 and 2023, surface temperatures across the Middle East increased by around 0.5 degrees Celsius (°C) per decade (IEA and CMCC, 2024), well above the world average decadal increase over this period of around 0.2 °C (NOAA, 2024). Heat waves have become more frequent and intense, increasing energy demand for cooling, while at the same time cutting the efficiency of power plants and networks. For example, Kuwait saw widespread power cuts due to a heat wave in June 2024.

The effects are not uniform across all countries in the Middle East. Changing precipitation patterns have aggravated existing water scarcity in some countries and prompted floods elsewhere. Countries near the Mediterranean Sea are having to cope with increasing drought while Iran, Oman, Qatar, Saudi Arabia and the United Arab Emirates have been experiencing intense rainfall and flash flooding.

These impacts are set to intensify in the future. In the STEPS, the mean temperature in 2041-2060 in the region is around 2.8 °C higher than pre-industrial levels (and higher than the global average increase of 2.1 °C in this scenario at that time) (IPCC, 2021). A mean temperature at this level would lead to more than 90% of solar photovoltaic (PV), gas-fired power plants and electricity networks in the Middle East experiencing an additional 20 days where temperatures exceed 35 °C, which would lead to a reduction in power output and increase the chances of forced outages. In addition, around 80% of natural gas power plants and oil refineries and 60% of oil-fired power plants in the region would experience a more than 10% increase in one-day maximum precipitation levels, raising the risk of forced outages and technical problems from flash flooding (Figure 5.5).

In the light of the projected increase in climate impacts, countries in the region are already pursuing measures to improve the resilience of their energy systems. This includes technical and structural enhancements to energy infrastructure and the development of digital technologies to enable operators to manage stresses and reduce the risk of potential damage from extreme weather events. Crisis management and contingency planning for climate-related disruptions also have a part to play, and so do longer term strategies to diversify energy sources and invest in resources that can better withstand extreme weather events.

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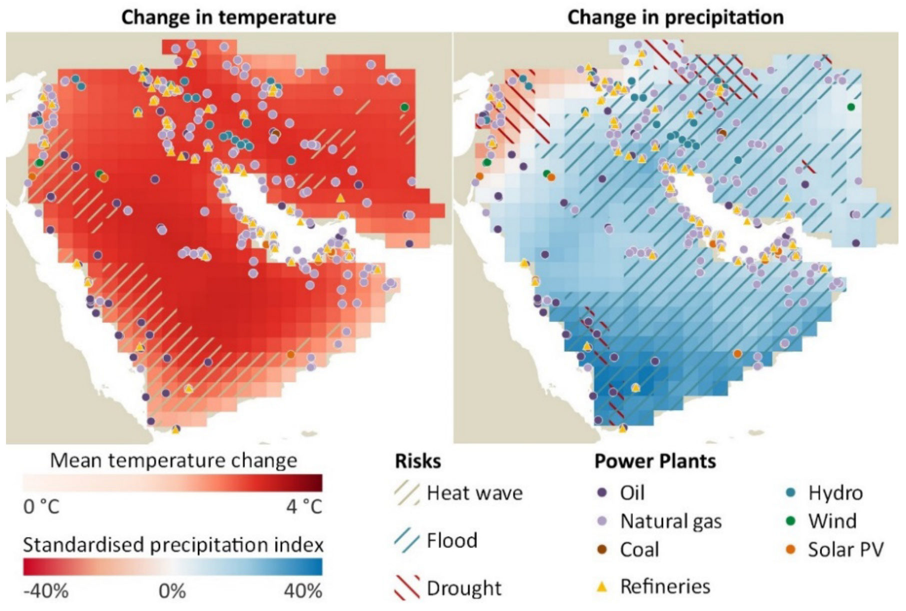
Figure 5.5 ⊳ **Temperature and precipitation change relative to pre-industrial level in the Middle East in the STEPS, 2041-2060**



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Rising temperature and changes in precipitation pose major challenges for energy supply infrastructure in the Middle East and require climate resiliency enhancements

Notes: Heat wave risk areas see 40 more days with maximum temperatures higher than 35 °C in 2041-2060 compared with the baseline. Drought risk areas see ten more consecutive dry days. Flood risk areas see at least a 10% increase in one-day maximum precipitation. Only power plants with an installed capacity above 100 megawatts are shown.

Sources: IEA analysis based on IPCC (2021), S&P Global (2021), Global Energy Monitor (2023, 2024).

Co-ordinated infrastructure planning in transitions

Efforts to reduce unabated fossil fuel use and scale up clean energy need to be carefully designed, which means, among other things, trying to map interdependencies and anticipate possible feedback effects. For example, a mismatch between the rate of expansion of low-emissions electricity generation, networks and electrified end-user equipment on the one hand and the decommissioning of natural gas-fired plants and gas networks on the other could lead to energy security risks. It could also disproportionately affect consumers that are unable to make the higher upfront investment often needed for electric end-use equipment.

Some existing infrastructure has a potentially important role to play in accelerating the development of low-emissions fuels. Some of these fuels, including biomethane, low-emissions hydrogen-based fuels and some liquid biofuels, can make use of existing infrastructure and end-use equipment. Delivery costs for others, including hydrogen, would

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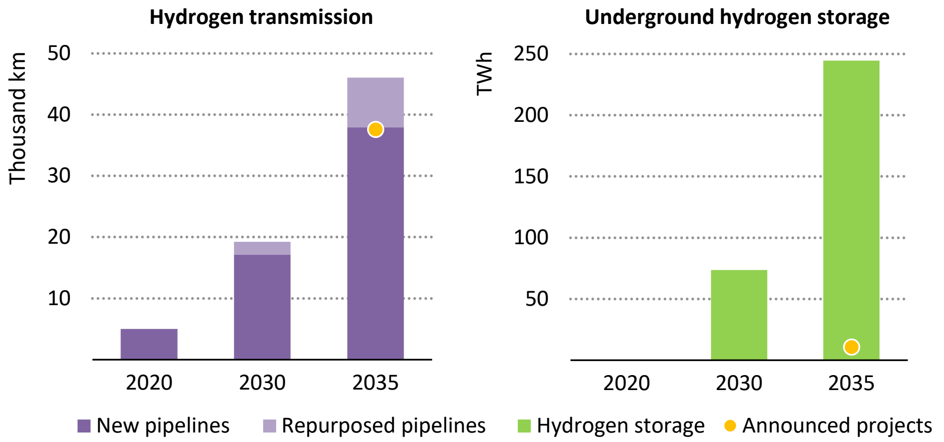
be much lower if the existing infrastructure were to be adapted specifically for their use. Such adaptation could help a number of countries that have the potential to be major producers to export these fuels and could similarly help countries with limited domestic resources to import them, and thus reduce their reliance on fossil fuel imports, diversify their energy mix and reduce their emissions.

Figure 5.6 ▷ Global hydrogen transmission pipeline length and underground storage capacity in the NZE Scenario, 2020-2035



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Existing infrastructure can help scale up low-emissions hydrogen, but new infrastructure is also needed and announced storage projects cover only a fraction of needs

Note: km =kilometres; TWh = terawatt-hours.

The scale up of low-emissions hydrogen in the NZE Scenario offers an illustrative example. In this scenario, around 400 million tonnes (Mt) of low-emissions hydrogen equivalent are consumed globally in 2050. Around 20% of this is traded internationally, including hydrogen converted into low-emissions hydrogen-based fuels. Low-emissions hydrogen is expensive to transport, and repurposing existing pipelines could reduce investment costs by 50-80% (IEA, 2022). Even if pipelines are repurposed in this way, new dedicated hydrogen transport infrastructure is still needed. There are currently plans to develop around 37 000 kilometres (km) of hydrogen pipelines globally by 2035, which is broadly in line with what is needed in the NZE Scenario. However, most of these projects are at an early stage and only a handful have reached final investment decisions, reflecting the generally slow pace of market development. It is more challenging to convert existing storage for use with hydrogen, and new facilities will be required, including depleted gas fields, hard rock caverns, salt caverns and aquifers. Overall investment in hydrogen storage is currently very low and announced projects cover only a small fraction of the needs in the NZE Scenario (Figure 5.6).

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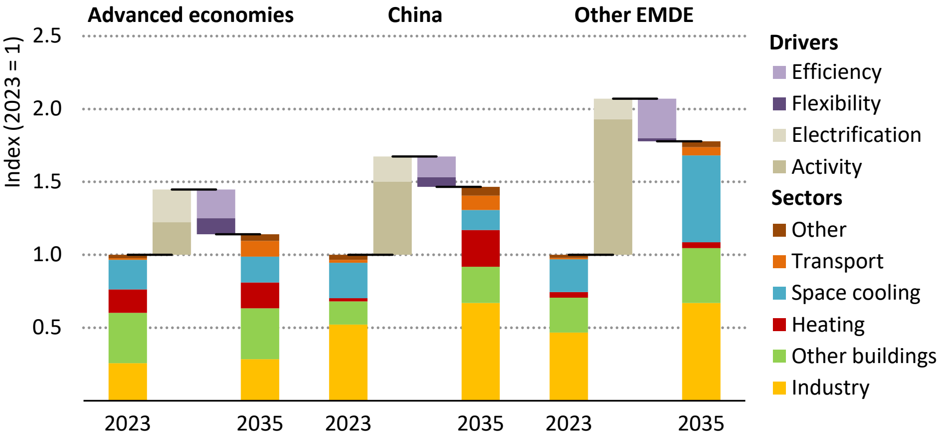
5.2.2 Electricity security

Adequacy and flexibility are both critical to the stability of electricity systems. Adequacy focusses on ensuring that there is enough capacity and supply to meet peak demand, while flexibility relates to the ability to handle variations in demand and renewable energy supply and to maintain a continuous balance between electricity demand and supply. Ensuring that electricity supply and demand are always in balance also requires secure and resilient electricity networks.

Adequacy

Electricity demand increases in all regions and scenarios over the next ten years and changing patterns of consumption have a significant impact on peak levels of demand. Anticipating peak demand growth and mitigating it where possible is key to ensuring electricity security. In the STEPS, peak demand rises by almost 15% in advanced economies to 2035, mainly because more consumers use electric heating and electric vehicles (EVs), and by up to 80% in emerging market and developing economies, most of which reflects increasing use of air conditioners and other forms of space cooling. In the APS, peak demand grows by a similar amount to the STEPS, as more electrification is compensated by higher energy efficiency gains and stronger deployment of demand-side flexibility measures.

Figure 5.7 ⊳ Peak electricity demand by sector and driver in the STEPS, 2023-2035



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Increased activity and end-use electrification are the key drivers of peak demand growth, but efficiency gains and nascent demand-side flexibility mitigate some of the increase

Notes: Other EMDE = emerging market and developing economies outside China. Other buildings = lighting, cooking and appliances. Peak demand is the average level of demand for the 100 hours of the year with the highest demand.

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Energy efficiency measures can significantly reduce peak electricity demand. Minimum energy performance standards for appliances, especially those used for cooling, improved buildings insulation and more efficient industrial motors all serve to reduce total and peak electricity demand. Demand-side flexibility measures can also bolster adequacy. In the STEPS, efficiency and demand-side flexibility measures mean that peak demand rises by less than 15% to 2035 in advanced economies: without these measures, peak demand would increase by more than 40% (Figure 5.7). In the APS, the widespread deployment of smart meters, dynamic tariffs and demand response-enabled appliances keeps peak demand in 2035 15% below the level it would otherwise reach in advanced economies. Peak demand is similarly reduced by improved efficiency and demand-side flexibility in China and other emerging market and developing economies, with efficiency gains playing an especially big role (Box 5.2).

There are other strategies to mitigate the rise in peak demand. These include increasing the capacity and number of interconnections, reinforcing existing grid infrastructure, developing new grid lines and protecting them from cyberattacks and climate-related damage. In addition to helping with the management of peak demand, these measures help reduce the need to expand fossil fuel dispatchable power plants to provide system adequacy. Nonetheless, the scale of the increases in peak electricity demand seen in all regions in both the STEPS and APS means that new dispatchable capacity is required.

Battery storage is the fastest-growing source of short-term dispatchable capacity to 2035 across all scenarios. In advanced economies, almost 600 gigawatts (GW) of batteries are added in the STEPS to 2035, and more than 850 GW are added in the APS; some new natural gas power plants are also built in both scenarios, primarily to replace existing capacity. A large amount of battery capacity is added in emerging market and developing economies, but gas- and coal-fired power plants also continue to play an important role in these economies.

Globally in the STEPS, batteries provide 55% of new dispatchable capacity, new natural gas power plants provide 20% and new coal power plants add a further 10% to 2035 (Figure 5.8). Around 50% of these coal capacity additions are in China, 20% in India and almost 10% in Indonesia; more than 50% of the total are already under construction or in the pipeline. In the APS, there is an even larger role for batteries, which provide more than half of dispatchable capacity, and 500 MW of coal capacity additions are equipped with carbon capture, utilisation and storage.

There is also an important role for new nuclear plants, which provide 6% of the additional capacity that becomes available in the STEPS: the majority of which is in emerging market and developing economies, with 40% of it in China. In advanced economies, extending the life of existing reactors where feasible remains the most economical way to maintain a stable nuclear fleet that contributes to a secure and affordable supply of electricity.

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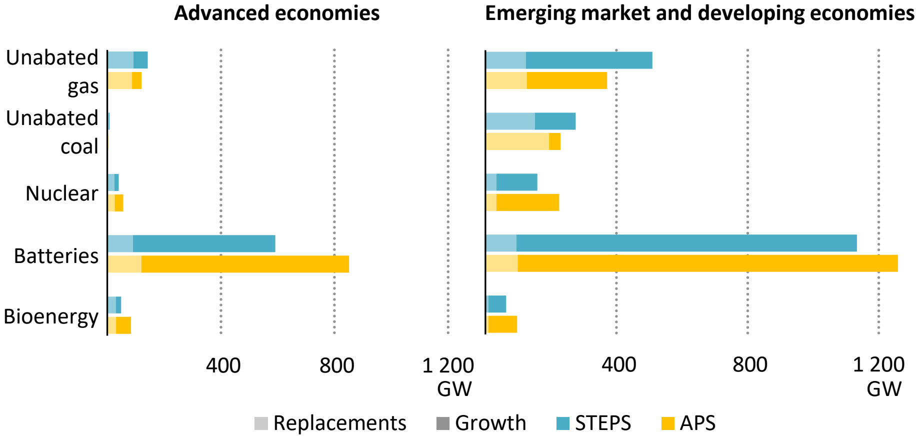
Figure 5.8 ▷ **Dispatchable capacity additions by type in the STEPS and APS, 2023-2035**



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Batteries are a key source of dispatchable capacity globally; coal and gas plants also play a key role to ensure adequate supply in emerging market and developing economies

Note: GW = gigawatts.

Flexibility

Flexibility needs over both short-term and seasonal timeframes vary widely across regions, largely due to differences in the share of renewables and in electrification rates.[1] In most markets, dispatchable thermal and hydropower, including pumped storage, provided nearly all short-term and seasonal power system flexibility in 2023, but this is set to change.

Short-term electricity flexibility needs, measured here as the largest hour-to-hour changes in residual load (total electricity demand minus wind and solar PV generation), rise sharply in the STEPS over the next ten years in many parts of the world, including Europe, China, India and United States (Figure 5.9). In the period to 2050, they increase in these countries by three- to seven-times more than total electricity demand, due mostly to rising shares of solar PV and wind and, to a lesser degree, evolving patterns of electricity demand. For example, short-term flexibility needs in Europe increase from 30 GW in 2023 to 170 GW to 2050 while average electricity demand increases from 360 GW to 610 GW.

Seasonal flexibility needs, measured as the highs and lows of residual load across the year, are driven primarily by electricity demand patterns, though the seasonality of renewable supply, notably wind and solar PV, also play a part. In Europe, seasonality is a feature of power systems today, mostly due to high heating demand in winter, and seasonal flexibility needs increase 50% faster than average electricity demand growth to 2035 in the STEPS as

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[1] Flexibility is defined as the ability of a power system to manage the variability of demand and supply, from ensuring the instantaneous stability of the grid to balancing demand and supply in each hour in all seasons.

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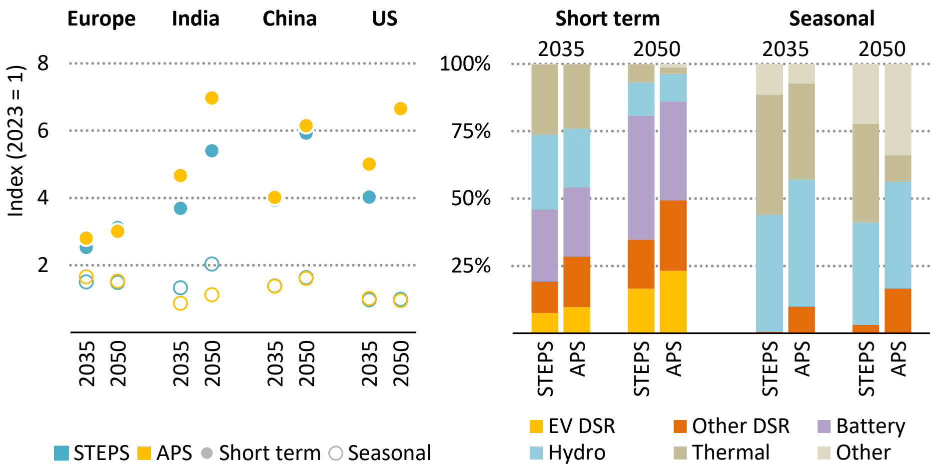
heating is increasingly electrified. In India, seasonal flexibility needs increase 30% faster than average electricity demand growth during the same period, where electricity demand almost doubles. Seasonal flexibility needs in India increase from a lower level than in Europe today, primarily due to strong demand growth for cooling. In China, seasonal flexibility needs increase 40% faster than average electricity demand growth to 2035 in the STEPS. In the United States, seasonal flexibility needs move broadly in line with increases in electricity demand. In the APS, more renewables and faster electrification increase the need for short-term flexibility in all regions. Higher energy efficiency can temper the growth in the APS for the needs for seasonal flexibility.

Figure 5.9 ⊳ Power system flexibility needs in selected regions and global flexibility supply in the STEPS and APS



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Electricity sector transitions raise short-term flexibility needs, primarily met by batteries and demand response, and seasonal flexibility, calling largely on hydro and thermal power

Notes: EV DSR = electric vehicle smart charging. Other DSR = other types of demand-side response, including operation of electrolysers. Thermal = fossil fuels, nuclear, bioenergy, hydrogen and ammonia. Other = renewables curtailment and other dispatchable sources. Flexibility needs are divided by the electricity demand and indexed to the value in 2023.

Batteries and demand-side response are set to provide the majority of short-term power system flexibility in both the STEPS and APS after 2035. Batteries provide short-term flexibility for periods of one to eight hours, helping to improve grid stability and enabling the rapid growth of solar PV by allowing electricity generated during the day to meet demand at other times. In both the STEPS and APS, they provide around 30% of short-term flexibility needs in 2035 and around 40% in 2050. Demand-side response also makes a major contribution to flexibility even when it affects a relatively small fraction of overall demand (Box 5.2).

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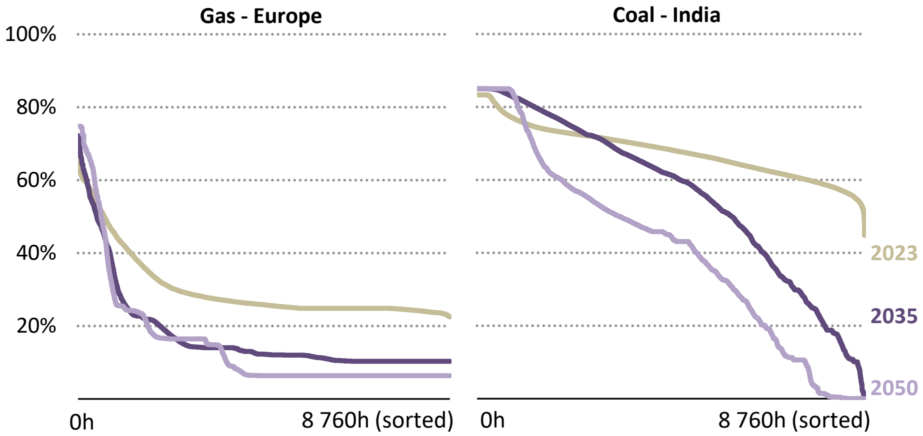
The role of thermal power plants to provide short-term flexibility in power systems evolves over time. Their share of the power mix declines but as short-term flexibility needs increase, they are called on to adjust their output more often and over a wider range. Downward ramping is needed during hours with high renewables output, for example in the middle of the day when solar PV production is at its peak, and upward ramping is needed when residual demand increases rapidly, for example at the end of the day when solar output declines. In the STEPS, gas-fired power plants in Europe in 2050 operate below a 25% capacity factor for most of the year, but they operate above 60% three-times as often as they do today (Figure 5.10). This more responsive operating mode will require upgrades to the existing dispatchable thermal fleet and measures to ensure that flexibility services are sufficiently incentivised to ensure their economic viability (IEA, 2024a).

Figure 5.10 ▻ Duration curve of hourly capacity factors of natural gas plants in Europe and coal plants in India in the STEPS, 2023, 2035 and 2050



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Dispatchable thermal power plants operate over a wider range throughout the year by 2035 than they do today, especially during periods of peak demand

Notes: h = hours. Curves show the capacity factor of plants for each hour of the year ranked from highest to lowest.

Seasonal flexibility needs are mostly provided by hydropower and thermal power plants to 2035. In the STEPS, these power sources cover 90% of seasonal needs in 2035 and 75% in 2050. The curtailment of some renewables output can also be part of a cost-effective approach to handle seasonal variability in power systems, and when planned for, can also help to reduce investment in other infrastructure such as electricity grids, storage and electrolysers. There is scope for electrolysers to contribute in the future to seasonal flexibility by using excess renewables generation to produce hydrogen that can be stored in long duration storage facilities. Weather patterns can vary significantly from year to year, influencing electricity demand through temperatures, and solar PV, wind generation and

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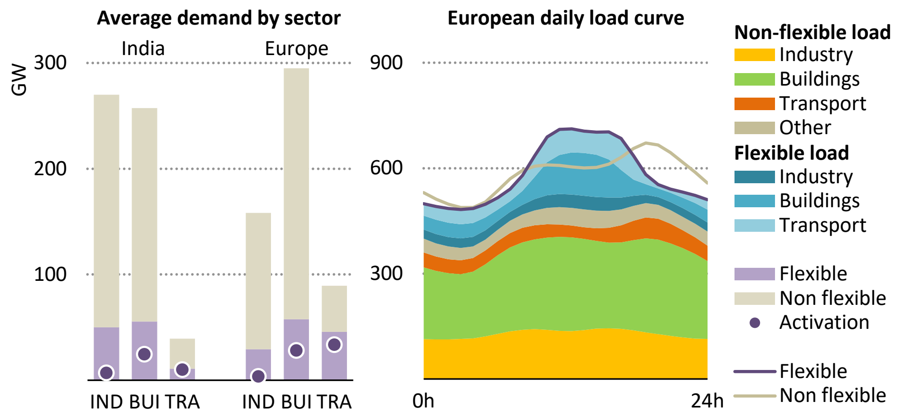
hydropower availability. Depending on the climate, this can lead to variations in seasonal flexibility needs, affect power plant operations and increase the variability of power system costs (IEA, 2024a).

Box 5.2 ▹ Harnessing the potential of demand response

Demand response – shifting the timing of electricity consumption from one part of the day to another without changing the level of service to consumers – has a major role to play in power system flexibility. In the STEPS, equipment that is responsible for around one-quarter of electricity demand in Europe is likely to offer some flexibility potential by 2050. Most of it is set to come from EVs and heating systems, but industry is also well suited to contribute to the provision of flexibility at times of peak demand, and high-temperature storage could enable longer shifting durations. In India, equipment responsible for almost 20% of demand could be flexible, with fans and air conditioners making a major contribution.

Figure 5.11 ▹ Demand flexibility potential and activation in the STEPS, 2050



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Around one-quarter of electricity demand could be flexible, activating less than half of this would reshape the profile of demand to better align with renewables output

Notes: GW = gigawatts; IND = industry; BUI = buildings; TRA = transport. Flexibility is activated when demand is shifted from one time of the day to another.

Our analysis for Europe and India finds that around 40% of the available flexibility would be activated on average over the course of the year (Figure 5.11). Equipment that can shift demand by the longest periods contributes the most, with more than half of available flexibility in the transport and buildings sectors being activated. Activating demand response helps reshape the overall demand curve: in Europe, for example, the peak in electricity demand is shifted from the evening to the middle of the day when

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renewables output is much larger. The widespread installation and use of smart meters, smart thermostats and digitalised grids is essential to unlock the potential for flexibility in all regions.

Demand response also frequently results in consumers paying less for the electricity they consume and in reduced emissions. As the share of solar PV rises, it creates a regular and predictable pattern of abundance during the day. In competitive markets, these periods are likely to be characterised by low wholesale electricity prices which incentivise a shift in consumption from periods when electricity prices are high to when they are lower. These periods of lower prices often coincide with the times when electricity generation produces lower than average emissions. Time-of-use tariffs are well suited for promoting this structural demand response.

For less predictable and regular events, such as heat waves or prolonged periods of low renewables output, more dynamic demand response measures are likely to be needed, such as shifts in the timing of industrial operations. Measures of this kind may require additional payment and may need to be triggered through some specific action rather than relying on market signals. Dynamic tariffs and aggregator services are generally effective ways of managing dynamic demand response, though they are likely to need to be combined with appropriate measures to shield consumers from very high prices if they are to command widespread public acceptance.

5.2.3 Security of clean energy supply chains and critical minerals

Clean energy manufacturing

Expansion of manufacturing capacities for many clean energy technologies has far exceeded the increase in clean energy technology deployment, contributing to the large drop in clean energy technology prices in recent years. For example, annual capacity additions of solar PV increased roughly fourfold between 2018 and 2023 from 100 GW to more than 420 GW while annual manufacturing capacity expanded by a factor of six from around 200 GW to 1 150 GW. Existing manufacturing capacity for solar PV modules and cells is almost sufficient to achieve what is necessary to meet demand in the NZE Scenario in 2030, with only modest gaps remaining for wafer and polysilicon manufacturing. For lithium-ion batteries, existing manufacturing capacities and projects that have reached final investment decision are within reach of the deployment needs in 2030 in the NZE Scenario, if fully utilised, even without other early-stage projects that are in the pipeline. For wind, existing capacity and announced projects would deliver just over 60% of 2030 deployment levels in the NZE Scenario (IEA, 2024b).

Manufacturing capacities are highly concentrated geographically. Owing to its supportive industrial policies, China has a very large proportion of existing manufacturing capacity for solar PV, wind, heat pumps, electrolysers and battery components. In the case of batteries, for example, China holds almost 90% of global capacity for battery cathode active materials,

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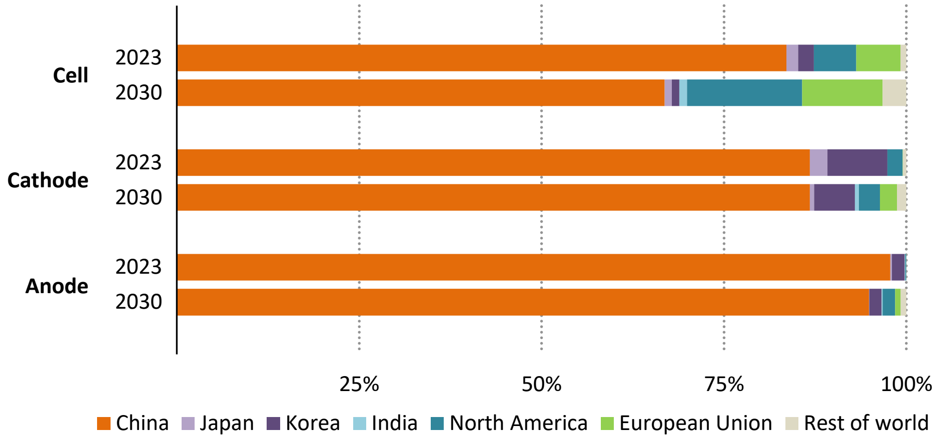
often a combination of lithium with nickel, cobalt and manganese, or iron phosphate, and 98% of capacity for battery anode active materials, frequently graphite or silicon-doped graphite. While the project pipeline is expanding rapidly worldwide, a large portion of planned projects are being developed in the regions where most capacity is already located, with China accounting for around 90% of announced capacity additions for both cathodes and anode active materials by 2030 (Figure 5.12). The overall level of geographic concentration in manufacturing is therefore set to remain high, even if all announced projects come to fruition.

Figure 5.12 ⊳ Current and announced battery cell and component manufacturing capacity, 2023 and 2030



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Announced battery cell manufacturing projects will provide some diversification, but battery component production is set to remain highly concentrated geographically

Note: 2030 value includes all operational capacity in 2023 together with the capacity of announced manufacturing projects through to 2030.

The situation is somewhat different for battery cell manufacturing. The share of existing manufacturing capacity in China is slightly lower than is the case for cathodes and anodes, and planned capacity additions in Europe and the United States means this is likely to fall further. In the European Union and the United States, announced battery cell manufacturing capacity is sufficient to meet the 2030 domestic deployment needs associated with their climate goals, provided that planned projects come online as scheduled (IEA, 2024c).

There are several barriers that hinder investment in new clean energy manufacturing capacities outside China, the chief of which is a large production cost gap. IEA analysis of more than 750 manufacturing facilities indicates that the capital and financing costs incurred in building a clean energy manufacturing plant in the United States and Europe are typically 70-130% higher per unit of output capacity than those in China (Figure 5.13). Energy,

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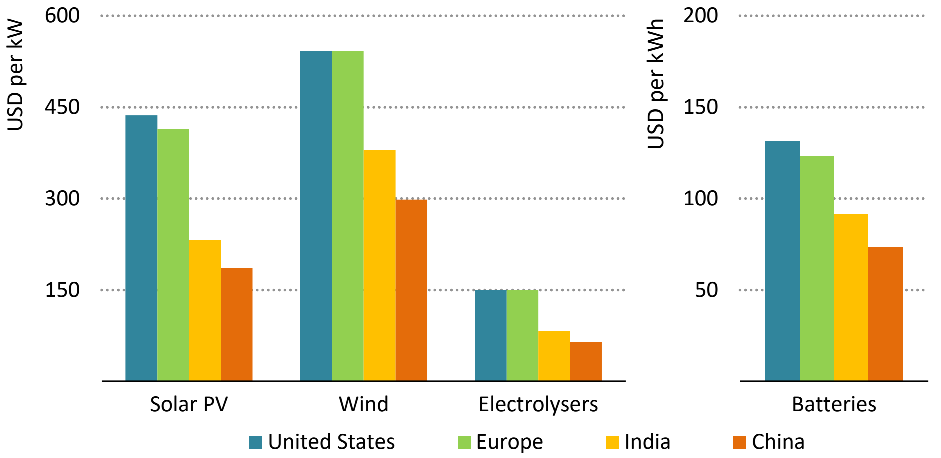
material, labour, and fixed operational expenditure can comprise 70-98% of the total costs of building and operating solar PV, wind and battery manufacturing plants, and lower operational costs in China amplify the cost differentials with advanced economies (IEA, 2024d).

Figure 5.13 ▷ Estimated capital costs for clean technology manufacturing facilities in selected countries, 2023



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There are large cost gaps between regions when it comes to building and operating clean technology manufacturing facilities, but non-cost factors also affect investment decisions

Notes: kW = kilowatts; kWh = kilowatt-hours. Capital costs are shown per unit of annual rated capacity. Solar PV includes polysilicon, wafer, cell and module production facilities. Batteries include cell, anode and cathode production facilities. Wind includes nacelle, tower and blade facilities. Electrolysers include only the final assembly step. Costs refer to greenfield, non-integrated facilities. No explicit policy incentives, e.g. tax credits, are applied.

Financial incentives for manufacturing to help reduce these cost gaps are often provided in the form of capital expenditure support, such as investment tax credits, grants, concessional loans and loan guarantees, or operating cost support, such as production tax credits. However, the challenges of investing in new manufacturing facilities are not limited to cost. The size of the domestic market and its political stability, workforce, infrastructure readiness, permitting processes, regulatory regimes and environmental, social and governance (ESG) requirements all affect corporate investment decisions. Policy interventions can help raise the attractiveness of investing by providing a high degree of policy stability, compressing project lead times, strengthening training and certification schemes for workers, enlarging domestic markets, reducing regulatory uncertainties and mandating higher ESG standards. Measures to support innovation, including R&D grants and support for rapid prototyping, can also make a difference.

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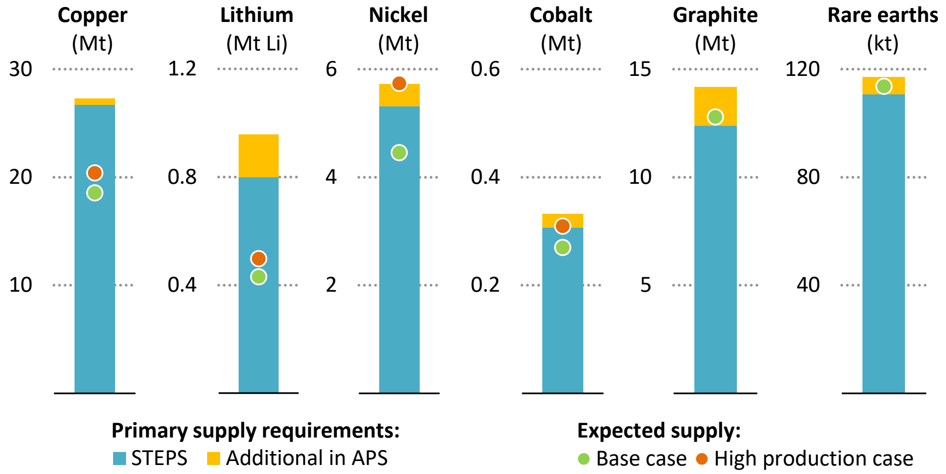
Critical minerals

Critical mineral markets were turbulent in 2023, with a sharp drop in the price of many materials. These lower prices have helped to bring about lower clean technology costs, including a 14% reduction in battery pack costs in 2023 but they are now dampening the investment appetite for new resource developments, with implications for future supply diversification (BNEF, 2023). In the case of nickel, for example, three-quarters of operating or potential projects that are at risk in today's price environment are outside the top-three producing countries. If they close because of low prices, supply will become further concentrated among the largest suppliers.

Figure 5.14 ▷ Primary supply requirements for critical minerals and expected supply from existing and announced projects by scenario, 2035



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Projected requirements for critical minerals in 2035 in the APS are within the range of expected supply from existing and announced projects, except for copper and lithium

Notes: Mt = million tonnes; Mt Li = million tonnes lithium content; kt = thousand tonnes. Graphite includes spherical graphite and synthetic graphite. Primary supply requirements are total demand net of secondary supply, which accounts for losses during refining operations. Base case includes production from existing assets and those under construction, along with projects that have a high chance of moving forward. The high production case, which exists only for copper, lithium, nickel and cobalt, includes projects that are less certain but are at a reasonably advanced stage of development, or are seeking financing or permits.

A number of projects to develop new critical mineral mines and refineries have been announced in recent years, but growth in the availability of critical minerals from the pipeline of announced projects – many of which have significant lead times – is set to be slower than expected growth in manufacturing capacity for a number of critical minerals. For example, in the APS in 2035, for copper and lithium, there is a sizeable gap between demand and expected supply based on announced projects (IEA, 2024e). Balances for nickel and cobalt

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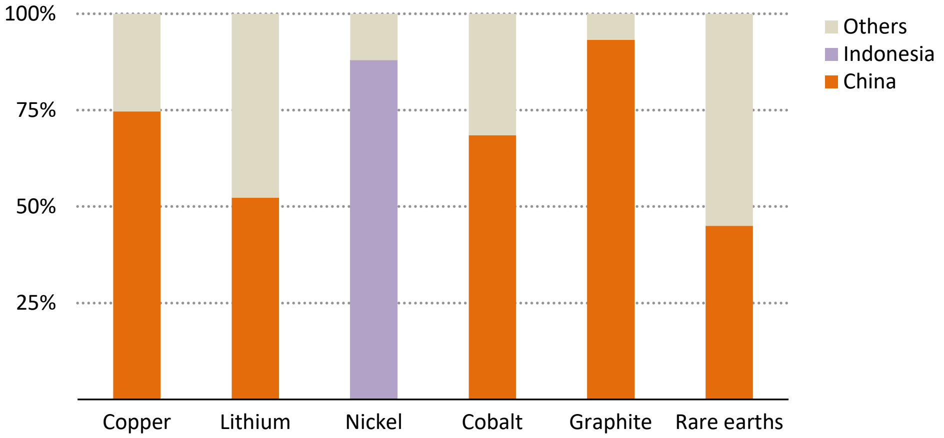
also look tight in terms of confirmed projects, but the outlook is better if projects at earlier stages of development are included (Figure 5.14).

These results should not be interpreted to mean that energy transition goals are unattainable due to material constraints. The gaps between future demand and anticipated supply could be closed by developing additional mining and refining projects, more diversified technology choices such as for battery chemistries or grid networks, promoting innovation, such as more efficient battery pack design, and boosting recycling (IEA, 2024e). They do however highlight risks to energy security based on current critical minerals investment and technology trends.

Further risks arise from the high degree of concentration of supplies of many critical minerals within a few countries. Based on the pipeline of announced projects, this looks unlikely to change over the next decade. From 2023 to 2035, some 50-75% of supply growth for refined copper, lithium, and cobalt is projected to come from today's largest producers, and the same is true for about 90% of battery-grade graphite supply and nickel growth. The figures for rare earth elements are lower, but these too face very high levels of market concentration (Figure 5.15).

Figure 5.15 ▷ Lead producing country in new refined capacity growth for selected minerals, 2023-2035



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Today's leading critical mineral suppliers provide most of the projected supply growth for all refined materials, suggesting that supplies are unlikely to become more diverse

Notes: Shows base case supply scenario. Graphite includes battery-grade spherical graphite and synthetic graphite; rare earth elements are for magnet rare earth elements only.

There are challenges in financing new critical mineral supply chains, including cost inflation, long-term price uncertainty and the limited value that consumers currently place on diversification. However, there is plenty of scope for demand-side actions such as recycling, innovation and behavioural change, e.g. right sizing EV batteries, to play a role to ease

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potential supply strains. In the NZE Scenario, for example, demand for copper increases by 50% to 2040 but primary supply rises only by 30% because of increased recycling.

Incentivising products which score highly on ESG criteria can also help diversify supply sources, but standards and regulatory interventions are likely to be needed to encourage the widespread use of sustainably and responsibly produced materials. Subsidies or tax credits are another option for supporting the production of responsibly sourced materials, for example by linking eligibility to the procurement of a certain percentage of material supply from responsibly and sustainably produced materials. Carbon accounting frameworks and carbon pricing schemes could also help drive pricing differentiation between various sources of materials, and disclosure policies such as those included in the European Union Battery Regulation could make it easier for purchasers and consumers to determine the emissions of different material sources.

5.3 Affordability and people-centred transitions

5.3.1 Energy bills

The 2022 global energy crisis provided a stark reminder of how much societies depend on reliable and affordable supplies of energy. Russia's invasion of Ukraine led to a huge increase in wholesale energy prices, prompting governments worldwide to spend USD 940 billion to support their populations by keeping energy more affordable. These interventions helped limit the cost pass-through to retail energy prices but were insufficient to safeguard households entirely, particularly those with low incomes. Worldwide, consumers spent on average 20% more on energy in 2022 than in 2021, with the rising cost of energy outpacing increases in disposable income over the same period. The situation began to improve in 2023, with declining wholesale energy prices, but the rollback of consumer affordability support measures meant end-user energy prices remained relatively high in some regions.

In advanced economies, the poorest 10% of households can spend up to a quarter of their disposable income on residential energy and transport fuels, even though they consume about half as much of these fuels as the richest 10%. This level of expenditure means that some households face difficult choices between heating or cooling their homes and meeting other basic necessities. In 2022, almost one-in-ten people in the European Union – more than 40 million people – were unable to keep their homes adequately warm (European Commission, 2023).

In emerging market and developing economies, modern energy use by households is on average only one-third of that in advanced economies: the richest 10% of households in emerging market and developing economies today consume about as much energy as the poorest 10% in advanced economies. The disparities between income groups in emerging market and developing economies is also wider than in advanced economies (Figure 5.16). In these economies, the poorest consume around one-quarter of the energy consumed by

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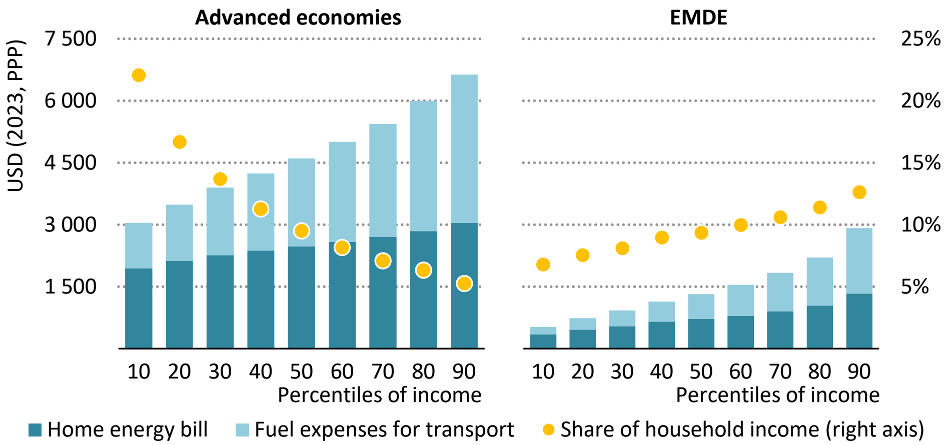
the richest. They are also heavily dependent on the traditional use of biomass, which meets one-third of residential energy demand and is not included in expenditure metrics.

Figure 5.16 ⊳ Annual household expenditure on residential energy and transport fuels by income decile, average for 2019-2023



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Energy bills weigh heavily on poor households in advanced economies, while in emerging market and developing economies, many poor households lack access to modern energy or do not own appliances or vehicles

Notes: EMDE = emerging market and developing economies; PPP = purchasing power parity. Income refers to household disposable income. Household disposable income deciles represent the weighted average of the deciles of each economic grouping assessed. This analysis considers government subsidies that directly affect the energy prices paid by consumers such as energy price caps. It does not include direct subsidies to households such as energy assistance payments, which have accounted for a significant portion of disposable income for low-income households in certain countries in recent years. The traditional use of biomass, which accounts for one-third of residential energy demand in emerging market and developing economies, is not included in expenditure metrics.

Source: IEA (2024e).

Total household spendings on energy, including residential energy and transport fuels, currently averages nearly USD 4 000 per year in advanced economies and around USD 700 per year in emerging market and developing economies. In the NZE Scenario, households in advanced economies soon start to see lower energy bills than in the STEPS thanks to investment in improved insulation, more efficient heating and cooling systems, behaviour changes and wholesale fossil fuel prices that have been driven lower by reduced demand. Public support for household investment in clean energy equipment also reduces direct household energy expenditure in the NZE Scenario. These savings also far outweigh the increased cost borne by consumers in adopting higher efficiency and fuel switching measures. In emerging market and developing economies, household energy expenditure is initially higher in the NZE Scenario than in the STEPS as a result of increased access to modern

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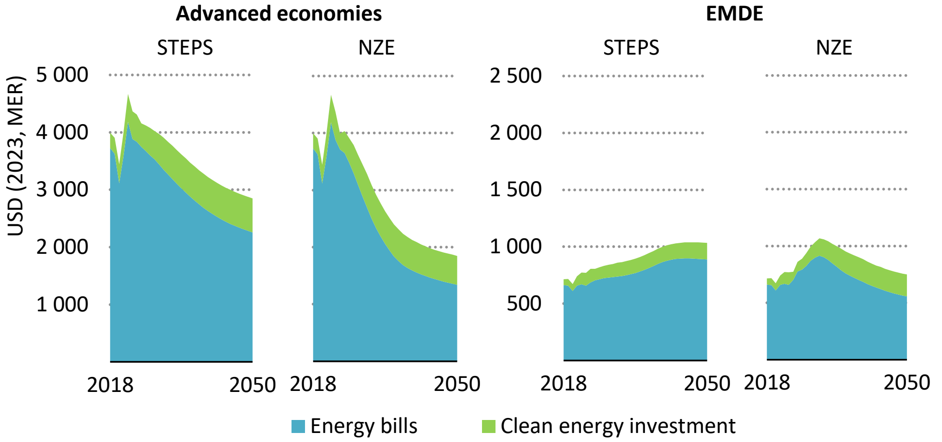
energy, reductions in fossil fuel subsidies and the introduction of CO_2 pricing. Household energy expenditure in the NZE Scenario nevertheless is around 25% lower than in the STEPS by 2050 (Figure 5.17).

Figure 5.17 ⊳ Average annual household energy expenditure by economic grouping and scenario, 2018-2050



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Energy spending in advanced economies is lower in the NZE Scenario than in the STEPS; it is higher in the near term in emerging market and developing economies, but soon falls

Notes: MER = market exchange rate. Clean energy investment is distributed across the economic lifetimes of the assets, rather than being incurred as a full upfront investment.

Many clean energy technologies are already the most affordable options when life cycle costs are considered. While their upfront costs in many cases are higher than those of their conventional equivalents, they often have much lower operating costs because they are more efficient. They also shield consumers from volatility in fossil fuel prices. However, the higher upfront costs of many clean technologies compared with their conventional counterparts is a significant barrier for low- and middle-income households. Addressing this issue is crucial because the energy transition cannot succeed if the poorest segments of the population are left behind. Potential measures include targeted subsidies for efficiency upgrades and fuel switching, tax rebates and low- or zero-interest loans. Ensuring that these households have access to affordable financing is especially important in emerging market and developing economies where higher interest rates exacerbate the financial burden of technologies with high capital costs.

An inequality that is sometimes given insufficient weight in today’s energy system is the disparity between urban and rural households. Rural houses are often more isolated and more expensive to connect to energy networks, and so they often face higher energy prices,

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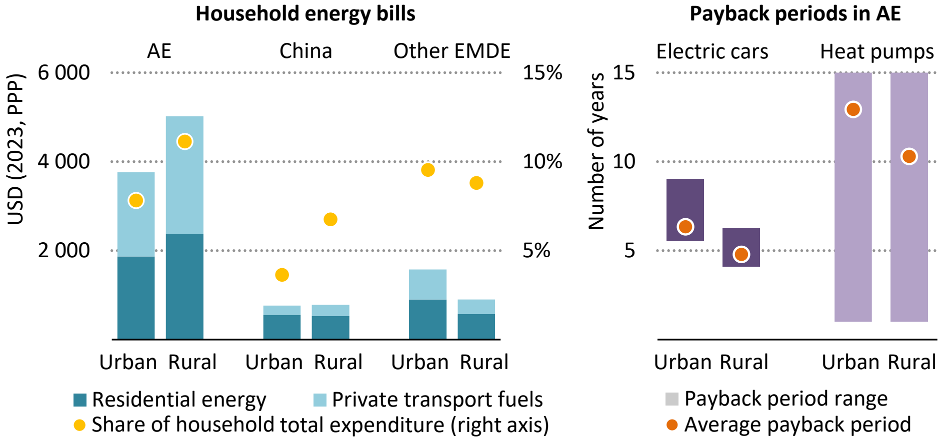
despite efforts by many governments to regulate electricity and natural gas prices so that they are broadly the same for households in rural and urban areas.

In advanced economies, rural households spend around one-third more on energy than their urban counterparts, and this expenditure represents a larger portion of their total expenditure. Several factors contribute: rural households tend to be larger and less efficient than those in urban areas, which drives up heating and cooling bills; they spend more on transport fuels because they have to travel further to get to work and to access essential services (they travel on average 35% further each year than urban households); and have less access to public transport and so tend to own and use personal vehicles more frequently.

Figure 5.18 ▹ Annual household energy bills and key clean technology payback periods by urban and rural areas, 2023



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Overcoming the higher upfront costs for many clean energy technologies is a challenge, but rural households might benefit more than urban households from lower operating costs

Notes: AE = advanced economies; Other EMDE = emerging market and developing economies outside China; PPP = purchasing power parity. Electric cars only refer to battery electric cars in this analysis. The calculation of the heat pump payback period includes existing upfront cost subsidies.

In emerging market and developing economies outside China, average energy bills for rural households are almost half the average level of urban households, yet they account for a very similar share of their total expenditure. Rural households tend to have more limited access to modern energy services and so rely more on the traditional use of biomass. They also tend to have lower incomes, lower levels of ownership of energy-consuming equipment, and less access to developed transport infrastructure.

In China, rural and urban households on average spend similar amounts on energy, though rural households devote a somewhat larger share of their budget on it. As in advanced economies, rural households in China primarily use modern energy sources and tend to be

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larger and less efficient than urban ones. However, lower levels of ownership of energy-consuming equipment limit their total energy expenditure.

Because rural households in advanced economies tend to spend more on energy than urban ones, they could potentially benefit more than urban households from the lower operating costs of clean energy technologies. For example, the average payback period for an electric car for rural households in advanced economies is under five years, compared with above six years for urban households, and the average payback period for heat pumps is 13 years for rural households, compared with ten years for urban ones (Figure 5.18). The availability of public charging stations in rural areas remains a major hurdle, especially in regions where long-distance driving is common. The clean energy technology proposition is less clear cut in emerging market and developing economies, where access gaps and lower disposable income lead to much lower levels of energy consumption in rural households.

5.3.2 Energy employment

Increasing clean energy investment has led to a steady increase in the number of people working in the energy sector. In 2023, more than 67 million people were employed in the energy industry worldwide, 4% more than in 2022, with most of the growth coming from clean energy industries (Figure 5.19). In a number of major economies, clean energy has been a prominent driver for new economy-wide employment, for example contributing as much as 10% of overall job growth in China in 2023.

A few key technologies are responsible for most of the new jobs. EV manufacturing and their batteries saw some of the biggest gains in employment: 0.4 million jobs were added in 2023, raising the global total to 2.7 million. Nearly three-quarters of the global EV and EV battery workforce in 2023 was located in China, with employers benefitting from new energy vehicle manufacturing incentives from the government. About one-fifth of the global EV and battery workforce was in the United States and the European Union, which both have large existing vehicle manufacturing capacities and have recently implemented policies that aim to boost domestic EV manufacturing. Solar PV and wind energy also saw substantial employment growth in 2023: they now account for a combined 6.2 million workers worldwide, most of which work in construction and installation.

The share of clean energy in economy-wide employment growth in most emerging market and developing economies outside China has been more muted than in advanced economies. This is partly because the non-energy economy of these countries has been growing rapidly, but also because they have seen much lower levels of clean energy investment than advanced economies and China. The largest share of clean energy jobs today is in the construction and installation of new energy projects, followed by jobs in operation. But in emerging market and developing economies, these roles tend to pay less than comparable jobs in advanced economies, even when adjusted for purchasing power parity.

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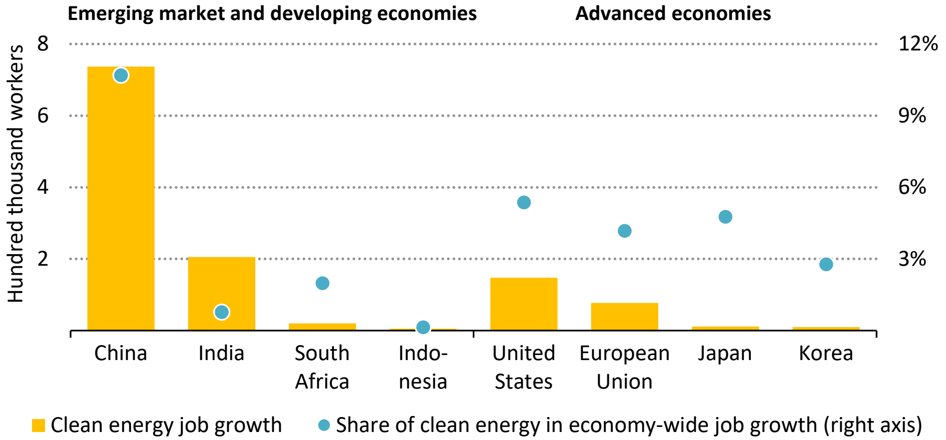
Figure 5.19 ⊳ Clean energy job increases and significance in economy-wide job growth by economic grouping, 2023



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Clean energy job additions accounted for a substantial share of economy-wide job growth in China, United States, European Union and Japan

Lower labour costs in emerging market and developing economies should be an advantage to attract new clean energy industries. However, most new clean technology manufacturing facilities to date have been concentrated in China, advanced economies and Southeast Asia. Growth in clean energy manufacturing employment has been particularly slow in Africa and Central and South America. This may reflect concerns on the part of prospective investors about relatively small domestic and regional markets for deployment, ample global manufacturing capacity for many clean technologies, and a relative absence of relevant adjacent industries and skills that are often a strong draw for clean energy manufacturers siting new facilities.

In the STEPS, more than 6 million new energy workers are needed worldwide by 2030. This figure rises to 15 million in the NZE Scenario. EVs and EV batteries see the largest gains to 2030, with the number of jobs in the STEPS increasing from 2.7 million today to 6.7 million in 2030. In the NZE Scenario, this rises to 10.5 million (Figure 5.20).

Job losses are associated with declining production and consumption of fossil fuels in each scenario. The global coal mining workforce has been shrinking for more than a decade, led by the push to modernise the mining industry in China, and this is set to continue in the years ahead. By 2030, the number of coal supply jobs worldwide falls by over 20% in the STEPS and by 50% in the NZE Scenario. The number of oil and natural gas supply jobs rises by almost 300 000 in the STEPS but falls by nearly 5 million jobs in the NZE Scenario to 2030. Many oil and gas companies, especially in advanced economies, are turning to contract work to manage short-term increases in worker demand while adopting strategies of portfolio diversification and upskilling to hedge against uncertainty in future demand.

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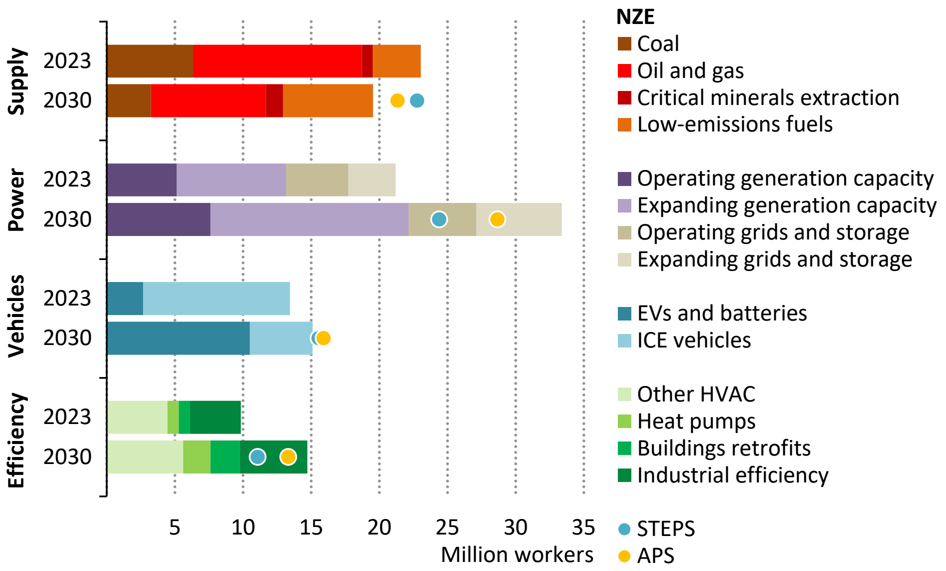
Figure 5.20 ▻ Energy employment by technology and scenario, 2023 and 2030



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Energy transitions in all scenarios are a net creator of direct jobs as decreases in fuel supply jobs are more than offset by increases in low-emissions power and end-use sectors

Note: ICE = internal combustion engine; HVAC = heating, ventilation and air conditioning.

The impact of these losses on individuals and communities can be huge. In some cases, workers may be able to find alternative work in other energy sectors. But even those workers that are best placed to make this switch, such as highly skilled oil and gas workers, face challenges: new jobs may not be located in or near the places where they currently work or offer the same benefits and remuneration as their previous occupation. In many other cases, the skills of energy workers may not neatly align with other energy jobs that are created. Coal workers may face particular challenges on this front. Co-ordination between government, labour unions and industry is critical to ensure that all workers that lose their jobs are able to access financial support and skills training and to promote the provision of alternative opportunities.

Several parts of the energy industry are facing skill shortages today. This poses a risk to clean energy transitions. Many clean energy sectors compete for the same limited pool of trade workers, including construction workers, welders and electricians, and those with the necessary skills are in many cases already in short supply in the general buildings sector. Some skilled workers may move into clean energy from sectors such as oil and gas, nuclear and hydropower, but these sectors are also facing skills losses as older workers retire. Notable shortages have also emerged in recent years in manufacturing and transport. Employers are using a range of strategies to cope with the lack of skilled labour. Options

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include raising wages, adopting automation, increasing on-the-job training, and in some cases, accepting insufficiently skilled candidates for critical roles.

The new clean energy economy offers substantial opportunities to stimulate local economies and improve the quality of life for workers. But capturing these benefits and preventing the skills gap from widening further requires both the public and private sectors to invest in education and training. Collaboration has an important part to play in getting the most from such investment. For example, closer partnerships between educational institutions and industry would help improve up-to-date curricula for future energy workers. Policies such as the European Skills Agenda and the US Inflation Reduction Act are looking to address these issues, but current efforts in these regions and elsewhere most likely need to be supplemented to prevent a shortage of skilled workers from becoming a bottleneck for the energy transition.

5.3.3 Energy access

The Covid-19 pandemic and global energy crisis setback efforts to expand electricity access. For the first time in decades, the number of people worldwide without access to electricity increased in 2022. The effects were felt most acutely in sub-Saharan Africa, where the number of people without electricity access increased by around 15 million between 2019 and 2022.

In 2023, the number of people worldwide without electricity access started to fall again, decreasing by around 13 million despite ongoing macroeconomic challenges. Accelerated grid connections were the main driver of renewed progress in Nigeria, Rwanda, Uganda, Senegal and Ethiopia. This was enabled by strong government support and affordability programmes such as the Hybrid Connection Programme in Uganda. There were also improvements in developing Asia, with Cambodia, Myanmar, Pakistan and the Philippines witnessing a large reduction in the number of people without access to electricity. Bangladesh achieved universal access in 2023. Solar home systems saw record sales for the second year in a row in 2023, with strong uptake in West Africa, even though there was an increasing share of grid-connected households in developing Asia (GOGLA, 2024). Despite this progress, however, almost 750 million people still have no access to electricity around the world, 80% of which are in sub-Saharan Africa.

Progress to achieve universal access to clean cooking also slowed in the 2019-2022 period in many countries. Increased strains on household incomes and rising energy prices hindered progress. Plus, millions of households that had previously gained access reverted, at least temporarily, to traditional cooking fuels. Recent gains have come from well-established, funded and targeted clean cooking policies, which were generally resilient even through the Covid-19 pandemic. Several notable programmes in China and India over the past ten years provided access to clean cookstoves to tens of millions of households. However, progress in sub-Saharan Africa has been slow, and the number of people without access to clean cooking continues to rise, with damaging effects on health and livelihoods, particularly for women

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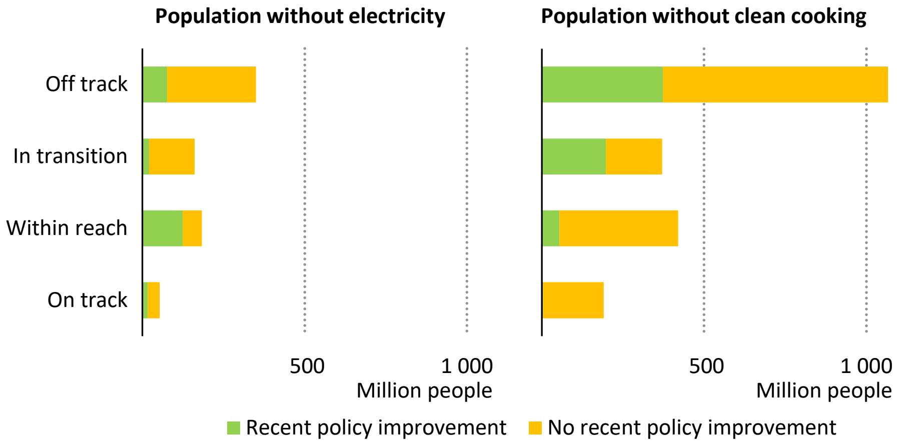
and children. Our latest estimates suggest that more than 2 billion people globally did not have access to clean cooking in 2023.[2]

Figure 5.21 ▻ Global population without access to electricity and clean cooking and status of access policies, 2023



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Access policies have recently improved in countries that represent more than 30% of both the population that lack access to electricity and clean cooking

Notes: Recent policy improvement indicates policies announced or enacted in the last two years. Off track relates to countries where current policies are expected to lead to very limited improvement in access. In transition relates to countries with weak but improving policy frameworks. Within reach relates to countries where fundamental policies are in place, but additional efforts are needed to achieve universal access by 2030. On track relates to countries with strong policies to expand access that are likely to reach universal access by 2030.

New policies are set to facilitate access to clean cooking solutions. Around 630 million people without access today live in countries where new and improved government initiatives and regulatory frameworks have been introduced in the past couple of years (Figure 5.21). This includes new national clean cooking plans in Kenya, Nigeria, Tanzania, São Tomé and Príncipe, and Uganda. Tanzania has plans to reduce import duties for clean cooking stoves and fuels and increase investment in liquefied petroleum gas (LPG) storage. Madagascar started working on its Integrated Energy Access Plan. There is renewed policy momentum in India with the launch of the National Efficient Cooking Programme. In Pakistan, a national clean cooking strategy is being developed in line with the 2023 National Clean Air Policy. The governments of Kenya, Rwanda and Sierra Leone have established clean cooking delivery units. Several other sub-Saharan countries are considering similar initiatives. At the Summit

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[2] This is a downward revision from the *WEO-2023,* which indicated that around 2.3 billion people did not have access to clean cooking in 2022, as new data indicate that access in China, India and Indonesia has been improving faster than previously known.

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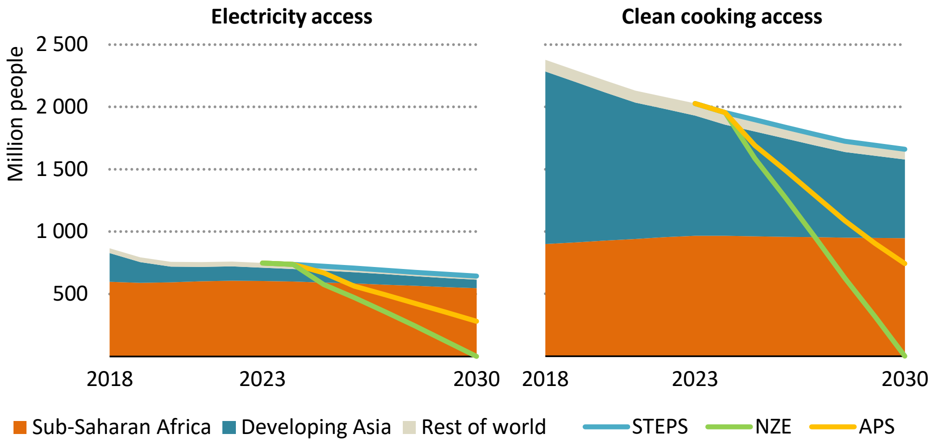
on Clean Cooking in Africa, co-hosted by the IEA in May 2024, more than USD 2.2 billion of new funding was committed for clean cooking initiatives in Africa, plus several other positive developments in policy, financing and partnerships.

Around 90% of both the population without access to electricity and clean cooking today live in countries that have official targets to improve access, though only around half live in countries with targets aligned to the United Nations Sustainable Development Goal (SDG) 7.1, with its objective to ensure universal access to affordable, reliable and modern energy services by 2030. In the STEPS, around 645 million people still lack access to electricity in 2030, and 1.7 billion lack access to clean cooking (Figure 5.22). This is a slight improvement over the STEPS in the *WEO-2023*, but it still falls well short of the SDG 7.1 goal. In the APS, where all official targets are met on time and in full, around 280 million people still lack electricity access in 2030, and the equivalent figure for clean cooking is around 745 million. In the NZE Scenario, universal access to electricity and clean cooking is achieved in full by 2030. In total, reaching universal access worldwide requires around USD 55 billion of capital investment each year through to 2030, of which around USD 10 billion annually is for clean cooking. Public and concessional finance has a crucial role to improve affordability and reduce perceived risks for private investors through programmes and initiatives such as the World Bank and African Development Bank commitment to provide 300 million people in Africa with access to electricity by 2030 (World Bank, 2024).

Figure 5.22 ▷ Population without access to electricity and clean cooking by region and scenario, 2018-2030



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Stated policies and announced pledges are insufficient to achieve universal access to electricity and clean cooking by 2030

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5.3.4 Behavioural change

Behavioural changes by consumers to reduce energy use are an under-employed lever for reaching energy security and climate goals. Behavioural change can help limit growth in energy demand and thus curb emissions, especially in sectors where technical alternatives are scarce or costly. Around 25 countries include behavioural measures in their Nationally Determined Contributions (NDCs) or long-term strategies. Most behavioural measures relate to transport. For example, many European countries aim to reduce the use of private cars through measures such as road space allocation schemes, low-emissions zones and investment in public transport infrastructure and cycle lanes. Bangladesh and Türkiye include targets for modal shifts from road transport to rail, while Colombia and Austria have set targets for bicycle use.

Measures in NDCs and other climate strategies are incorporated into the APS, and they account for less than 1% of the difference in emissions between the APS and the STEPS in 2035. This relatively small share reflects a perception by policy makers that measures to encourage behavioural change are unpopular. However, there is mounting evidence that it is possible to win public support for effective policies. For example, support for congestion charging in Stockholm, London and elsewhere increased significantly in the years following its introduction as parallel improvements were made in public transport and as citizens increasingly realised the benefits of reduced congestion and air pollution. Discretionary changes, such as reducing thermostat settings, were made by many people during the global energy crisis in 2022, in part in response to public awareness campaigns. In addition, many people that worked from home during the Covid-19 pandemic continue to do so, thereby reducing commutes.

The NZE Scenario taps the full potential for behavioural change to reduce emissions (Figure 5.23). In total, around 5% of the difference in emissions reductions between the STEPS and the NZE Scenario in 2035 stem from behavioural change. On a per capita basis, CO_2 reductions from behaviour change are more than four-times larger in advanced economies than in emerging market and developing economies. Measures to reduce car use in cities and promote shared mobility are adopted widely, which reduces CO_2 emissions by around 300 Mt globally in 2035. Moderating space heating and cooling in buildings where this is feasible saves about 150 Mt and introducing a levy on frequent flying cuts emissions by a further 80 Mt in 2035.

Two-thirds of the emissions reductions in the NZE Scenario from behavioural change are facilitated or mandated by governments, such as congestion charging or reduced speed limits on roads. Around 40% of the behavioural measures adopted require investment in dedicated infrastructure, such as cycle lanes or high-speed rail networks (Box 5.3). The remaining one-third of emissions reductions are mainly from discretionary changes, half of which revolve around energy saving measures in homes that can be encouraged by information and awareness campaigns in conjunction with home energy consumption reports.

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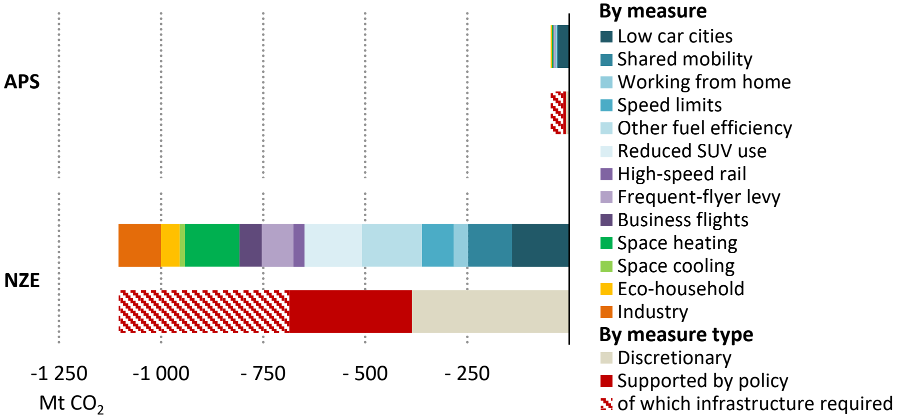
Figure 5.23 ⊳ CO₂ emissions reductions from behavioural change by measure and scenario, 2035



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A range of behavioural change measures could reduce emissions, but many of them depend on policy support and new infrastructure

Notes: Mt CO_2 = million tonnes of carbon dioxide; SUV = sport utility vehicle. Eco-household measures include line drying clothes instead of using a machine; reducing laundry temperature; switching off lights in unoccupied rooms; unplugging appliances when not in use and reducing water heating temperature. Shared mobility measures include ride sharing services and carpooling. Other fuel efficiency measures include eco-driving and air conditioning measures. Industry measures include reuse, recycling and vehicle activity reduction. Reduced flying includes shifts to high-speed rail, frequent-flyer levies and replacing long-haul flights for business trips with teleconferencing.

Box 5.3 ⊳ How infrastructure shapes transport choices

Emissions associated with moving around cities vary widely depending on the local transport infrastructure, the services available and the density of the built environment. In many cities, there is limited scope for walking, a lack of cycling and public transport infrastructure and locked-in car dependency for services, which leads to elevated levels of emissions from travel and poor air quality. Zoning laws that prioritise low-rise, single-use developments can exacerbate this trend by increasing travel times to essential services.

Major changes in transport behaviour are possible with the right policies, infrastructure and services (Figure 5.24). For example, in Paris, the share of journeys accounted for by private car travel fell from 65% in the late 1980s to 15% in 2023 as a result of measures to discourage car use, such as road space reallocation and parking restrictions, investment in public transport, and a major increase in support for cycling infrastructure. In Santiago, the figure fell from 34% in 2001 to 28% in 2012 following significant investment in the development of cycle paths in the late 2000s. There are also many examples where a lack of policy and support for walking, cycling and public transport has led to very high and increasing dependency on private transport. In Jakarta, for example,

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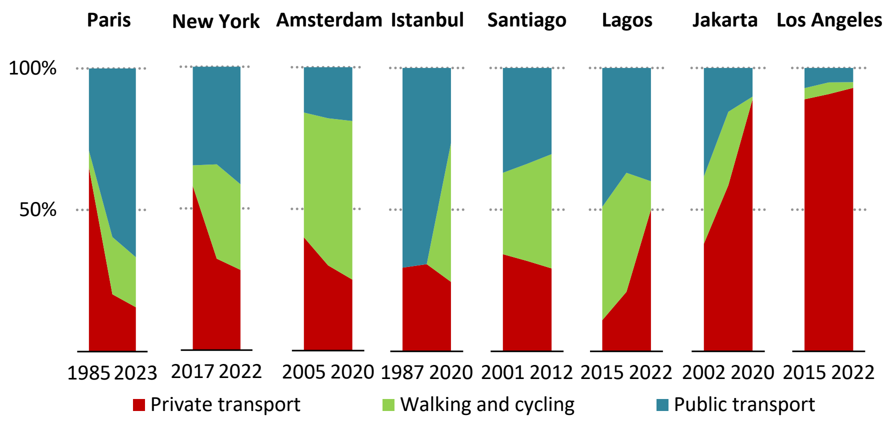
only 7% of roads have adjacent pedestrian walkways and the number of journeys involving private transport rose from 38% of the total in 2002 to 88% in 2020. In Los Angeles, where 93% of transport is private, the average person spends more than 100 hours in traffic jams every year, and a one-kilometre journey produces almost six-times more CO_2 emissions on average than a journey of the same length in Amsterdam.

Figure 5.24 ▷ Passenger transport by mode in selected cities, 1985-2023



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Infrastructure investment and policy choices largely determine the mobility choices of individuals, leading to radically different ways of travelling in cities

Note: Private transport includes taxis.

Sources: IEA analysis based on mobility surveys for the cities. *Paris*: Bloomberg (2018), Héran (2017) and SFCTA (2023). *New York*: Deloitte (2018), Oliver Wyman Forum (2022a) and NYC DOT (2022). *Amsterdam*: CINEA (2021). *Istanbul*: GIZ (2013) and Deloitte (2020a). *Santiago*: Government of Chile (2001) and MMT (2015). *Lagos*: TUMI (2015), Cirolia, Harber and Croese (2020) and Oliver Wyman Forum (2022b). *Jakarta*: Nobel (2024) and Deloitte (2020b). *Los Angeles*: Katona and Juhasz (2020), Deloitte (2020c) and Oliver Wyman Forum (2022c).

Broader awareness and higher investment are needed to support active and public transport options for rural communities. In England, for example, rural residents using public transport spend twice as long commuting to reach essential services as urban residents do, while those using private cars experience only a minor increase in travel times. Across northwest Europe, car ownership rates for rural residents are 65% higher than for urban residents. Options that would help address the "last mile" challenge of connecting residents to regional transport corridors include local and regional authority support for rural mobility hubs, smart and affordable ticketing solutions, investment in public minibus services, and cycling infrastructure that can be used for small battery electric powered transport like electric bikes, scooters and two/three-wheelers. Without measures of this kind, the majority of energy use reductions from active and public transit options will remain concentrated in cities.

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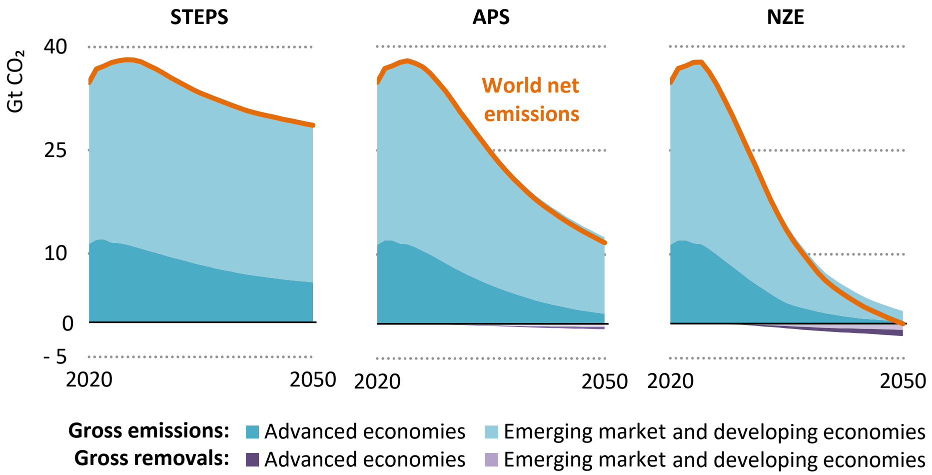
5.4 Sustainability

5.4.1 Emissions trajectories and temperature outcomes

Energy-related CO_2 emissions increased by just over 1% in 2023 to a record high of 37.7 gigatonnes (Gt). In the STEPS, CO_2 emissions reach just over 38 Gt in the mid-2020s and then fall to less than 29 Gt in 2050. Around 60% of the decline in emissions to 2050 occurs in advanced economies, mainly due to declining emissions from electricity generation and transport. Emissions in emerging market and developing economies fall more slowly, with reductions in emissions from electricity generation partially offset by increases in road transport and industry (Figure 5.25).

Figure 5.25 ▷ Energy-related CO_2 emissions in advanced and emerging market and developing economies by scenario, 2020-2050



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Emissions peak and fall in the STEPS, they fall much faster in the APS and NZE Scenario, net zero is achieved in aggregate in advanced economies around 2045 and globally by 2050

Note: Gt CO_2 = gigatonnes of carbon dioxide.

In the APS, global CO_2 emissions fall to around 32 Gt in 2030 and 12 Gt in 2050. Advanced economies collectively reduce their emissions to close to zero in 2050. The pace of emissions reductions in emerging market and developing economies accelerates in the early 2030s, but they still emit around 10 Gt CO_2 in 2050.

In the NZE Scenario, global CO_2 emissions decline to around 25 Gt in 2030, a 33% reduction from 2023 levels, and to net zero in 2050. Net zero electricity sector emissions are achieved in aggregate around 2035 in advanced economies and in 2045 in emerging market and developing economies. Advanced economies achieve net zero emissions in aggregate by the mid-2040s, and they collectively remove around 0.9 Gt CO_2 from the atmosphere via carbon

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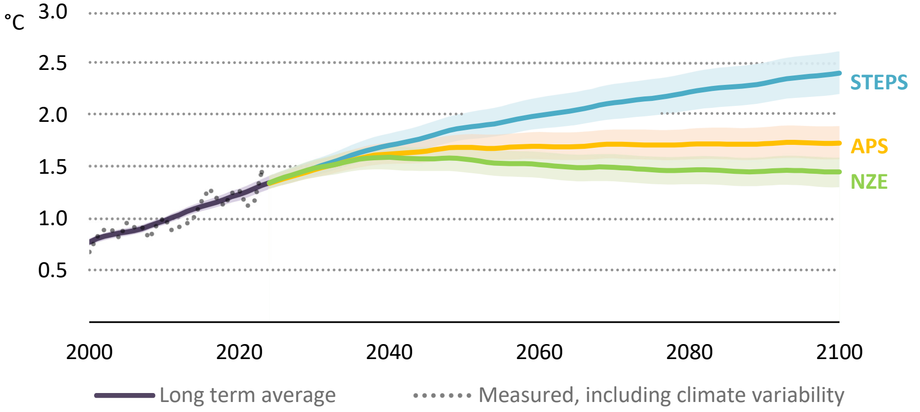
removal technologies in 2050. China reaches net zero emissions around 2050 and other emerging market and developing economies only well after 2050.

Various pathways for future CO_2 emissions lead to very different temperature outcomes (Figure 5.26). In the STEPS, the global average long-term temperature rise, which currently stands at around 1.3 °C above pre-industrial levels, exceeds 1.9 °C around 2050 and reaches 2.4 °C in 2100.[3] The lower levels of future emissions in the APS lead to a global average surface temperature rise of around 1.7 °C in 2100. The NZE Scenario sees a peak temperature rise of less than 1.6 °C around 2040 before falling back to below 1.5 °C by 2100. Because of uncertainties about the physical response of the climate to future emissions and warming, higher (and lower) temperature outcomes cannot be ruled out. For example, in the STEPS there is about a one-third chance of a temperature rise above 2.6 °C in 2100, and in the NZE Scenario there is about one-third chance of the temperature rise remaining above 1.6 °C in 2100.

Figure 5.26 ▻ Global average temperature rise including natural variability since 2000 and long-term average temperature rise by scenario



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In the STEPS, the temperature rise reaches 2.4 °C in 2100; in the APS it reaches 1.7 °C, and in the NZE scenario it peaks below 1.6 °C and then falls to below 1.5 °C in 2100

Notes: Solid line is median warming; shaded area is 33-67% confidence interval. Temperature rise above pre-industrial levels is the combined land and marine near-surface annual temperature anomaly compared with the 1850-1900 average; average of HadCRUT5, Berkeley Earth and National Oceanic and Atmospheric Administration data.

Sources: IEA analysis based on Climate Resource and MAGICC 7.5.3, University of East Anglia and Met Office (n.d.); Berkeley Earth (2024) and NOAA (2024).

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[3] Temperature rises here are median estimates, meaning there is a 50% chance of remaining below the stated level. All changes in temperatures are relative to 1850-1900 and match the Intergovernmental Panel on Climate Change Sixth Assessment Report (IPCC AR6) definition of warming of 0.85 °C between 1995-2014 (IPCC, 2023).

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These levels of warming refer to the long-term average temperature rise. Short-term climate variability arising from natural cycles – such as the El Niño Southern Oscillation – can raise or lower global temperatures by up to 0.2 °C and so the temperature rise in any given month or year can be higher or lower than the long-term average trend. Several estimates of the global average temperature rise during the 12-month period from July 2023 to June 2024 exceed 1.5 °C. However, the temperature goals of the Paris Agreement are generally interpreted as long-term warming levels.[4] Even if the global temperature exceeds 1.5 °C for a short period, the temperature can fall back from that level in the long term. Every tenth of a degree matters, and countries around the world need to bring emissions down to net zero as soon as possible to avoid the worst impacts of climate change (Box 5.4).

Box 5.4 ⊳ Impacts of climate change on energy demand and supply

Climate change is already having pronounced impacts. For the energy sector, these include reducing the effective capacity of power plants, increasing transmission losses, increasing energy demand for cooling and decreasing energy demand for heating. Extreme weather events, which are becoming more frequent because of climate change, also have major implications for energy use. In 2023, for example, around 800 terawatt-hours (TWh) of electricity was used for cooling during extreme heat events, up from less than 300 TWh in the 1990s.

The total cost of meeting cooling demand during extreme heat events has risen from just over USD 10 billion each year in the 1990s to nearly USD 30 billion a year in the last decade (Figure 5.27). Just over one-quarter of this increase stems from the increasing number of extreme heat events experienced around the world, while the rest is attributable to the increasing uptake and use of air conditioning. The figures cover only energy costs and so do not reflect all the costs incurred by electricity grids to expand generation and deliver power. Globally, decreased demand for heating has offset some of the increased demand for cooling, but meeting the rise in cooling demand during peak times will likely result in higher system costs in the future.

Hydropower faces declining output in many parts of the world, in large part due to climate change-induced shifts in precipitation patterns, increased variabilities in runoff, and physical damage to dams caused by extreme weather events. These factors have contributed to the decrease of hydropower capacity factor from 44% in the 1990s to 41% in the 2020s (IEA, 2024f). This implies a loss of around 330 TWh of annual power generation today, which is broadly equal to the amount of generation from all new solar PV added worldwide in 2023. Compensating for the loss of generation resulting from the derating of hydropower, including pumped storage, is estimated to have cost around USD 18 billion each year over the last ten years.

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[4] The IPCC AR6 bases the long-term temperature rise on the midpoint of a twenty-year period (IPCC, 2023).

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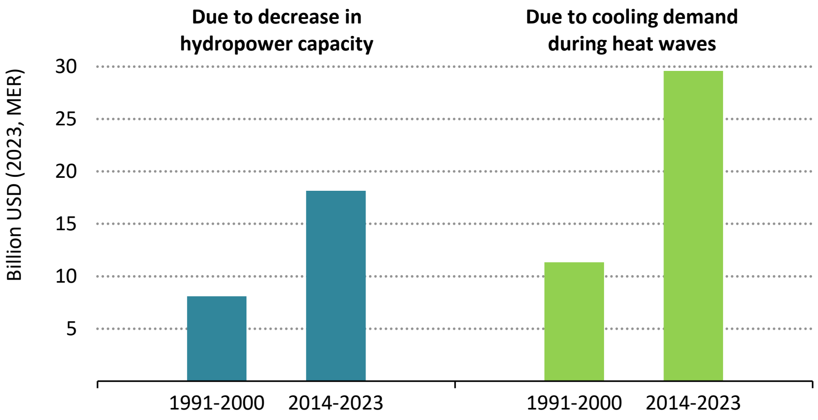
Figure 5.27 ▷ Annual costs of climate impacts to hydropower capacity and increased cooling demand



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Annual climate-related costs from lower hydropower output and higher cooling demand have already risen by around USD 30 billion since the1990s

These costs underestimate the full costs caused by climate change to electricity systems. Extreme weather events such as heat waves, floods, droughts and storms have led to damage to all types of energy infrastructure and to power outages and disruption of energy supply chains, causing temporary price surges and lost economic output. Costs are expected to rise, especially in scenarios with higher temperature outcomes.

5.4.2 Methane abatement

Methane is responsible for around 30% of the long-term rise in global temperature, and rapid and sustained reductions in methane emissions are essential to reduce near-term global warming. The fossil fuel sector is responsible for nearly 120 million tonnes (Mt) of methane emissions each year, or around one-third of total methane emissions from human activities, and there is scope for immediate and low-cost reductions. The IEA estimates that around two-thirds of methane emissions from fossil fuels could be avoided through the deployment of known and readily available technologies, often at low – or even negative – cost, and an emissions price of USD 20/tonne CO_2-equivalent would be enough to make it cost effective to deploy nearly all measures to abate fossil fuel methane emissions.

There is mounting momentum for action on methane. Some 157 countries, which together are responsible for around half of global human-caused methane emissions, have signed the Global Methane Pledge, committing them to a collective effort to reduce global methane emissions by at least 30% from 2020 levels by 2030. A group of 54 oil and gas companies have joined the Oil and Gas Decarbonisation Charter, an industry initiative committed to

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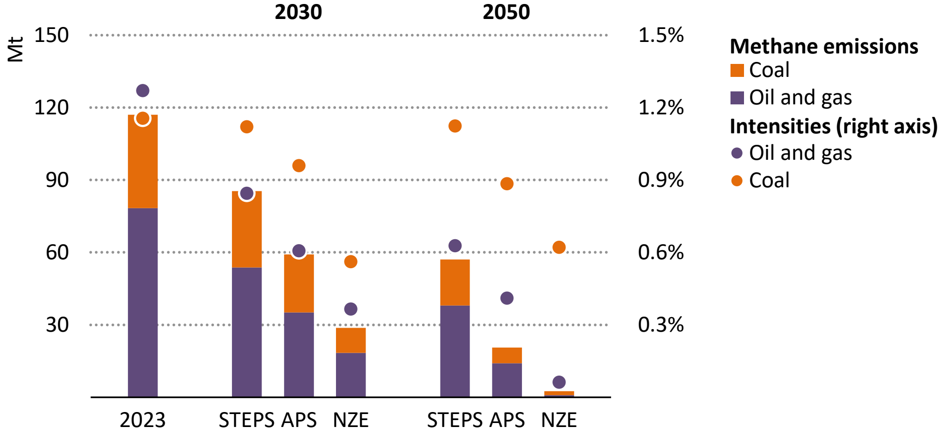
reducing upstream methane emissions to near zero by 2030. We estimate that achieving all methane pledges made by countries and companies would cut emissions from fossil fuels by 50% by 2030. However, many pledges are not backed by detailed implementation plans, and several major emitters have not committed to act on methane, including Russia and India.

Methane emissions from fossil fuel operations fall in each scenario from 2023 to 2030. In the STEPS, they decline by around 25%, in the APS by 50%, and in the NZE Scenario by 75%. In the STEPS, reductions take place where cost-effective abatement options exist or where policy requirements are in place, for example, in the United States and the European Union. In the APS, pledges to tackle methane, including through the Global Methane Pledge, other climate commitments, and company efforts to deliver near zero methane emissions targets are assumed to be achieved in full. As a result, methane emissions from oil and gas drop 55% by 2030 and emissions from coal drop almost 40% by then. In the NZE Scenario, all fossil fuel producers reduce their methane emission intensities by 2030 to the levels being achieved today by the world's best operators: the methane emissions intensity of oil and gas operations falls from 1.3% today to less than 0.1% in 2050 and the intensity of coal operations falls from 1.2% today to 0.6% (Figure 5.28).

Figure 5.28 ▹ Methane emissions from fossil fuel operations and related intensities by scenario, 2023-2050



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Today coal activities on average emit less methane than oil and gas per unit of energy, but reductions in methane intensities are fastest in the oil and gas industry in all scenarios

Notes: Mt = million tonnes; Oil and gas intensity = methane emissions from oil and gas supply chains divided by total oil and gas supply; Coal intensity = methane emissions from coal supply chain divided by coal supply. Assumes methane has an energy density of 55 megajoules per kilogramme.

New technology and tools for tracking emissions, including satellites and other remote sensing technologies, can speed up action. Their widespread use would help increase transparency on emissions and facilitate regulatory oversight. It would also provide useful

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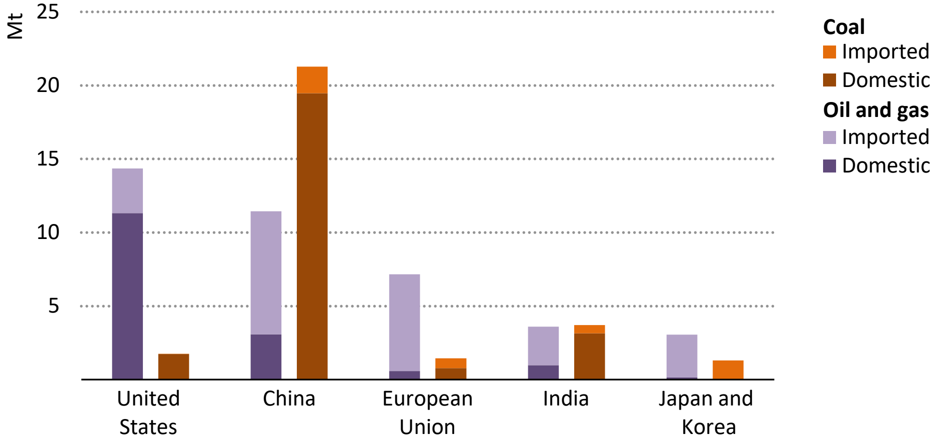
information for other interested stakeholders, including buyers and investors looking at climate credentials. Low- and middle-income countries may require technical assistance or support to identify abatement opportunities, obtain financing and develop regulations.

There is increasing interest in some countries in tackling methane emissions from fossil fuel imports (Figure 5.29). In advanced economies, methane emissions arising from the production of oil and gas that they import amount to around 15 Mt annually, which is similar to the level of emissions that occur within their borders from domestic production and local distribution. The European Union Methane Regulation, adopted in May 2024, requires natural gas, oil and coal imported into the European Union under contracts concluded after January 2027 to meet reporting requirements equivalent to those for domestic sources. It also references a methane intensity standard for new contracts as from 2030.

Figure 5.29 ⊳ Methane emissions from fossil fuel consumption in selected countries/regions, 2023



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Five regions are responsible for well over half of methane emissions from fossil fuels, and for many, the fuels they import are a larger source of emissions than domestic operations

Notes: Mt = million tonnes. Domestic emissions are from domestic fossil fuel operations that satisfy consumption within that country or region.

Harmonised measurement, monitoring, reporting and verification standards can bolster efforts to reduce emissions while also supporting energy security by increasing the amount of natural gas captured during production and subsequently made available for sale. There are many examples of current initiatives, including: the United Nations Environment Programme Oil and Gas Methane Partnership 2.0 (UNEP, 2024); the Coalition for LNG Emission Abatement toward Net Zero (JOGMEC, 2023); and the Measurement Monitoring Reporting and Verification Framework being led by the US Department of Energy and the European Commission (US DOE, 2024).

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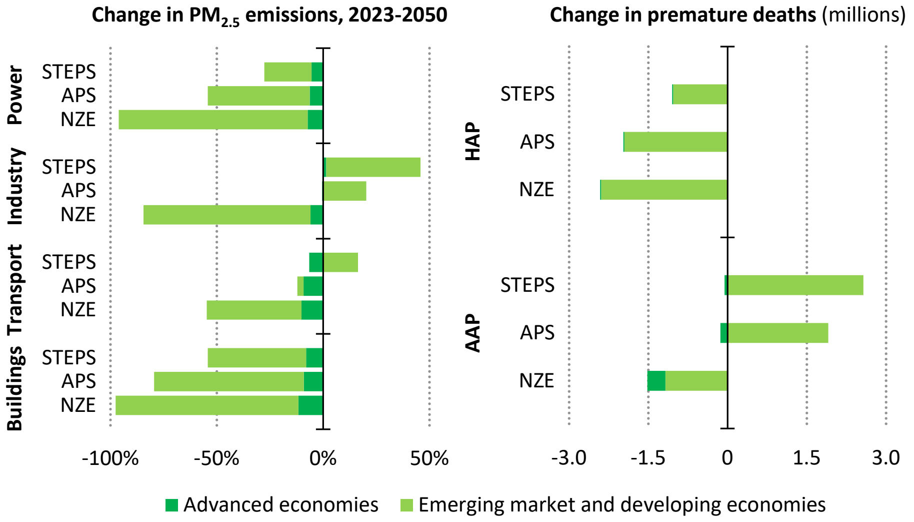
5.4.3 Air pollution and public health

Exposure to air pollution causes more than 17 000 premature deaths every day, making it deadlier than smoking or obesity.[5] In 2023 nearly 3 million people died prematurely from household air pollution, while ambient (outdoor) air pollution was responsible for more than 4.5 million deaths. The worst consequences of air pollution are felt in emerging market and developing economies: more than 99% of people exposed to heavily polluted air live in these economies, and more than 90% of premature deaths occur there.[6] The economic costs of air pollution associated with productivity losses and direct healthcare costs exceeds 10% of gross domestic product in some developing economies. Air pollution also harms ecosystems, for example by making forests less resistant to disease, and by polluting lakes and rivers via acid rain.

Figure 5.30 ▷ Change in $PM_{2.5}$ emissions by sector and premature deaths from ambient and household air pollution by scenario, 2023-2050



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Steep cuts in air pollution in the NZE Scenario result in around 3.5 million fewer premature deaths from polluted air in 2050 than today

Note: HAP = household air pollution; AAP = ambient air pollution; STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario; NZE = Net Zero Emissions by 2050 Scenario.

In the STEPS, total emissions of fine particulate matter ($PM_{2.5}$) air pollution are largely unchanged through to 2050, although there are significant differences by sector (Figure 5.30). There is a 55% reduction in $PM_{2.5}$ emissions from the buildings sector to 2050

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[5] Premature deaths in this section are from exposure to fine particulate matter ($PM_{2.5}$) air pollution.

[6] Heavily polluted air corresponds to having a $PM_{2.5}$ density greater than 35 microgrammes per cubic metre, in accordance with the World Health Organisation Interim Target 1 (WHO, 2021).

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as a result of increased use of clean cooking fuels and reduced reliance on solid biomass for heating, but this is in part offset by more industry activity and the increased use of bioenergy and waste for industrial heat, especially in emerging market and developing economies. In total, around 2.5 million more people die annually from ambient air pollution in 2050 than today. Annual premature deaths from household air pollution drop by almost 40% to 2050, with large reductions in some parts of the world – in China these deaths are all but eliminated by 2050 – but there are increases elsewhere, including in Africa, as a result of population growth and a failure to achieve universal access to modern energy services. In total, household and ambient air pollution causes around 190 million premature deaths to 2050 in the STEPS, just under 95% of which are in emerging market and developing economies.

In the APS, there is a 30% reduction in $PM_{2.5}$ emissions between 2023 and 2050, mainly from a reduction in the use of biomass and waste for cooking and from a reduction in coal use in electricity generation and oil use in road transport. Nonetheless, population growth and urbanisation mean that there is still a 40% increase in annual premature deaths from ambient air pollution between 2023 and 2050. Annual premature deaths from household air pollution decline by 70% to 2050, mainly as a result of pledges on clean cooking access in sub-Saharan Africa. In total, around 160 million people die prematurely from air pollution between 2023 and 2050 in the APS.

In the NZE Scenario, the number of people exposed to high concentrations of $PM_{2.5}$ emissions declines dramatically from current levels. Emissions from electricity generation are almost entirely eliminated by 2050 as fossil fuel use declines, emissions from transport are cut by 85% to 2050 as EVs rapidly gain ground, and emissions from industry are cut by 75% as input fuels become cleaner. This results in around 1.5 million fewer premature deaths from ambient air pollution in 2050 than in 2023. Achieving universal access to clean cooking by 2030 cuts exposure to household air pollution, resulting in around 2.4 million fewer premature deaths in 2050. In total, around 110 million fewer people die prematurely from air pollution between 2023 and 2050 in the NZE Scenario than in the STEPS, and around 80 million fewer than in the APS.

5.5 Investment and finance

5.5.1 Energy investment

Global energy investment is expected to surpass USD 3 trillion for the first time in 2024. About USD 2 trillion is set to be spent on clean energy technologies and infrastructure and USD 1 trillion on fossil fuel supply and power generation. This picture is markedly different from ten years ago: total energy investment was then around USD 2.8 trillion, with about 60% spent on fossil fuels and only 40% on clean energy. Since 2015, investment in fossil fuels has declined by more than 30% while spending on clean energy increased by almost 70%.

Around USD 860 billion is set to be invested in oil and gas supply in 2024, which is about 20% more than what is invested in 2035 in the STEPS. Around USD 165 billion is set to be spent on coal in 2024, which is more than twice the level seen in the STEPS in 2035. In the APS,

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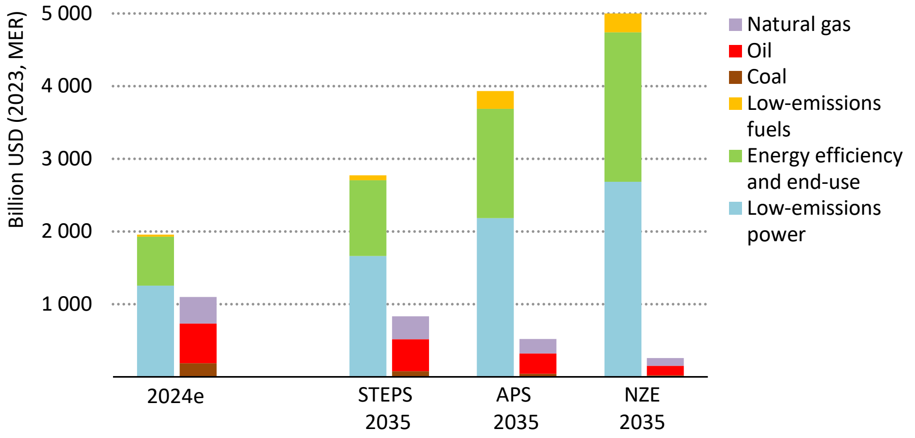
investment in existing and some new oil and gas fields is necessary, but there is no need in aggregate for new exploration. In the NZE Scenario, declines in demand are sufficiently steep that no new long lead-time conventional oil and gas projects are required, and no new coal mines or coal mine lifetime extensions are needed either. As a result, fossil fuel investment in the NZE Scenario falls by more than 75% to 2035.

Clean energy investment increases in each scenario. In the STEPS, more than 75% of total energy investment of USD 3.5 trillion is directed towards clean energy by 2035; in the APS, clean energy comprises close to 90% of USD 4.5 trillion of energy investment by 2035; in the NZE Scenario, clean energy accounts for more than 95% of investment totalling USD 5.2 trillion (Figure 5.31). Investment in low-emissions power generation and grid infrastructure rises rapidly in the next few years, and the transport sector attracts more end-use investment than any other sector by 2035 in all scenarios, driven by the adoption of EVs and the necessary investment in support infrastructure.

Figure 5.31 ⊳ Annual energy sector investment by sector and scenario, 2024 and 2035



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For every USD 1 invested in fossil fuels today, around USD 2 is invested in clean energy. By 2035, this rises to USD 3 in the STEPS in 2035, USD 7 in the APS, and USD 20 in the NZE Scenario.

Note: MER = market exchange rate; 2024e = estimated value for 2024.

Nearly 85% of total clean energy investment in 2024 takes place in advanced economies and China even though they are home to only 35% of the world's population. The high cost of capital remains a major barrier to investing in clean energy projects and infrastructure in many emerging market and developing economies. Financing costs for a typical utility-scale solar PV project are at least twice as high in emerging market and developing economies as in advanced economies and in China. This mainly reflects weak macroeconomic conditions and country-specific circumstances in many emerging market and developing countries, but

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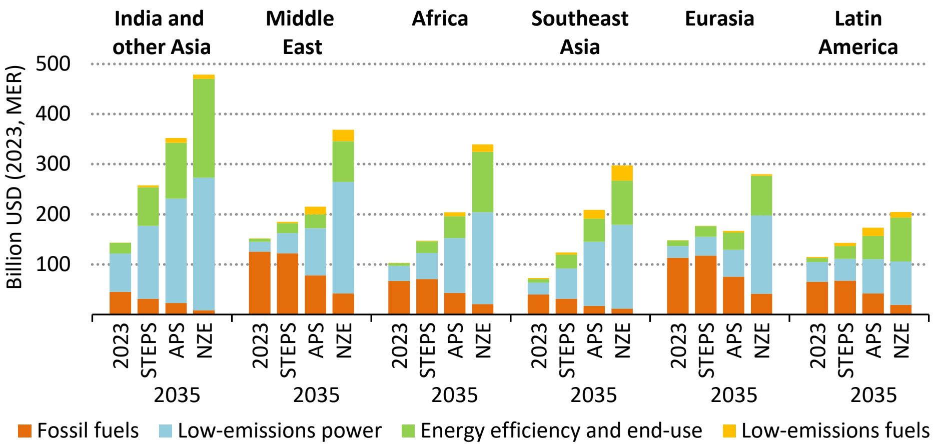
the lack of available local currency domestic lending pools and the high cost of currency de-risking tools are also factors.

Advanced economies and China increase their clean energy investment by more than 30% to 2035 in the STEPS, by 60-80% in the APS and by 70-100% in the NZE Scenario. Clean energy investment in other emerging market and developing economies doubles in the STEPS, triples in the APS and rises by a factor of six in the NZE Scenario over this period (Figure 5.32). In the NZE Scenario, 40% of clean energy investment globally occurs in these regions in 2035, up from 15% today.

Figure 5.32 ▻ Annual energy sector investment in selected emerging market and developing economies by scenario, 2023 and 2035



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Most investment in emerging market and developing economies is still devoted to fossil fuels and the high cost of capital remains a major barrier to investing in clean energy

Investment in the power sector

Global investment in the power sector is expected to reach more than USD 1.3 trillion in 2024, most of which is for low-emissions power assets such as renewables, nuclear power, grids and battery storage. Despite concerns over high interest rates and the profitability of renewables firms, this represents an increase of 8% over total low-emissions power investment in 2023. By 2035, investment in low-emissions power accounts for almost all power sector investment in the STEPS and the APS, and it rises in these scenarios to USD 1.7 trillion and USD 2.2 trillion respectively.

The level of investment is higher still in the NZE Scenario. Achieving the goal of tripling installed renewables capacity by 2030, as in this scenario, requires doubling current investment levels in renewable power, grids and battery storage to USD 2.5 trillion by 2030. This rises further to USD 2.7 trillion by 2035 as the world rapidly electrifies large parts of the

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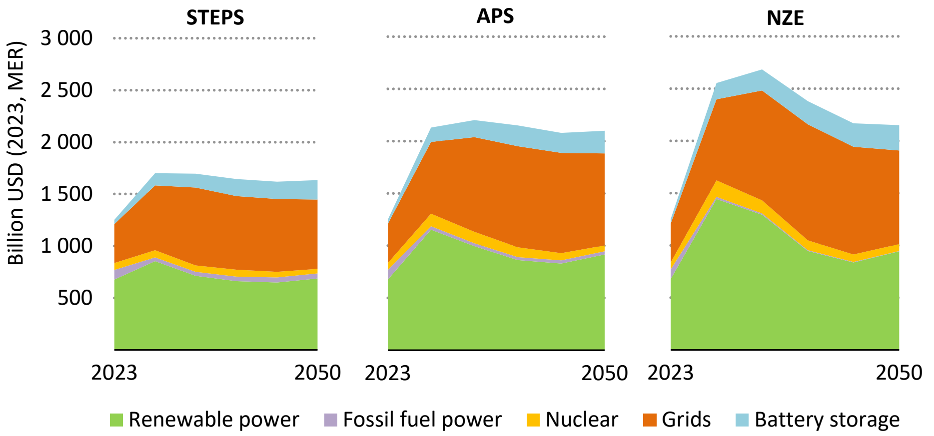
global economy to meet climate and energy access goals and as demand rises rapidly in emerging market and developing economies.

Across all scenarios, power sector investment peaks around 2035 and declines afterwards as costs for renewable power and battery storage continue to decrease and as the number of new renewable capacity installations falls slightly from the mid-2030s once power systems are fully decarbonised (Figure 5.33). The reduction is particularly pronounced in the NZE Scenario because renewable power costs decline faster than in the other scenarios in response to the strength of the initial ramp up in capacity installations in this scenario. To enable this rollout of renewable power, spending on grids and battery storage doubles from around USD 0.6 per dollar invested in 2023 to USD 1.2 per dollar invested in 2050 in all scenarios.

Figure 5.33 ▻ Power sector investment by type and scenario, 2023-2050



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Power sector investment doubles by 2035 in the NZE Scenario, driven by the need for rapid growth in renewables, grids and battery storage

The European Union Green Deal helped drive a 70% increase in spending on clean power in Europe between 2019 and 2024 and the United States Inflation Reduction Act led to a 60% rise in the United States over the same period. China has also seen a major increase in clean power investment, doubling its spending on renewable power, nuclear power, grids and batteries over the past five years. In the NZE Scenario, clean power investment increases from USD 560 billion in 2024 to more than a trillion in 2035 in advanced economies, and from USD 450 billion to USD 650 billion in China.

Today around 20% of clean power investment globally is in emerging market and developing economies other than China. In the NZE Scenario, there is a more than a fourfold increase in clean power investment in these countries, and their share of the global total rises to 40% by 2035. Lowering their cost of capital is vital to stimulate investment. This requires a combination of clear and stable regulations, political commitments, derisking instruments

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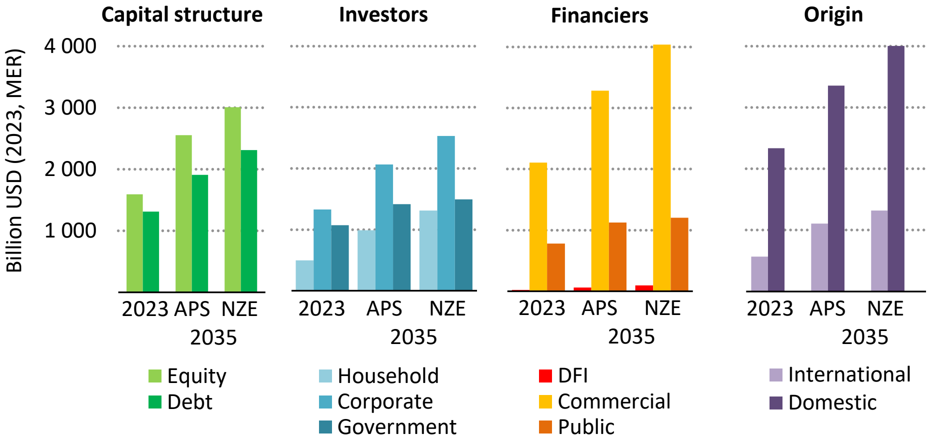
and concessional finance in order to attract more private capital. Concessional finance provided by development finance institutions (DFIs) can play a catalytic role to mobilise private investment, especially in low-income countries: it will not be sufficient on its own to increase investment to the levels in the NZE Scenario, nonetheless its role in enabling investment in emerging market and developing economies is indispensable.

Solar PV investment is set to increase to USD 450 billion in 2024, not far off the levels of investment in 2035 in the NZE Scenario. Increases in solar PV module and battery manufacturing capacity have helped to push their prices down to record lows, but the high degree of concentration of production capacity highlights some of the challenges faced by countries and companies looking to gain a foothold in the clean energy economy by supporting domestic manufacturing.

5.5.2 Sources of finance

Examining the sources of finance for energy projects helps to provide a better understanding of how they can be scaled to meet investment needs. There are significant variations between projects in terms of the capital structure of investment, the investors, the financiers and whether the investment originates from domestic or international sources.

Figure 5.34 ▹ Characteristics of energy sector financing in the APS and NZE Scenario, 2023 and 2035



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A major increase in financing from a wide range of sources is projected in both scenarios

Note: DFI = development finance institutions.

Capital structure: Around 45% of current energy investment is financed via debt (Figure 5.34). Debt financing plays a large part in clean power generation and grid investment projects. Many new generation projects are backed by long-term power purchase agreements, and, in the case of grids, by regulated tariffs. These provide for more predictable

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revenues, making debt financing easier to access. In contrast, a large share of investment in industry today is financed via equity, often through household savings, and many oil and gas developments are financed through retained earnings.

The amount of energy investment financed via debt remains around 45% to 2035 in all scenarios. Debt financing increases as clean energy generation and grid investment increases, while equity financing increases with growth in end-use sector investment such as residential solar panels, home energy storage systems, EVs and energy-efficient appliances. There is an increasing use of off-balance sheet project finance structures for renewables developments in all scenarios: these help spread risk and attract more investors because they do not directly impact the balance sheets of the companies involved.

Investors in energy include corporations, households and governments. Corporations provide around half of energy financing today because they are investing heavily in renewable energy projects. Commercial financiers are also significantly increasing their capital allocations to the clean energy sector. In the APS and the NZE Scenario in 2035, corporate investment as a share of the total remains broadly constant, but in absolute terms it increases by 50% in 2035 in the APS and by 80% in the NZE Scenario.

Households are responsible for around USD 500 billion annual energy sector investment today. Big increases in household end-use sector investment doubles this amount to 2035 in the APS and nearly triples it in the NZE Scenario. However, high upfront costs of some home energy efficiency measures are likely to remain beyond the means of low-income households, which may lead to a ramp-up in government support for those households.

Governments are responsible for around USD 1 trillion of energy sector investment today through state-owned companies and assets. By 2035, investment by governments increases by around 35% in the APS and by 40% in the NZE Scenario. This is a smaller increase than for other types of investors since government investment and public financing is assumed to be constrained by high levels of indebtedness.

Financiers of energy investment include public bodies, commercial organisations and development finance institutions. DFI financing represents a relatively small share of overall financing today, but it plays a crucial role in financing projects that would otherwise be too risky for private investors, particularly in emerging market and developing economies. DFI financing increases 5.5-times in the APS to 2035 and by a factor of eight in the NZE Scenario.

Around 80% of energy investment today has a domestic origin component and around 20% comes from international sources. Many emerging market and developing economies are financially constrained, and the sharp increases in needed clean energy investment requires a large increase in support from international investors and institutions. International financing more than doubles from current levels over the next ten years in the APS and it triples in the NZE Scenario. The share of international financing in the overall energy sector investment rises to 25% in the NZE Scenario in 2035.

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Chapter 6

Regional insights

Many roads to follow

SUMMARY

- Behind global aggregates lie distinctive regional trends. The regions and countries considered here – which account for 90% of global GDP, population and energy demand – have diverse starting points, priorities and ambitions. They also have varying trajectories for energy and emissions which are informed by their different socio-economic circumstances, policies, regulations and more.
- This chapter shines a light on the outlook for these regions and countries. It covers energy supply chains as well as energy itself. Securing positions in the new clean energy economy is increasingly important for many policy makers, as underscored by the European Union's Net-Zero Industry Act and India's Production Linked Incentives programme, both of which incentivise cleantech manufacturing.
- Two scenarios are used to explore these regional outlooks: the Stated Policies Scenario (STEPS), which is based on current policy settings and market conditions, and the Announced Pledges Scenario (APS), which incorporates regional and national energy and climate targets and assumes they are met in full and on time.
- Comparing key metrics across regions highlights important differences. For example, car ownership is twice as high in the European Union as it is in Eurasia, but the latter has twice the per capita CO_2 emissions of the former. Countries are at different stages of economic and energy development and have different resource endowments. This shapes their policy priorities and the way they approach clean energy transitions.
- The chapter also looks at topical issues for each region or country that it covers. These include the prospects for electricity demand growth in the United States and China, and the mix of fuels and technologies that can meet it; the role of biofuels and low-emissions hydrogen in Latin America; how clean energy transitions can bring down the European Union's electricity costs; the potential for critical minerals in Africa; opportunities to accelerate clean energy deployment in the Middle East and to modernise the gas sector in the Caspian region; the role of two/three-wheelers and buses in India's transport policies; the importance of innovative technologies for power sector transformation in Japan and Korea; and how to tackle emissions from coal-fired power plants in Southeast Asia.
- Across all regions, the energy mix is being reshaped by accelerating deployment of clean energy technologies, notably in the power sector. Although regional circumstances vary, there is a widespread need for enhanced action to speed up the adoption of clean energy technologies by key energy-intensive industrial sectors which face the challenge of decarbonising while simultaneously maintaining competitiveness. International co-operation has a key role to play in this.

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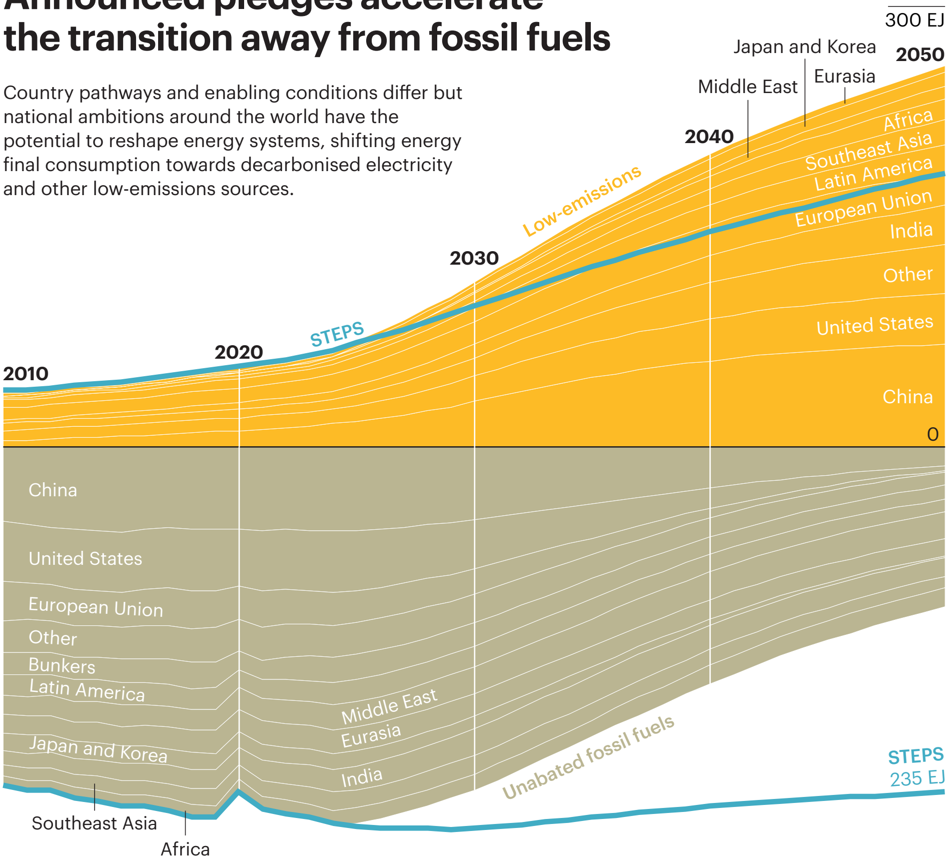
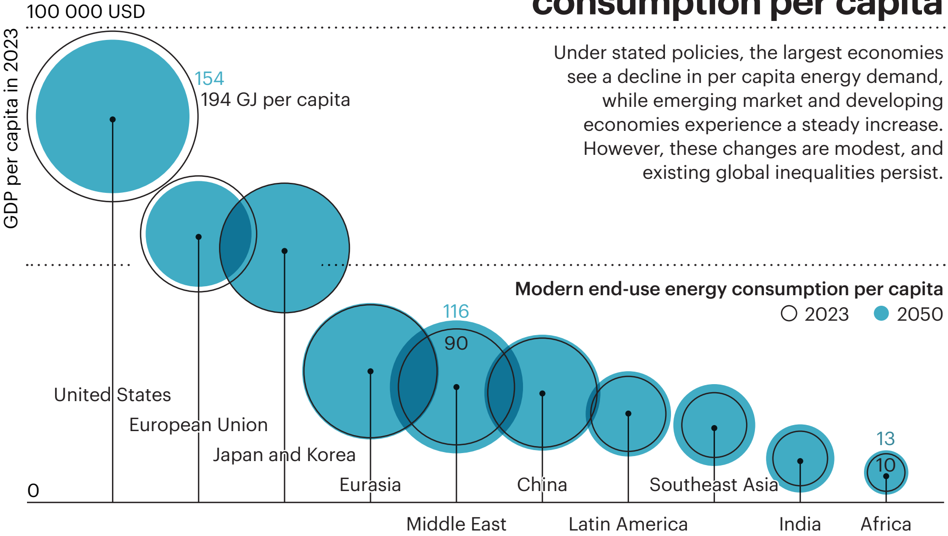
Announced pledges accelerate the transition away from fossil fuels

Country pathways and enabling conditions differ but national ambitions around the world have the potential to reshape energy systems, shifting energy final consumption towards decarbonised electricity and other low-emissions sources.



GDP and modern energy consumption per capita

Under stated policies, the largest economies see a decline in per capita energy demand, while emerging market and developing economies experience a steady increase. However, these changes are modest, and existing global inequalities persist.



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Introduction

This chapter examines selected regions and countries that collectively account for nearly 90% of the world's gross domestic product (GDP), population and energy demand (Table 6.1). It highlights the specific issues and dynamics that affect them, taking account of their different circumstances and ambitions, and starting from consideration of factors including population, urbanisation, per capita income, economic structure, availability of natural resources and geography. Each section includes an overview of the outlook for energy and related emissions, and also provides insights on a topical issue. The chapter includes insights from the Stated Policies Scenario (STEPS) and the Announced Pledges Scenario (APS); in almost all cases, a further acceleration in the pace of change at country or regional level would be needed to align with Net Zero Emissions by 2050 (NZE) Scenario.

Table 6.1 ⊳ Key economic and energy indicators by country/region, 2023

	Population (million)	**Energy demand** (EJ)	**Electricity demand** (kWh per capita)	**Cars per thousand people**	**CO_2 emissions** (Gt)	**CO_2 emissions** (t per capita)
United States	338	92	11 957	680	4.6	13
Latin America and the Caribbean	663	37	2 225	163	1.6	2
European Union	449	53	5 298	516	2.4	5
Africa	1 458	34	500	27	1.4	1
Middle East	269	36	4 190	137	2.2	7
Eurasia	240	43	5 036	228	2.4	10
China	1 419	170	6 060	202	12.6	8
India	1 429	45	1 057	35	2.9	2
Japan and Korea	176	28	8 428	480	1.6	9
Southeast Asia	685	33	1 758	75	1.9	3

Note: EJ = exajoules; kWh = kilowatt-hours; Gt = gigatonnes; t = tonnes.

General notes related to key energy and emissions trends

Each section in this chapter starts with figures to illustrate key metrics including energy supply, fossil fuel demand, vehicle sales, industrial energy use, energy intensity relative to GDP, investment and carbon dioxide (CO_2) emissions. Economic data are presented in real terms in year-2023 US dollars (USD), with power purchasing parity (PPP) rates used in relation to GDP and market exchange rates (MER) for investment. CO_2 emissions refer to net carbon dioxide emissions related to the energy and industry sectors. Common units used in the figures include: Gt CO_2 = gigatonnes of carbon dioxide; GWh = gigawatt-hours; MWh = megawatt-hours; TWh = terawatt-hours; GW = gigawatts; EJ = exajoules; mb/d = million barrels per day; kb/d = thousand barrels per day; Mt = million tonnes; Mtce = million tonnes of coal equivalent; bcm = billion cubic metres; PV = solar photovoltaics; t = tonne.

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6.1 United States

Population
Million people

2023	2050
338	373

GDP
Trillion USD
(2023, PPP)

2023	2050
27.5	46.1

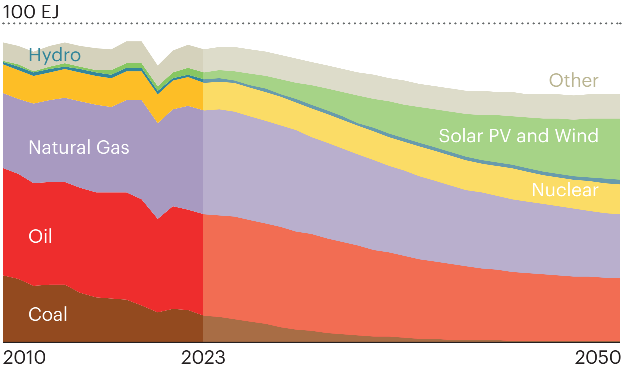
2050
Net zero emissions target year

100%
Low-emissions electricity target by 2035

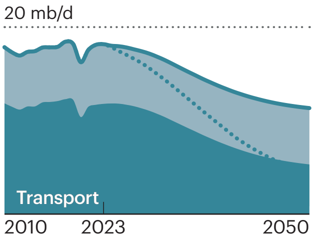
540 **Billion USD**
Support for energy security, clean energy and mass transit under the Inflation Reduction Act and Bipartisan Infrastructure Investment and Jobs Act

50-52%
GHG reduction target by 2030 from 2005 levels under the updated Nationally Determined Contribution

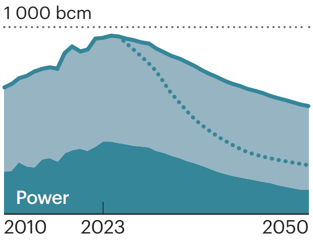
Energy demand in the Stated Policies Scenario



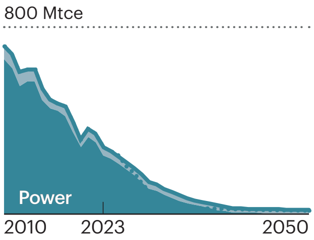
Oil demand



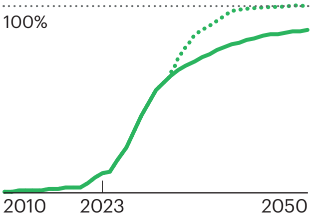
Natural gas demand



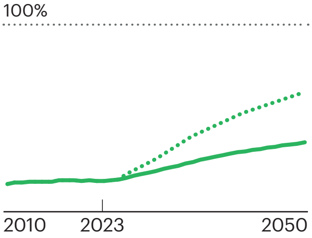
Coal demand



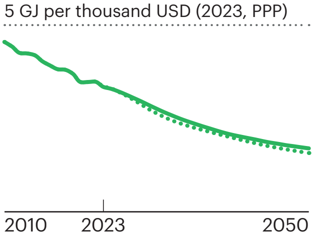
Zero-emissions vehicles in car sales



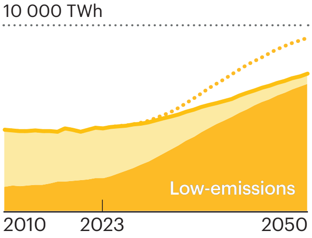
Low-emissions energy in industry



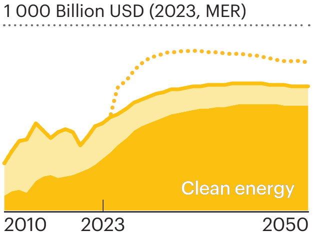
Energy intensity of GDP



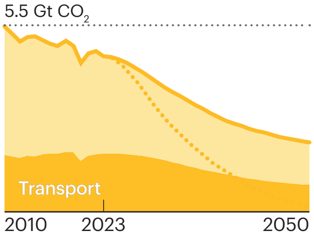
Electricity generation



Investment



CO_2 emissions



— Stated Policies Scenario ••• Announced Pledges Scenario

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The US economy grew by 2.5% in 2023 and is expected to continue expanding at an average rate of 2.1% per year through to 2035. Inflation, which spiked in 2022, almost halved in 2023 and further declined in the first months of 2024. Recent industrial policies, most importantly the Infrastructure Investment and Jobs Act of 2021 and the Inflation Reduction Act of 2022 (IRA), have spurred a rapid increase in clean energy investment and manufacturing. In addition, the US Environmental Protection Agency issued new rules that raise standards for fossil fuel-fired power plants and introduce multi-pollutant emissions standards for vehicles, though these may face legal challenges.

Energy demand in the United States reached a high point in 2007 and is on a declining trajectory to 2050 in the STEPS. This decline is driven largely by energy efficiency gains, including electrification, with the average annual rate of energy efficiency improvement rising to 2.8% over the period to 2030. Electricity demand growth accelerates, driven by electrification of transport and industry, and the rapid growth of data centres. Renewable sources of electricity, led by solar PV and wind, meet all new demand and displace a considerable amount of coal- and gas-fired power generation. Total renewables capacity more than triples from 2023 to 2035 in the STEPS, and the share of generation accounted for by renewable energy increases from 22% in 2023 to almost 60% in 2035 and 80% in 2050.

Fossil fuels see a significant reduction in demand in the STEPS to 2035 and beyond. Coal demand has been steadily declining over the past 15 years and is set to fall by 80% from 2023 to 2035 in the STEPS, leading to the closure of ageing coal-fired power plants. Efforts to limit the impact on affected communities will be essential to ensure just transitions.[1] Natural gas demand is set to peak in the near term and then gradually to decline, reflecting in large part the ramping up of renewables and battery storage in the power sector. Oil demand also peaks in the near term and then decline more rapidly from around 2030, driven largely by the uptake of electric vehicles (EVs). Reduced demand enables more natural gas and oil to be available for export. These changes mean that overall CO_2 emissions are almost one-third lower by 2035, and nearly 60% lower by 2050.

Decarbonising electricity by 2035 and achieving net zero energy-related emissions by 2050 in the APS requires faster deployment of renewables, nuclear and other low-emissions sources. In this scenario, investment in clean technologies rises from USD 280 billion in 2023 to over USD 750 billion in 2035, which is more than 40% above the level in the STEPS. Faster electrification, resulting in part from more rapid adoption of EVs, accelerates electricity demand growth. Renewables deployment accelerates, doubling power sector investment to nearly USD 400 billion in 2035 compared with USD 300 billion in the STEPS, and the deployment of nuclear power, carbon capture technologies and low-emissions hydrogen also proceeds more quickly. Total CO_2 emissions drop by one-third from present levels to 2030 and by 60% to 2035.

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[1] These efforts are driven domestically through the US Department of Energy Transitions Initiative and supported internationally through the likes of the IEA Clean Energy Labour Council.

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The United States is one of the largest energy producers in the world. It produced more crude oil in 2023 than any country before has ever done in one year, having increased its output by nearly 80% over the past decade. It was also the largest natural gas producer in the world in 2023, producing two-thirds more than Russia and four-times as much as Iran. Its liquefied natural gas (LNG) exports are set to play an expanding role in international natural gas markets in the coming years. It is a large coal producer, though production is set to decline in step with demand. The United States is increasingly engaged in manufacturing clean energy technologies, including solar cells, wind turbines, electrolysers and heat pumps. Announced plans for domestic battery production would be enough to meet all projected domestic needs by 2030.

Electricity demand in the United States is returning to strong growth, and renewable generation is set to increase even more quickly

Electricity demand in the United States increased by just 4.4% from 2011 to 2023, but it rises by 25% from 2023 to 2035 in the STEPS, up by nearly 1 000 TWh (Figure 6.1). The uptake of EVs accounts for nearly 60% of electricity demand growth to 2035. Industry is the next largest driver of demand growth, with the use of electricity expanding in many sub-sectors. Despite efficiency gains, use of electricity in buildings also rises, some of which reflects rapidly expanding demand for data centres. While there is some uncertainty about the rate of growth for data centres linked to artificial intelligence (see Chapter 4), we currently project that the potential impact on overall US electricity demand growth by 2035 is modest relative to other sectors, with a set of low-emissions options available to meet this demand.

Electric car sales in the United States increase from 1.4 million in 2023 to close to 11 million in 2035 in the STEPS, raising their share of total new passenger car sales from 10% today to around 70%. In 2023, price cuts for key EV models halved the average price difference between EVs and conventional cars, and the increase in demand to 2035 is supported by further projected declines in EV costs. Policy support is also poised to boost uptake, notably through the following: USD 5 billion in federal funding for EV chargers along highways; USD 2.5 billion for charging and other alternative fuelling infrastructure, including hydrogen, in urban and rural areas and alternative fuel corridors; and USD 5 billion for zero emissions buses. There is uncertainty about the pace of EV uptake; if EV sales in 2030 are around 2 million lower than in the STEPS, this would raise US oil consumption by around 600 kb/d and CO_2 emissions by over 70 Mt CO_2 (see Chapter 4).

Renewables are set to far outpace electricity demand growth. In the STEPS, they expand by nearly 2 200 TWh to 2035, more than triple the level in 2023. This raises their share of electricity generation from 22% to 58%, reflecting the availability of high-quality renewable resources, the existence of established markets with low technology costs and strong policy support at both federal and state levels. Solar PV sees the biggest expansion by 2035 – solar output increases by more than electricity demand growth on its own – and wind output also doubles. As a result, the share of wind and solar PV in electricity generation rises from 15% in 2023 to 50% in 2035. Other renewables and nuclear power also increase slightly over the

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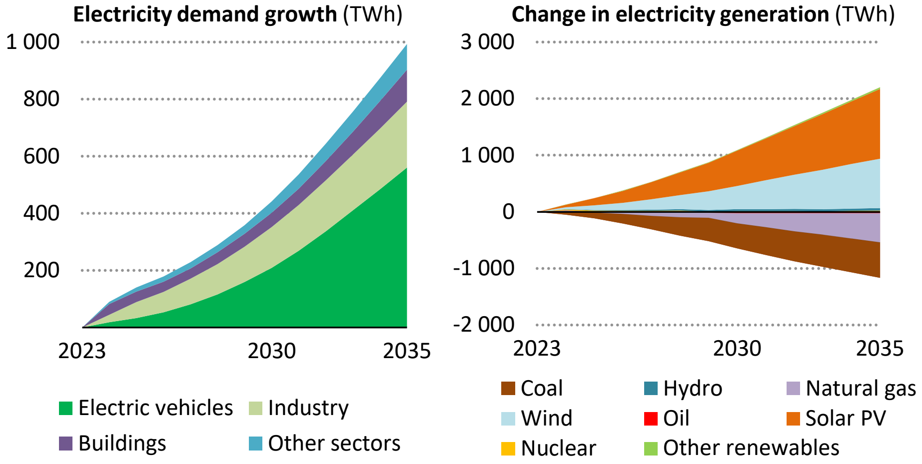
period. In the APS, renewables increase more than fourfold from 2023 to 2035 to fulfil the ambitious target of fully or predominantly decarbonised electricity by 2035, raising the share of renewables to nearly 75%.

Figure 6.1 ⊳ Electricity demand growth and changes in electricity generation in the United States in the STEPS, 2023-2035



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US electricity demand is set to rise by 25% to 2035, a step up from recent trends, with new solar PV and wind able to meet all new demand and reduce the need for fossil fuels

Electricity generation from fossil fuels declines in the STEPS by about 40% from the current level to below 1 500 TWh by 2035. Coal-fired generation continues to decline: in 2023, it was two-thirds below the peak level seen in 2005, and by 2035 it is 95% below that level. Natural gas-fired generation is projected to peak in the near term, after more than three decades of growth: it falls by 30% from 2023 to 2035, though capacity declines by just 10% because many gas-fired plants remain in place to support electricity system reliability. To 2035, the blending of low-emissions hydrogen in gas-fired power plants also makes inroads in the APS.

To ensure electricity security throughout clean energy transitions, short-term flexibility in power systems increases four-times faster than electricity demand in the STEPS from 2023 to 2035, though seasonal flexibility needs grow in step with demand growth. Natural gas and hydro dispatchable power plants remain primary providers of flexibility: coal contributes too but diminishes rapidly. New sources of flexibility emerge, led by battery storage and demand-response measures. Battery storage complements solar PV very effectively, and its costs are falling: behind-the-meter and utility-scale applications together are projected to increase by over 300 GW to 2035 in the STEPS, a 16-fold increase over today's level, and by 2035 battery storage is second only to natural gas as a source of dispatchable capacity.

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6.2 Latin America and the Caribbean

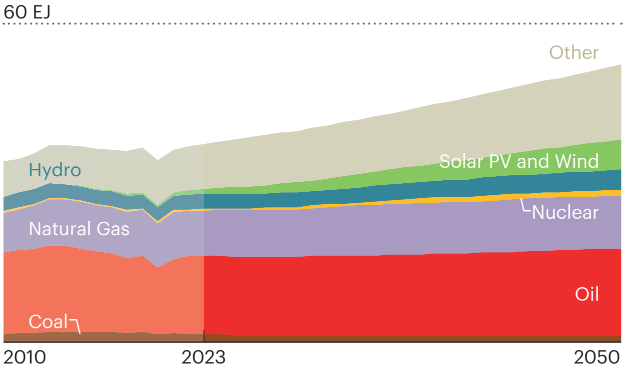
Population
Million people

2023 **663**
2050 **748**

GDP
Trillion USD (2023, PPP)

2023 **12.8**
2050 **24.0**

Energy demand in the Stated Policies Scenario



16 out of 33

Countries with a net zero target

7 Mt

Low-emissions hydrogen production from announced projects by 2030

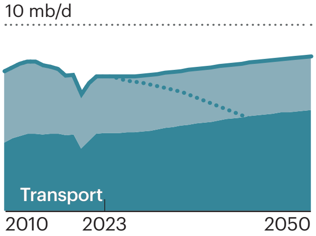
>30%

Biofuel share in the transport energy mix in Brazil by 2033, compared to 21% today according to the New Industry Brazil policy

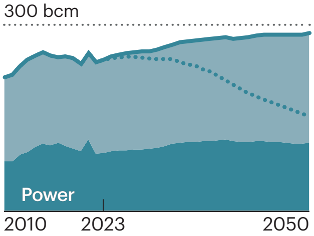
42%

Colombia's GHG reduction target by 2030 from 2020 levels under the updated Nationally Determined Contribution

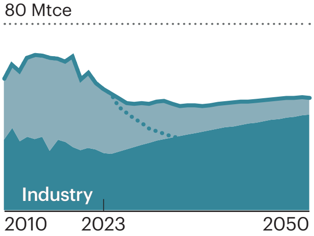
Oil demand



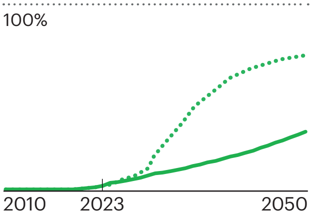
Natural gas demand



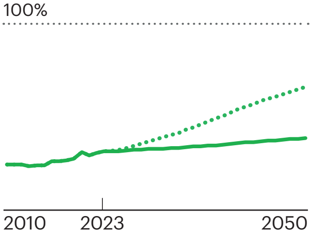
Coal demand



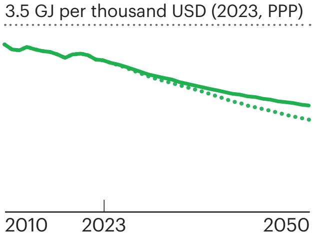
Zero-emissions vehicles in car sales



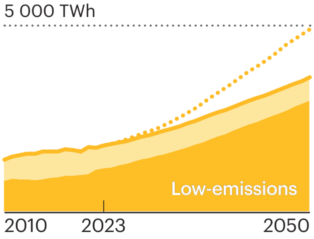
Low-emissions energy in industry



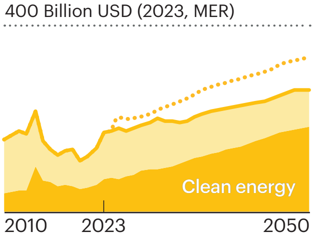
Energy intensity of GDP



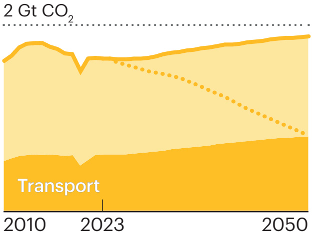
Electricity generation



Investment



CO_2 emissions



— Stated Policies Scenario ••• Announced Pledges Scenario

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The Latin America and the Caribbean region (LAC) has substantial clean energy potential and making the most of this could help to bolster its economy and its energy security. The LAC energy sector already has one of the lowest CO_2 emissions intensities worldwide, underpinned by significant hydroelectric power, a relatively small share of energy-intensive industries, and the use of biofuels for transport. Prolonged drought and record temperatures in 2024 are straining electricity supply across the region as hydroelectric generation falters, leading to blackouts and forced power cuts in several countries. Boosting solar PV and wind generation could help avoid future disruptions, reducing the region's vulnerability to extreme weather conditions and the need for fossil fuel imports.

Investment in clean energy is increasing, yet it needs to ramp up further to meet the energy and climate goals set by LAC countries. In a record year for renewables in 2023, 27 GW of solar PV and wind capacity were added, led by installations in Brazil (20 GW). In the STEPS, current LAC renewable trends imply that installed capacity of wind and solar PV increases nearly three-times by 2035 relative to 2023 levels. In the APS, net zero emissions pledges help expand installed renewables capacity more than four-times.

Fossil fuels continue to play an important role in LAC energy systems. Oil accounts for 60% of current fossil fuel demand in the region, natural gas for 34% and coal for 6%. In the STEPS, fossil fuel use grows 5% by 2035, mainly due to increased demand from transport and industry. Several LAC countries are significant fossil fuel producers: Brazil was the third-largest contributor to the increase in global oil supply in 2023. Guyana was also in the top-ten. Argentina plans to become a net natural gas exporter in the near term.

LAC is well-positioned to electrify both the transport and industry sectors, thanks to the region’s low-emissions power systems and significant potential to expand renewables. In the APS, the deployment of biofuels accelerates, as does electrification: 18% of vehicles on LAC roads are electric by 2035, around ten percentage points more than in the STEPS. There is support for this: several large EV manufacturers plan to produce in LAC, and the 2024 MOVER programme in Brazil looks to provide over USD 3 billion in subsidies to EV manufacturers (Government of Brazil, 2024). In industry, increasing use of electricity, mostly for low- and medium-temperature processes, lifts the share of electricity in energy demand by five percentage points in the APS compared with the STEPS, raising it to 31% by 2035. Together with energy efficiency improvements, especially for air conditioning and appliances in buildings, renewables and electrification play a central role in helping fossil fuel demand peak around 2025 in the APS.

LAC is in a good position to meet its energy needs and reap economic benefits as clean energy transitions advance. Today the region produces about a quarter of global liquid biofuels; leveraging bioenergy could also support low-emissions hydrogen production. The LAC region is endowed with rich mineral resources with over one-third of global silver, copper and lithium reserves. Global mineral demand for clean energy technologies is set to double by 2030 in the STEPS and APS. Expanding clean energy value chains would strengthen employment opportunities and could contribute to sustainable growth, for example by processing the minerals in the region and using low-emissions hydrogen to produce fertilisers or iron.

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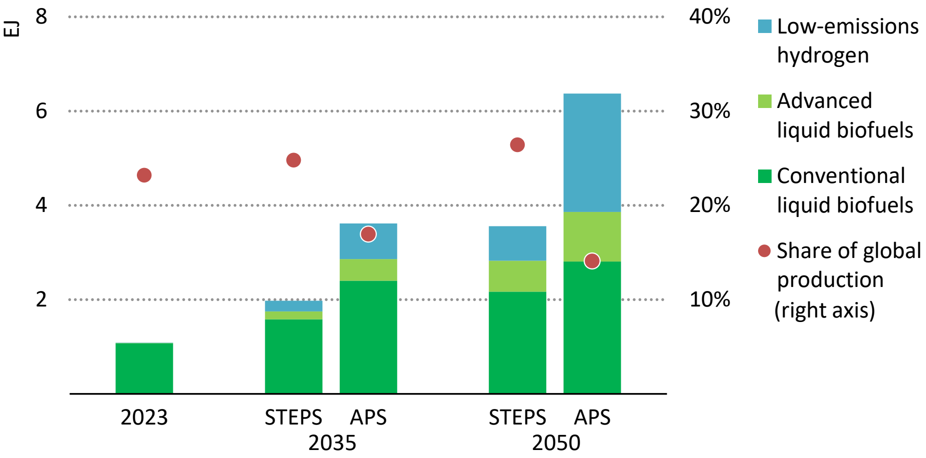
Expanding role of bioenergy and low-emissions hydrogen

Bioenergy and low-emissions hydrogen are important for energy transitions because they can substitute fossil fuels in some hard-to-abate sectors. Biofuels are a key priority for Brazil, which holds the 2024 G20 Presidency and will host the Conference of the Parties (COP) 30 in 2025.

LAC is already a leader in biofuels production. Brazil's pioneering experience developing supply and demand for ethanol dates to the 1970s. Brazil is the largest producer and consumer of liquid biofuels in the region and the second-largest producer worldwide. Argentina and Colombia are emerging as prominent suppliers.

Figure 6.2 ▷ Liquid biofuels and low-emissions hydrogen production in Latin America and the Caribbean in the STEPS and APS, 2023-2050



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Production of biofuels and low-emissions hydrogen more than triples to 2050 in the STEPS and increases nearly sixfold in the APS

Biofuels production in LAC today is dominated by conventional ethanol and biodiesel for use in road transport (Figure 6.2). Biofuels are poised to become a key resource for decarbonising hard-to-abate sectors around the world, offering an opportunity to build on the region's biofuels production experience. In aviation, for instance, global demand for biojet kerosene is increasing, and LAC could emerge as a major supplier of biojet kerosene in the next decade, providing 15% of global production in the STEPS in 2035. Beyond the production of liquid biofuels, solid bioenergy and biogases are also set to play a critical role in decarbonisation in the region, with heavy industries, notably steel and chemicals, increasing their bioenergy demand by 34% in the STEPS and 67% in the APS by 2035.

Bioenergy demand in LAC, for both liquid biofuels and solid bioenergy, rises by 20% in the STEPS and 43% in the APS by 2035. Cropland for bioenergy expands to meet this demand but

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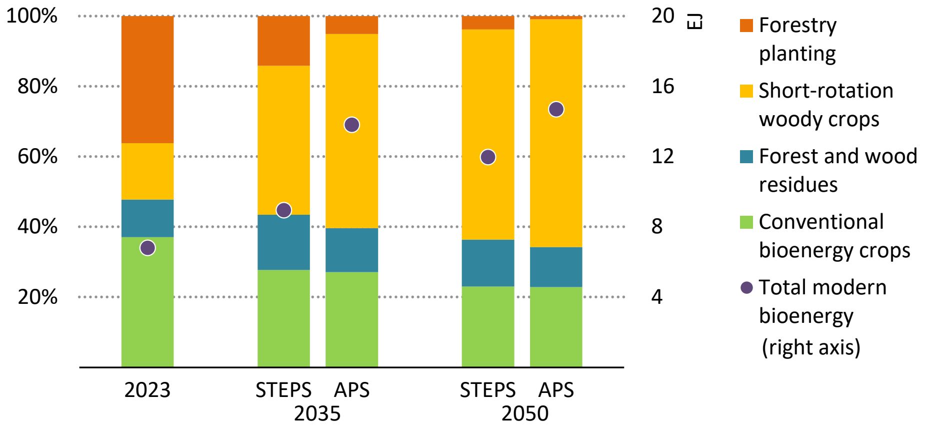
must be balanced with the pressing need to tackle deforestation and avoid greenhouse gas (GHG) emissions from land-use change. Careful planning could help meet demand for land for bioenergy, without increasing deforestation, through a focus on restoring degraded land, reducing land allocated to livestock, and prioritising short-rotation woody crops. With an energy intensity per hectare six- to eight-times higher than conventional crops, short-rotation woody crops become the dominant source of biomass being used either directly or as a feedstock for biofuels or biogas (Figure 6.3). Their share rises from around 15% of supply in 2023 to nearly 40% by 2035 in the STEPS, and about 55% in the APS.

Figure 6.3 ▷ **Modern biomass by source in Latin America and the Caribbean in the STEPS and APS, 2023-2050**



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Short-rotation woody crops support increased bioenergy production, making efficient use of land and helping to avoid deforestation

Source: International Institute for Applied Systems Analysis modelling based on IEA scenarios.

The region is also very competitive for low-emissions hydrogen production thanks to its exceptional renewable potential, for example, solar PV in the Atacama Desert in Chile, and wind in northeastern Brazil and Patagonia. To capitalise on these potentials, many countries in LAC have published hydrogen strategies, but few projects are moving to the investment stage. Opportunities for hydrogen production vary significantly between our scenarios – 2 Mt of low-emissions hydrogen are produced in 2035 in the STEPS, and over three-times that amount in the APS. The bulk of hydrogen use today is in oil refineries and ammonia production. Local hydrogen production could support the decarbonisation of those industries and reduce import dependency. In the APS, 33% of ammonia production uses electrolytic hydrogen in 2035, compared to less than 1% in the STEPS. Cheap low-emissions hydrogen could also lead to new export opportunities for goods such as near-zero emissions iron and synthetic fuels, where synergies between the hydrogen and biofuel industries could be helpful.

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6.3 European Union

	2023	2050
Population Million people	449	425
GDP Trillion USD (2023, PPP)	25.4	35.1

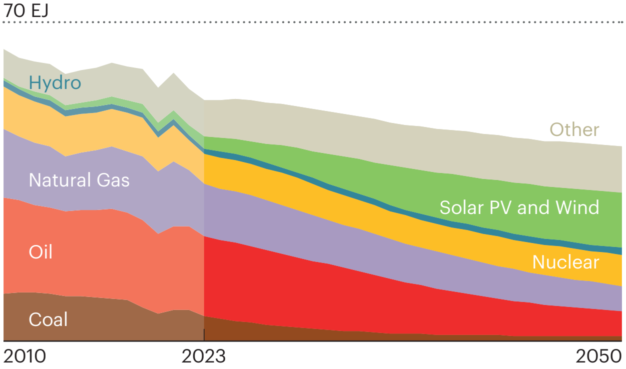
2050
Net zero emissions target year

596 **Billion USD**
Emergency affordability support allocated from 2021 until today

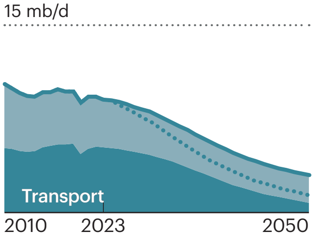
55%
GHG reduction target by 2030, compared to 1990 levels

42.5%
Binding target for share of energy from renewable sources by 2030

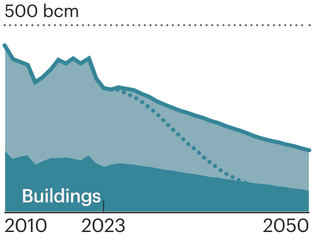
Energy demand in the Stated Policies Scenario



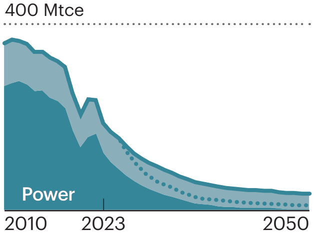
Oil demand



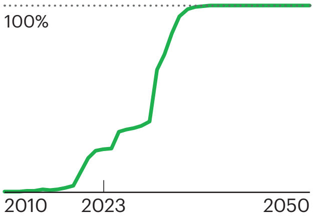
Natural gas demand



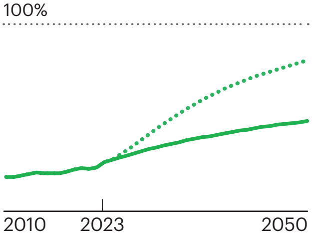
Coal demand



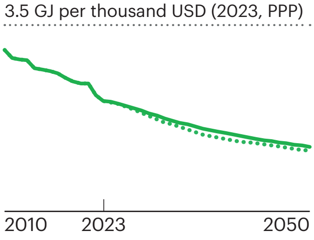
Zero-emissions vehicles in car sales



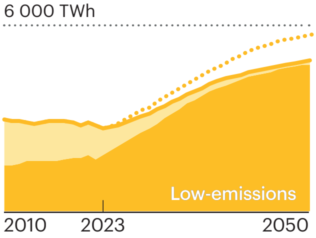
Low-emissions energy in industry



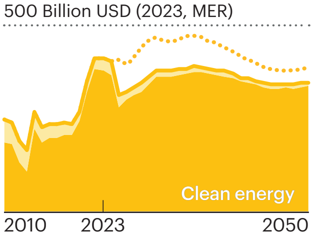
Energy intensity of GDP



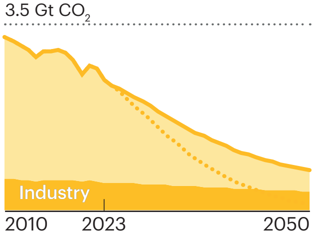
Electricity generation



Investment



CO_2 emissions



— Stated Policies Scenario ••• Announced Pledges Scenario

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The European Union (EU) is home to 6% of the world population and accounts for approximately 10% of global energy demand. It continues to be a clean energy leader, with energy-related CO_2 emissions in 2023 declining more steeply than in 2022, driven by increased electricity production from renewables, a recovery in hydro and nuclear power, reduced emissions in industry, plus a mild winter. Many aspects of the EU Fit for 55 package, which is the implementation framework for the European Union Green Deal, are moving forwards: recent developments include revision of the EU Emissions Trading System and CO_2 emissions standards for heavy-duty vehicles.

In the STEPS, oil demand in the European Union is set to drop by 15% from today's levels by 2030, natural gas demand by around 10% and coal demand by nearly half. CO_2 emissions fall by almost 50% from their 1990 level. The share of electric cars in new registrations expands from just under 25% today to 100% by 2035, and the share of renewables in electricity generation rises from 45% today to around 80%. The outlook for heat pump sales is generally positive, although a slowdown in sales in 2023 looks to have continued into 2024: the growing role of heat pumps in meeting energy demand in buildings contributes to a reduction of nearly 5 billion cubic metres (bcm) in gas use in 2030 compared with today. Policy developments in France, Sweden, Poland and Belgium are reinforcing the role of nuclear power in the European Union. In the APS, faster progress is made, including on ambitious components of the Fit for 55 such as retrofit targets for buildings. The result is to reduce fossil fuel demand by 20% in 2030 compared to 2023, to reduce CO_2 emissions by 55% relative to 1990 levels, and to meet the REPowerEU goal of eliminating dependence on natural gas from Russia before 2030.

The European Union aims to become a hub for clean energy manufacturing; the new Net Zero Industry Act sets a goal for EU manufacturing capacity to reach at least 40% of its annual clean energy deployment needs by 2030. The European Union was the world's second-largest installer of most clean technologies in 2023, second only to China. EU member states added almost 60 GW of solar PV capacity, with over 60% coming from rooftop installations, twice the level seen in 2021. Member states integrated over 15 GW of wind capacity, an increase of 40% compared to 2021. Expanding clean technology adoption in the European Union continues in each scenario, with installed capacity of wind and solar PV projected to more than double from the 2023 level in the STEPS by 2030. Annual electric car sales rise from around 2.5 million units today to over 7 million units in 2030 in the STEPS, accounting for nearly 20% of global EV sales. Announced battery manufacturing capacity is set to swell by four- to six-times by 2030 from current levels. Similarly, annual heat pump sales increase from 25 GW today to over 45 GW in 2030, driven by supportive regulations and financial incentives.

European consumers were heavily exposed to price spikes during the global energy crisis, but there are signs that the outlook is improving. Electricity prices for households fell on average by over 10% year-over-year in 2023, and wholesale natural gas prices dropped nearly 70% from the extremely high levels seen in 2022, though they remain higher than in 2021. Tightness in natural gas markets should be eased by the new LNG export terminals that are due to come online from 2025, primarily in Qatar and the United States, adding over 250 bcm of capacity by 2030. Since Russia invaded Ukraine, efforts to diversify gas supply have cut the

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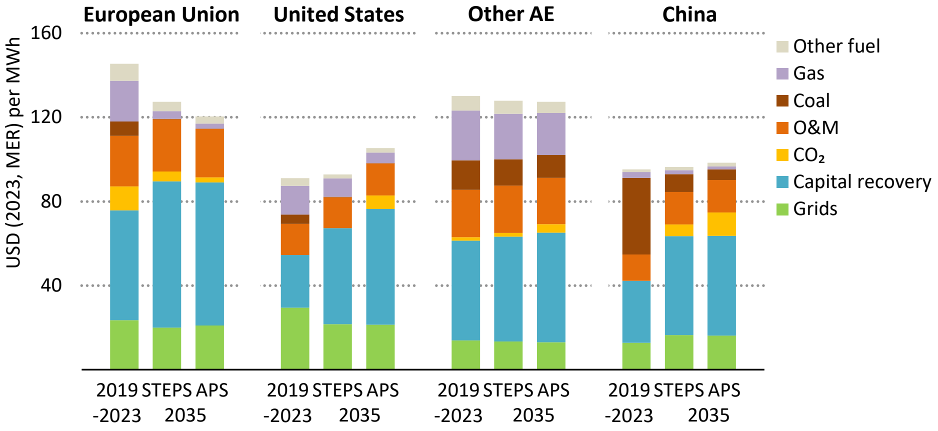
share of total EU energy imports from Russian pipeline gas from over 40% in 2021 to below 10% today. This is due in part to efforts to improve energy efficiency and boost renewables, but it also reflects a major switch away from Russian pipeline gas to LNG, which now accounts for more than 40% of European Union gas imports.

Clean energy transitions offer an opportunity to reduce electricity costs

The drive to decarbonise power generation and the impacts of the energy crisis together have brought the cost structures of electricity systems in EUs member states under close scrutiny. Clean energy transitions depend heavily on electrification and expansion of renewables, both of which require significant changes in electricity systems. The diversity of electricity mixes and decarbonisation pathways chosen by the various member states adds to the challenges.

Between 2019 and 2023, the average system cost per unit of generated electricity, including the development and maintenance of grids, reached USD 145/MWh in the European Union, which is 60% higher than in the United States, and around 10% higher than in other advanced economies. A key factor behind this difference is the cost of repaying past capital investment in the European Union, which is nearly double that of the United States, and accounted for a third of total system costs on average in the 2019-2023 period. These higher costs stem from the European Union's early efforts to develop low-emissions electricity sources, and in particular from its work in pioneering the large-scale deployment of wind and solar PV in the 2010s at a time when they were nascent technologies and relatively expensive compared to today.

Figure 6.4 ⊳ Total electricity system costs by component, region and scenario, 2019-2035



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Average system costs have been higher in recent years in the European Union than elsewhere, but clean energy transitions present opportunities to close the gap

Note: MER = market exchange rate; MWh = megawatt-hours; O&M = operation and maintenance costs; AE = advanced economies.

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Also contributing to high electricity costs in many EU member states is the cost of fossil fuel used in electricity generation, including natural gas imports. This accounts for around a quarter of electricity costs across the European Union. While member states have significantly reduced their reliance on coal for electricity generation in recent years, and more recently have significantly cut natural gas pipeline imports from Russia, the extent to which many of them depend on natural gas imports continues to drive up overall electricity costs. EU member states that rely less on natural gas for power generation, such as Denmark, France and Sweden, are less exposed to these high fuel costs.

Clean energy transitions provide an opportunity for EU member states to reduce their average electricity system costs. Continuing the shift from coal- and gas-fired power plants to low-emissions electricity sources could reduce total EU electricity system costs by around 12% by 2035. Additional decarbonisation efforts in the APS and achievement of the REPowerEU objectives could reduce system costs a further five percentage points. Investment levels needed for renewable energy sources and grid development are large, but the cost per unit of electricity for the grid component is similar to that in other parts of the world, and investment in renewables is necessary to reduce future electricity costs and GHG emissions. The accelerated transition seen in the APS leads to a more rapid fall in electricity costs.

Average electricity system costs are not the same as end-user electricity prices, and one of the challenges of energy transitions is ensuring that reductions in electricity system costs are reflected in consumer tariffs. Reforms in electricity market design and use of instruments such as long-term contracts, including contracts for difference or power purchase agreements, can help align electricity prices with system costs. The expansion of renewables, the growth of nuclear capacity and the development of flexibility sources should all also weaken the link between the costs of natural gas-fired power generation and wholesale electricity market prices. Changes along these lines are likely to lower electricity prices and reduce exposure to fossil fuel price volatility while maintaining an efficient balance between supply and demand.

The expansion of renewables will not do much to lower overall electricity costs if they cannot be successfully integrated into electricity systems. Grid congestion and redispatch costs, which hit EUR 4 billion in 2023, are expected to rise, underlining the crucial need to invest in grid infrastructure and to expand interconnections (ACER, 2024). The investment required is necessary to unlock the benefits of renewables and would be offset by the savings gained from reduced fossil fuel imports. Delays in investing in the necessary grid infrastructure and the provision of flexibility are all too likely to result in increased congestion and price cannibalisation from surplus generation that cannot be integrated. Over time, this could undermine producer revenues and overall security of supply. Further European Union electricity market integration would also help to foster integration of renewables, ensure reliable supply and mitigate price differences between bidding zones.

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6.4 Africa

Population
Million people
2023 1 458
2050 2 482

GDP
Trillion USD (2023, PPP)
2023 9.0
2050 25.9

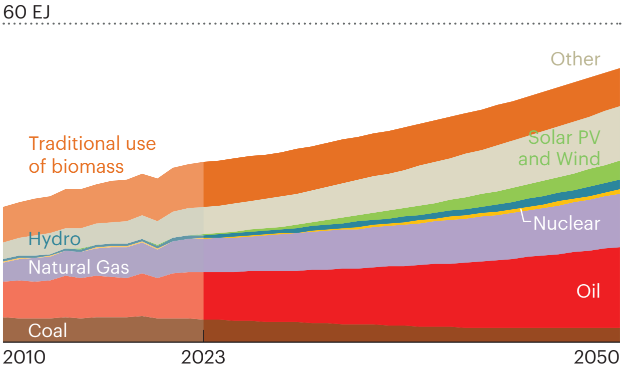
18 out of 54
Countries with a Net Zero Pledge

300 GW
Increase Africa's renewable energy generation capacity from 56 GW in 2022 to at least 300 GW by 2030 in the Nairobi Declaration

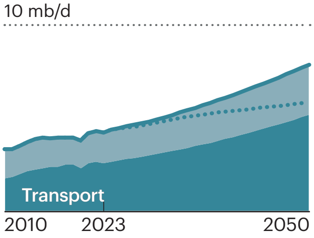
40 out of 47
Countries with an Access to Electricity target (47 still do not have full access to electricity)

29 out of 52
Countries with an Access to Clean Cooking target (49 still do not have full access to clean cooking)

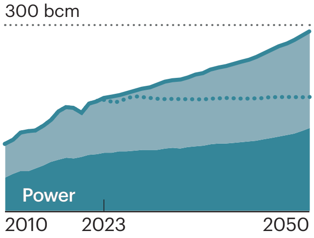
Energy demand in the Stated Policies Scenario



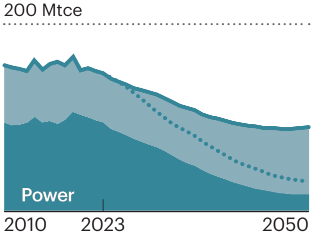
Oil demand



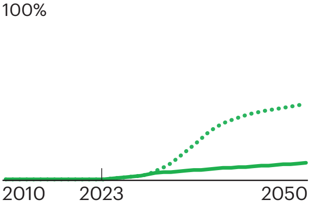
Natural gas demand



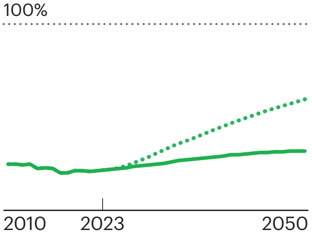
Coal demand



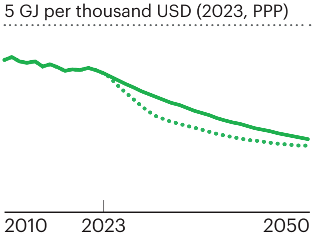
Zero-emissions vehicles in car sales



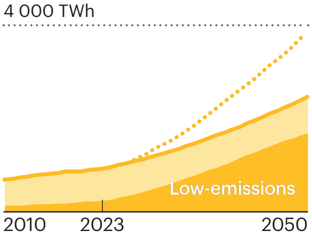
Low-emissions energy in industry



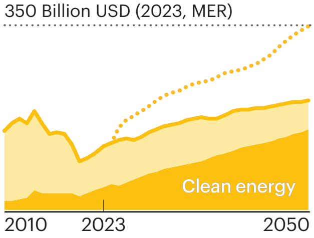
Energy intensity of GDP



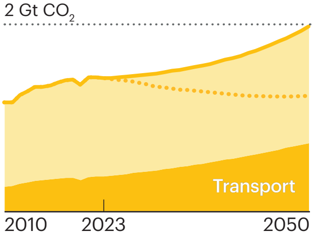
Electricity generation



Investment



CO_2 emissions



— Stated Policies Scenario ••• Announced Pledges Scenario

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Africa's economy is expected to expand by an average of 4% per year to 2030, and its population to expand by more than 1 billion people by 2050; both factors will require a major expansion in the continent's energy system. Renewable energy is growing fast, albeit from a low base: clean energy investment rose by 16% in 2023, but this is concentrated in a handful of countries that have favourable policy environments and lower perceived risks. Just five countries account for nearly 70% of private investment in energy infrastructure in Africa over the last five years (IMF, 2024). A promising project pipeline in the STEPS is set to boost clean energy investment 42% by 2030, though high financing costs pose a major challenge. Many more projects are required if clean energy investment is to double by 2030, as it does in the APS, and new international efforts to address project bankability are essential in this context.

After setbacks from 2020 to 2022, progress on electrification in Africa has resumed. Access rates are projected to reach almost 70% by 2030 in the STEPS, up from 59% today. With electricity consumption in Africa set to rise sharply, financing for new sources of generation and grids will be crucial. Around 80% of new generation capacity through to 2030 is projected to be renewables in both the STEPS and APS, mostly from solar PV, geothermal and hydropower. A positive trajectory has also resumed for access to clean cooking solutions: new policy commitments and new investment – including those announced at the IEA Summit for Clean Cooking in Africa in May 2024 – have improved the outlook. For the first time, the number of people without access to clean cooking is projected to plateau by 2030 in the STEPS.

Coal demand in Africa declines by 16% to 2030 in the STEPS. Upgrades to coal plants have extended the lifespan of some facilities, reduced widespread power outages and played a crucial role to support the integration of variable renewables into the grid. At the same time, the rapid expansion of rooftop solar PV is significantly driving down coal use. Natural gas demand in Africa rises by 12%, driven by increasing use in the power sector, desalination projects in North Africa and in industry in sub-Saharan Africa.

Demand for oil products in Africa rises by 13% to 2030, largely due to a 20% increase in transport demand and the increased use of liquefied petroleum gas for cooking. Subsidy reforms in countries such as Nigeria and Ghana prevent the rise in demand from being even larger. Increasing demand for oil in Africa is the main driver for increased energy-related CO_2 emissions in the STEPS. In the APS, the level of transport demand growth projected in the STEPS is moderated by import restrictions on inefficient vehicles, measures to displace diesel backup, and an increase in electric two/three-wheelers, yet oil demand still rises by 16%.

Although new oil prospects and production are coming online, for example in Namibia, continent-wide oil production is expected to decline as a result of low investment in existing basins. Conversely, natural gas production is set to climb by 8.5% to 2030, with gas production in North Africa remaining broadly at its current level and production in sub-Saharan Africa increasing by two-thirds. Refining capacity remains limited, relative to projected demand, and the continent is set to continue to be a significant net importer of refined products, despite the startup of the Dangote refinery in Nigeria and other planned projects.

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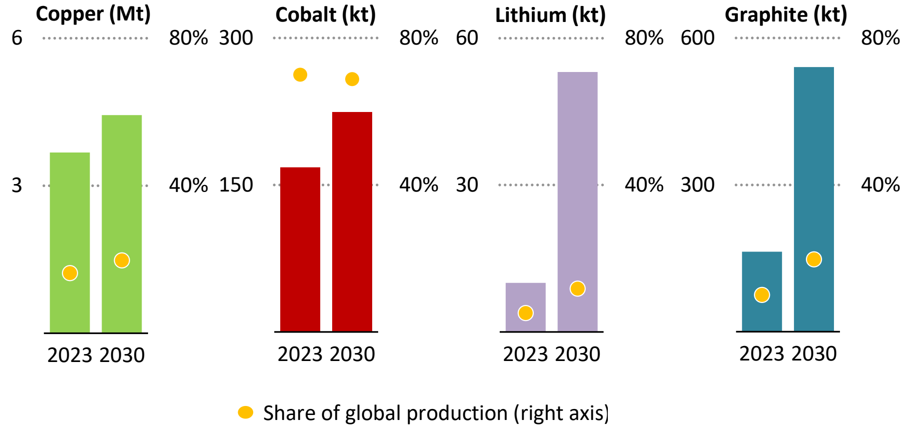
Upside potential for critical minerals in Africa

Africa is already a key player in the global critical minerals mining sector. In 2022, mining and extractive industries represent over 30% of total exports in 23 African countries, and critical minerals produce around USD 20 billion of revenue each year across the continent. The Democratic Republic of the Congo (DRC), South Africa, Zimbabwe and Mozambique are leading producers, but a number of other countries also contribute.

Figure 6.5 ▹ Production of selected minerals in Africa in the STEPS, 2023 and 2030



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Africa's production of key minerals and its share of global production are both expected to rise significantly by 2030, underlining its key role in cobalt, lithium and graphite supply

Note: Mt = million tonnes; kt = kilotonnes.

Spending on critical mineral exploration in Africa is rebounding after years of decline and is now rising rapidly. The continent already accounts for 70% of global cobalt production and 16% of global copper production. New projects are set to expand Africa's share of copper, lithium and natural graphite production by 2030: the DRC is on course to become the world's second-largest copper supplier by 2030; production of lithium could increase more than fivefold by 2030, depending on production in Zimbabwe and new discoveries in Nigeria; and the share of global production of graphite is expected to rise from 10% to 20%, due to projects in Mozambique and Madagascar (IEA, 2024).

Supporting the existing mining project pipeline requires at least USD 1.3 billion in cumulative capital investment by 2040, with a possibility to reach around USD 1.8 billion if projects that are at slightly less advanced stages of development or are seeking financing and/or permits are also considered (IEA, 2024). Further investment will be needed to expand related infrastructure such as ports. Among other factors, investors are looking for environmental, social and governance improvements in key areas, including action to address child labour.

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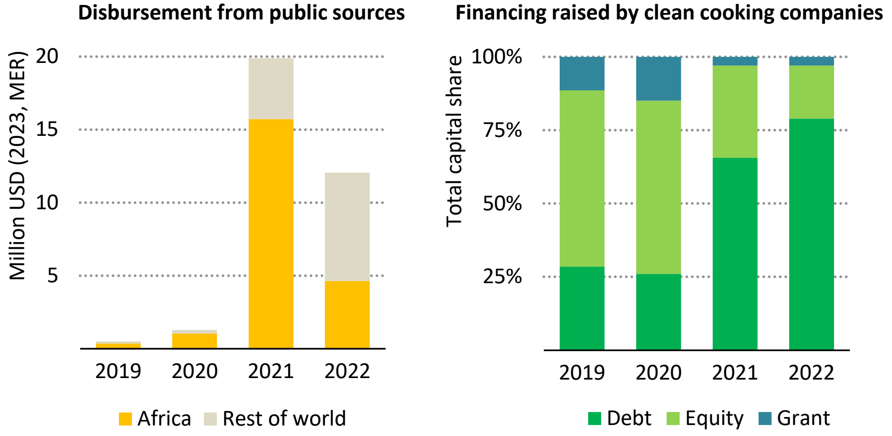
Box 6.1 ▷ Could 2024 be a turning point for clean cooking?

Together with the Governments of Tanzania and Norway and the African Development Bank, the IEA hosted the first major Summit for Clean Cooking in Africa in May 2024. At the summit, 130 delegations endorsed the Clean Cooking Declaration and thus pledged to increase efforts to improve access to clean cooking. Delegations from 12 African governments pledged to implement proven policy measures and make clean cooking a national priority. The summit helped to mobilise an unprecedented USD 2.2 billion for clean cooking access in new financing from government and private sector sources.

Spending related to clean cooking access, however, is still far below the level needed to achieve the United Nations goal of universal access by 2030. Capital investment of around USD 4 billion per year is needed in sub-Saharan Africa to achieve that goal, together with additional funds for the needed infrastructure and affordability support.

Innovation in financing models is contributing to increased investment in clean cooking access. Firms have demonstrated more ability to raise debt capital, although calling upon equity and concessional public funds remains key. Public sector support, which plays a central role to attract private capital, has been decreasing both in absolute terms, with a 70% reduction from 2021 to 2022, and as a share of the capital of firms. Developments such as carbon markets and new instruments such as the first-ever green bond for clean cooking are providing fresh ways to attract capital.

Figure 6.6 ▷ **Financing clean cooking projects, 2019-2022**



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Public funding for clean cooking projects has fluctuated; clean cooking companies have attracted finance from a variety of sources, with an increasing share of debt

Sources: OECD (2024) and CCA (2024).

IEA. CC BY 4.0.

6.5 Middle East

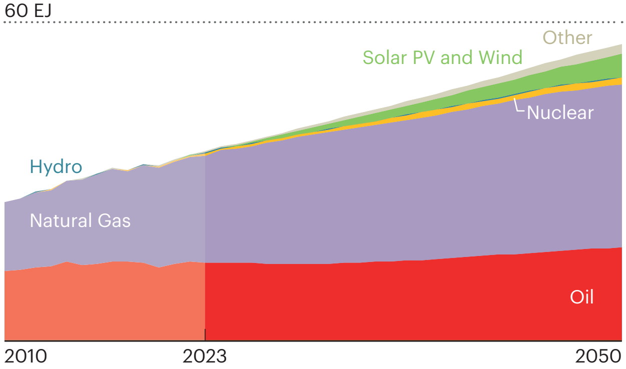
Population
Million people

2023 **269**
2050 **364**

GDP
Trillion USD
(2023, PPP)

2023 **6.7**
2050 **15.6**

Energy demand in the Stated Policies Scenario



5 out of 12

Countries are committed to net zero by around mid-century

44%

Share of renewables in power generation capacity in UAE by 2050 under the National Energy Strategy

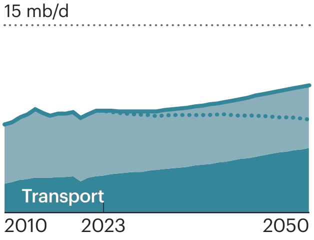
16 Mt CO_2 per year

Operational and planned carbon capture capacity by 2030

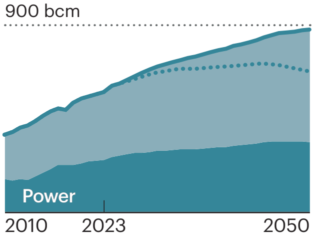
5

National oil companies in the region have signed the Oil and Gas Decarbonization Charter, committing to near zero upstream methane emissions by 2030

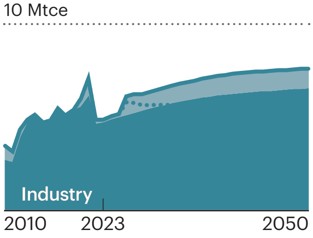
Oil demand



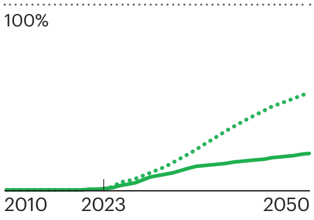
Natural gas demand



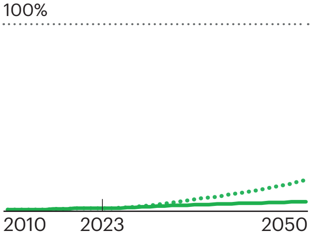
Coal demand



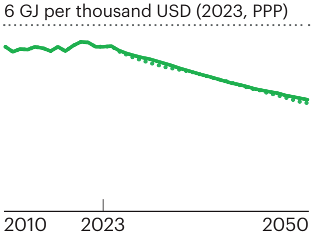
Zero-emissions vehicles in car sales



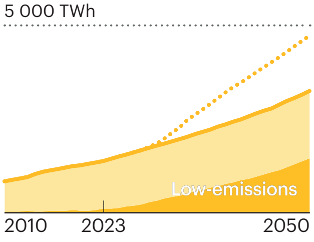
Low-emissions energy in industry



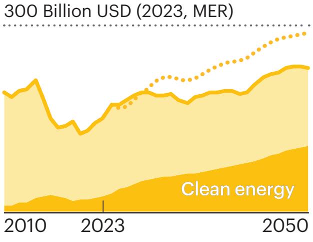
Energy intensity of GDP



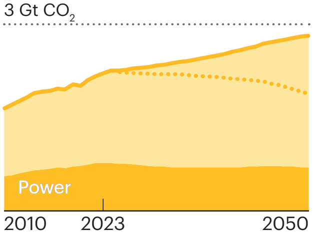
Electricity generation



Investment



CO_2 emissions



— Stated Policies Scenario ••• Announced Pledges Scenario

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Growth is the common denominator for many energy trends in the Middle East. There are, however, significant variations between the Gulf Council Cooperation (GCC) members[2] and other countries in the region, which include Iran, Iraq, Jordan, Lebanon and Syria. The region is a major producer and consumer of energy, and the spectre of spiralling hostilities cast a large shadow over its supply and demand prospects as well as for global energy markets.

Fossil fuels dominate the energy mix in the Middle East, with oil and natural gas responsible for around 98% of the 36 EJ of energy demand in 2023. In the STEPS, energy demand grows by nearly 25% by 2035, while the share of oil and natural gas falls to 92%. In the APS, energy demand growth remains broadly similar to that in the STEPS, even as the share of oil and natural gas falls to 85%. CO_2 emissions rise by more than 10% by 2035 in the STEPS and are broadly flat in the APS. In the power sector, the share of oil and natural gas declines from 95% in 2023 to around 80% in 2035 in the STEPS. Renewables generation increases ten-fold over this period, mostly solar PV. In the APS, renewable generation increases twenty-times to 2035 and the share of oil and natural gas falls below 60%.

Natural gas demand in total final consumption (TFC) in the Middle East was about 270 bcm in 2023, with the industry sector accounting for the largest share. Gas demand in TFC rises to more than 350 bcm in 2035 in the STEPS and to 315 bcm in the APS. In the STEPS and the APS, natural gas remains the main source of energy for desalination, even with faster increases from solar thermal power in the APS.

Investment in fossil fuel supply reaches a high point over the course of this decade in the STEPS, followed by a gradual decline. In the APS, investment in fossil fuels peaks earlier and declines more steeply, reducing by over 35% by 2035. Much of this investment is likely to come from Middle Eastern national oil companies (NOCs), which accounted for 20% of the global hydrocarbon upstream spending in 2024, up from less than 10% in 2015. A major investment is the North Field West project in Qatar, which will add 20 bcm of new LNG capacity. This project is the latest in a series of investments which, combined, will nearly double Qatar's LNG export capacity to around 200 bcm per year. Saudi Aramco also has plans to scale up investment in gas supply, including domestic gas infrastructure and the Jafurah development, a large liquids-rich shale gas play. International investments include stakes in LNG export facilities in North America and Australia, signalling an interest in geographical diversification.

Opportunities to accelerate clean energy deployment in the region

The 2023 COP28 climate summit in Dubai highlighted the potential role of the Middle East – especially the GCC – in global clean energy transitions. Amid rising physical climate risks, many countries are now paying close attention to climate and transition priorities as a way to diminish high dependence on fossil fuels for energy and revenue. There is huge scope for the Middle East to accelerate investment in clean energy technologies, based on the region’s significant resource endowments, especially for solar, significant financial resources in many countries, relevant expertise in some high-skilled energy companies, and the possibility to

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[2] Comprising of Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates.

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use or repurpose some existing infrastructure. From USD 26 billion in 2023, clean energy investment across the region is set to rise to USD 63 billion by 2035 in the STEPS, and to USD 137 billion in the APS.

The push for a more diverse energy system is reflected in many national policy objectives, including Nationally Determined Contributions (NDCs), and investment strategies. ACWA Power develops, builds, owns and operates desalination and power generation projects, including solar and wind, in the Middle East, Africa and Asia. Masdar, an energy company partially owned by ADNOC, has also expanded beyond the Middle East, and has formed a strategic agreement with Iberdrola, a leading wind power producer and one of the largest electric utilities in the world.

Some GCC countries have well developed capital markets and sizeable sovereign wealth funds (SWFs), although the use of these funds for clean energy investment, as with all investment, requires adequate returns. Saudi Arabia, Kuwait, Qatar and the United Arab Emirates (UAE) hold high sovereign credit ratings for their public funds, while those of Oman, Bahrain and Jordan fall into the medium-grade category. Outside the GCC, countries such as Iraq do not have SWFs, have very low credit ratings and have limited access to capital. However, the recently established Iraq Development Fund was specifically designed to support non-oil economic developments. Syria, Yemen and Lebanon face major security and geopolitical challenges, which makes progress on clean energy transitions extremely difficult. In many countries, actions such as phasing out inefficient fossil fuel subsidies, adjusting SWF mandates, promoting innovative public-private partnerships and encouraging foreign investment could unlock more capital.

There is significant potential to develop new low-emissions generation in the region. Solar PV and wind generation increases from around 30 TWh in 2023 to 430 TWh in 2035 in the STEPS, displacing oil as the second-largest source of electricity generation. Several important developments are underway, notably Saudi Arabia's objective to increase its renewable energy capacity from less than 5 GW to reach between 100 and 130 GW by 2030, though only about 20 GW are planned to date under the National Renewable Energy Programme, including the 2.6 GW Al Shuaibah solar PV project. Elsewhere in the region, the UAE is moving forward with the Mohammed bin Rashid Al Maktoum solar PV park, 5 GW by 2030 in phases, and Iraq is moving ahead with its first utility-scale solar PV project, a 1 GW facility. Natural gas demand – and supply – also rise rapidly in the Middle East, although this is tempered in the APS by a much more rapid increase in wind and solar PV generation, which approaches 1 000 TWh in 2035 in the STEPS.

Electric vehicles have made little headway so far in the region, but there are some signs of change. Jordan cut import duties and saw a significant uptick in EV sales. The market share for EVs in the UAE was 13% in 2023. Saudi Arabia meanwhile unveiled its first EV assembly plant in 2023 and has plans to significantly expand the network of public chargers.

Critical mineral resources related to energy, such as lithium for batteries, are starting to attract more interest, with countries looking to position themselves both as investors in resource-rich countries and as midstream players in refining and processing, the latter helped by relatively low energy costs. Saudi Arabia has initiated a USD 207 million geologic

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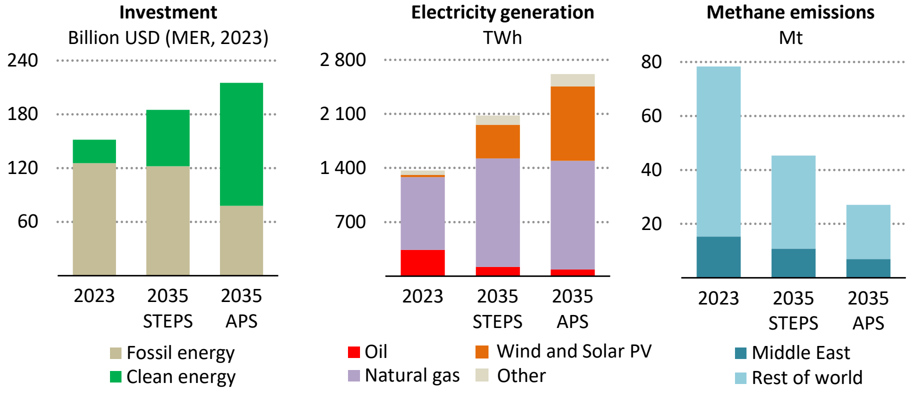
mapping project of the Arabian shield, and three lithium refining projects are currently underway in Saudi Arabia and the UAE.

Figure 6.7 ⊳ Energy investment, electricity generation and methane emissions in the Middle East in the STEPS and APS, 2023 and 2035



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Investing in clean energy solutions and abating methane emissions from oil and gas production offer significant opportunities for the region to advance climate goals

Note: MER = market exchange rate; TWh = terawatt-hour; Mt = million tonnes.

Reducing emissions from traditional oil and natural gas upstream and midstream operations is a major part of energy transitions agenda for the region. A number of countries and companies have made commitments to bring these emissions down: most of the major producers in the region participate in the Global Methane Pledge and many of the large NOCs have also joined the Oil and Gas Decarbonisation Charter initiative that was launched at the COP28, including Saudi Aramco and the Abu Dhabi National Oil Company (ADNOC). We estimate that around 15 Mt of methane are released to the atmosphere each year from oil and gas operations in the region, with more than half of this being possible to abate at no net cost, because the cost of the abatement measure is less than the value of the additional gas that is captured and available to market. Taking full advantage of the abatement opportunity would require around USD 2.5 billion in annual investment, a small fraction of the amount generated by the region's oil and gas industry each year.

The Middle East has extensive and well characterised geological pore capacity as well as the technical expertise to deploy carbon capture, utilisation and storage (CCUS) projects at scale. Activity is picking up with the oil and gas industry in the lead. The UAE recently approved two CCUS projects to capture emissions from gas processing plants with a combined capacity of 3.0 million tonnes carbon dioxide (Mt CO_2). Qatar is developing a 4.3 Mt CO_2 project to capture emissions from its LNG facilities and Saudi Arabia is advancing plans for a 9 Mt CO_2 hub. Total CCUS capacity in the region is projected to reach over 30 Mt CO_2 in 2035 in the STEPS, but could grow much faster, and it reaches more than 100 Mt CO_2 in the APS in 2035.

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6.6 Eurasia

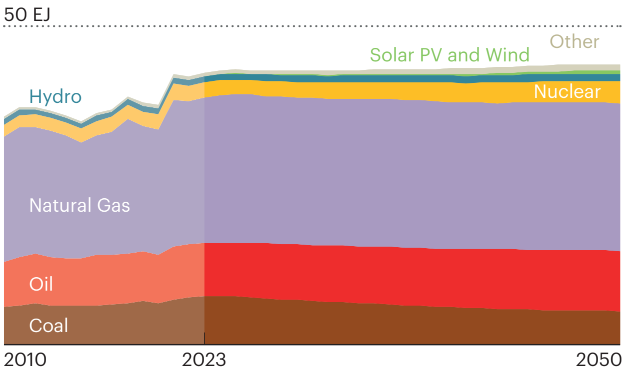
Population
Million people

2023 **240**
2050 **255**

GDP
Trillion USD
(2023, PPP)

2023 **6.8**
2050 **10.0**

Energy demand in the Stated Policies Scenario



5 out of 9

Eurasian countries have a net zero target by 2050-2060

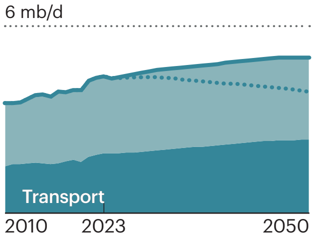
100%

All countries in the Caspian region are signatories of the Global Methane Pledge. The pledge commits to reduce global methane emissions by at least 30% from 2020 levels by 2030.

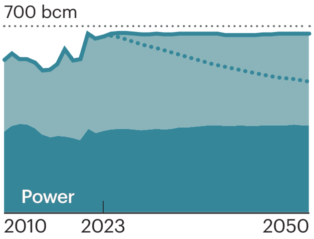
6 out of 9

Eurasian countries have committed to the COP 28 Global Renewables and Energy Efficiency pledge

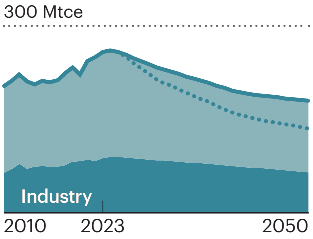
Oil demand



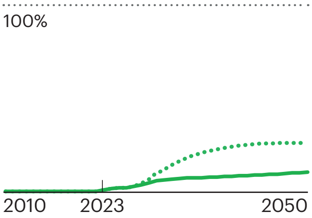
Natural gas demand



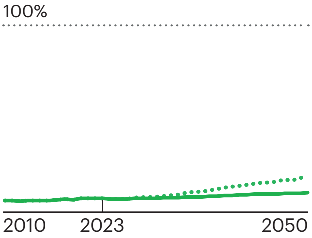
Coal demand



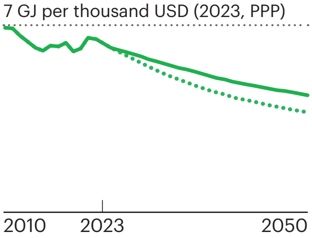
Zero-emissions vehicles in car sales



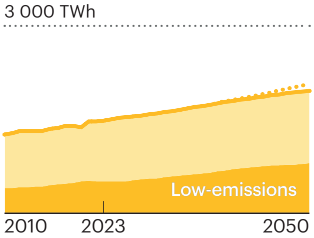
Low-emissions energy in industry



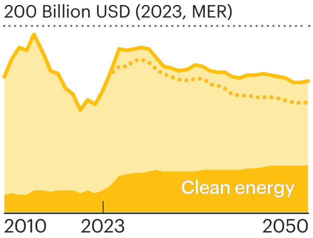
Energy intensity of GDP



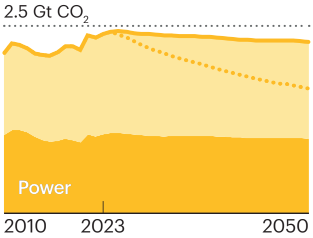
Electricity generation



Investment



CO_2 emissions



▬ Stated Policies Scenario ••• Announced Pledges Scenario

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In Eurasia, which comprises the Caspian region and the Russian Federation in our modelling, GDP per capita rose over 3% in 2023 to reach a level 30% higher than the global average. Russia plays an outsized role in the energy architecture of the region, but the continuing war between Russia and Ukraine, following Russia's full-scale invasion in 2022, is shifting priorities and creates huge uncertainty for projections of energy demand and supply. The loss of Europe as its key export market prompted Russia to reach out to its Central Asian neighbours to expand energy partnerships and reinvigorate long-standing plans to deliver natural gas to Kazakhstan, Uzbekistan and further afield, though there remains significant uncertainty around the pace and scale of these diversification efforts.

The energy sector in Eurasia faces challenging conditions. Ageing building stock and industrial facilities, under-maintained pipelines that transport fuel over large distances, and a cold climate mean that the regional energy intensity of GDP is 70% higher than the global average. There are inefficiencies in energy supply, distribution and use. Fossil fuels are heavily subsidised in Eurasia, notably Russia, Kazakhstan, Uzbekistan, Turkmenistan and Azerbaijan. These subsidies total over 6% of the region's annual GDP.

Eurasia is both a major consumer and producer of fossil fuels. In 2023, fossil fuels constituted 90% of Eurasia's energy demand, the second-highest regional average after the Middle East. The region is also a large net exporter of fossil fuels, selling around 200 bcm of natural gas in 2023, along with nearly 10 mb/d of oil and 175 Mtce of coal. Russia accounts for around 75% of the region's oil and gas exports, although these have been significantly affected by sanctions imposed after its invasion of Ukraine: in 2023, Russia's natural gas exports were at half their pre-war level of around 250 bcm.

With current policy settings, the share of fossil fuels in the region's energy mix is projected to remain high. By 2035, fossil fuels account for nearly 90% of the energy mix in the STEPS, staying broadly constant to 2050. Oil demand rises 8% by 2035 as a result of growth in the transport and industry sectors. Natural gas demand in the STEPS remains almost unchanged, with just a 2% increase by 2050. This small change comes mostly from the power sector, where gas demand grows by 7%. Almost half of the increase in electricity consumption in the STEPS to 2035 is met by fossil fuels. Renewable capacity nearly doubles between 2023 and 2050, which is the lowest regional rate of growth in the STEPS. Hydropower remains the dominant source of renewable electricity in 2050.

Azerbaijan will host the 29th Conference of the Parties, the annual United Nations Framework Convention on Climate Change conference in 2024. It is a significant opportunity to strengthen the regional collaboration related to energy trade, clean energy investment, methane reduction efforts and energy efficiency commitments. All countries in the Caspian region are signatories to the Global Methane Pledge. Six-out-of-nine Eurasian countries have committed to the COP28 Global Renewables and Energy Efficiency pledge to triple renewables capacity and double the global annual rate of energy efficiency improvements by 2030. Kazakhstan, Georgia, Russia, Kyrgyzstan and Armenia also have longer term net zero emission targets.

If announced national energy and climate pledges are achieved in full and on time, as in the APS, this would move the region's energy system onto a very different footing. In the APS,

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the share of fossil fuels in the energy mix in Eurasia falls to 75% by 2050, driven by rapid deployment of renewables and nuclear capacity. Natural gas demand drops nearly 15% (85 bcm) by 2035, while a rise in the sales share of electric cars from 1% to 20% help to generate a 3% fall in oil demand by 2035. Coal undergoes the steepest decline in demand among fossil fuels: it falls about 30% by 2035. This drop in fossil fuel use is produced by a rapid rise in clean energy investment, which more than triples to 2035, resulting in a doubling of renewables capacity in the power sector over the same period. It also requires large-scale modernisation of the region's electricity grids. These efforts bring about a peak in CO_2 emissions in the APS by the mid-2020s, and emissions in the APS are 30% lower in 2050 than current levels, compared to 4% in the STEPS.

Modernising the Caspian natural gas sector

Turkmenistan, Azerbaijan, Kazakhstan and Uzbekistan face a common challenge as major gas producing countries in the Caspian region to maintain ageing gas infrastructure while meeting rising demand, which is often heavily subsidised. Upgrades to the gas infrastructure have a critical role to play in the broader modernisation of the region's energy system, alongside the expansion of renewables, and as a way to unlock needed improvements in energy efficiency. Over 15% of the world's natural gas is transported in pipelines that traverse Russia and the Caspian region. Much of this infrastructure was built during the Soviet era, and its condition has deteriorated in many cases due to a lack of investment. As a result, many Caspian countries suffer from power rationing, outages and even blackouts, as well as major fugitive methane emissions.

Taking action to reduce methane emissions is highly cost effective. Around 10 Mt of methane in the Caspian region is estimated to be lost as fugitive emissions each year and an additional 2 Mt are flared. If instead this natural gas had been exported in 2023, it would have been worth up to USD 8 billion. Improving the efficiency of the ageing infrastructure could cost USD 500 000 to USD 3 million per kilometre depending on the location, while the annual investment cost of tackling methane emissions to 2030 is estimated at around USD 700 million.

Without action to improve energy efficiency and upgrade infrastructure, some countries are likely to see increasing strains on their natural gas balance. Kazakhstan and Uzbekistan are already struggling to meet rising domestic natural gas demand, compelling them to reduce gas exports to China in 2023. In our projections, domestic demand rises from over 135 bcm to nearly 160 bcm in the STEPS by 2035, although it stabilises at around today's levels in the APS. The export opportunity depends also on broader market considerations, including competition from LNG: in the STEPS, the Caspian region is projected to export 95 bcm of natural gas in 2035, up from 70 bcm today. But in the APS, these flows dwindle to 55 bcm as the main export markets start to shift away from gas.

Some of the main opportunities for natural gas-related efficiency gains in the APS, compared with the STEPS, are in the power sector. Almost 40% of the savings come from efficiency improvements in gas-fired combined heat and power plants, where 6.5 GW of new capacity additions come online in the APS between 2024 and 2035 to replace ageing, inefficient units.

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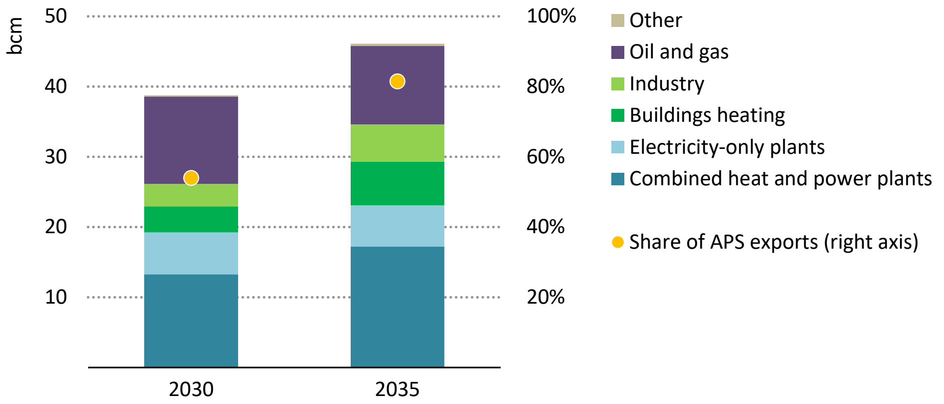
A quarter of the savings come from efficiency improvements in the oil and gas sector, including reductions in methane leakage and flaring. Methane intensity in the oil and gas sector in the Caspian, currently three-times higher than the global average, is reduced 70% by 2030, while flaring intensity sees a decline of more than 95% by the end of the decade in the APS. A further 13% (6 bcm) is saved by gas heating technology improvements in the buildings sector, and another 13% is saved by 2035 through more efficient gas turbines in power generation. Under 12% of savings come from efficiency improvements in industry. If implemented, all these measures to improve the efficiency of natural gas use would account for around 70% of what is needed to double overall energy intensity improvements by 2030.

A successful energy efficiency improvement programme requires policies, regulations and technical standards to curb emissions and to incentivise investment to upgrade outdated infrastructure. This includes modernising compressor stations, investing in leak detection and repair programmes, and implementing digital tools for flow optimisation and predictive maintenance. Pairing such a programme with implementation of CCUS technologies would further reduce emissions intensity, although this would require substantial additional investment. Fostering higher levels of collaboration between international oil companies operating in the region and NOCs in order to share know-how and global best practices would also bring benefits, as would collaborative partnerships with importing regions on emissions management in oil and gas supply.

Figure 6.8 ⊳ Natural gas demand savings from energy efficiency improvements in the Caspian and share of total exports in the APS, 2030 and 2035



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Thanks to efficiency improvements in the natural gas sector, the region reduces its natural gas demand by over 45 bcm by 2035 in the APS, equivalent to 80% of total exports

Notes: Oil and gas include efficiency improvements in upstream, midstream and downstream, as well as cutting methane emissions and flaring. Industry includes energy efficiency improvements in heating equipment and production processes that use natural gas. Other includes energy efficiency improvements in heat production plants, compressed natural gas vehicles, agriculture and non-energy use applications.

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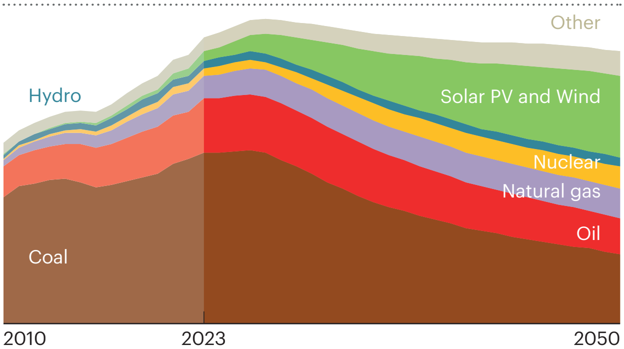
6.7 China

Population
Million people

	2023	2050
Population (Million people)	1 419	1 307

GDP
Trillion USD
(2023, PPP)

	2023	2050
GDP (Trillion USD (2023, PPP))	33.5	69.3

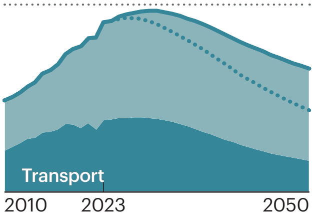

Energy demand in the Stated Policies Scenario

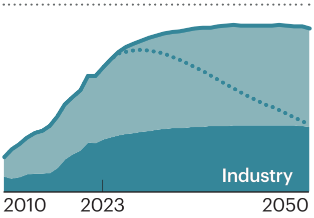
2060
Net zero emissions target

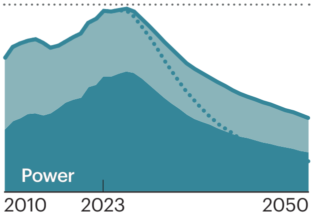
25%
Share of energy demand from non-fossil fuels by 2030, compared to 14% in 2023

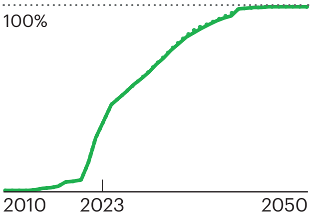
Before 2030
Target to peak emissions

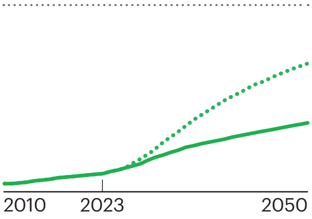
10%
Aim to reduce $PM_{2.5}$, NO_X and VOC emissions in cities compared with 2020 levels

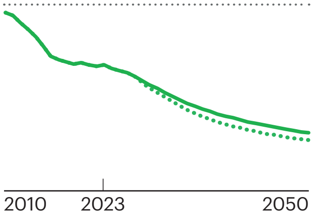

Oil demand

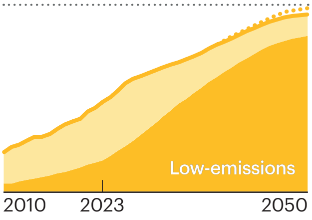

Natural gas demand

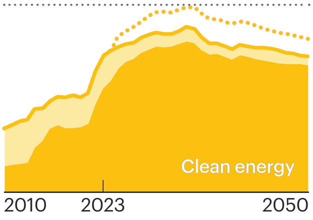

Coal demand

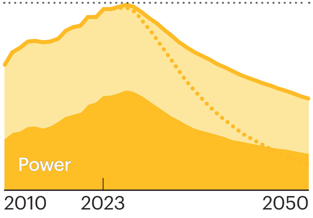

Zero-emissions vehicles in car sales


Low-emissions energy in industry


Energy intensity of GDP


Electricity generation


Investment


CO_2 emissions

— Stated Policies Scenario ••• Announced Pledges Scenario

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In recent years, China has shaped global energy markets more than any other country. It is responsible for over two-thirds of global oil demand growth in the decade to 2023 and one-third of global natural gas demand growth. It is also responsible for around 80% of the growth in global CO_2 emissions over the last decade and is now, by far, the largest emitter worldwide. At the same time, China is a clean energy powerhouse. China accounts for more than 40% of global installed capacity for wind and solar PV, and more than half of the electric cars in the world today. In 2023, China added almost 50 GW of new coal-fired power plants, but also a record 260 GW of solar PV and over 75 GW of wind. Over the outlook period, China's GDP is set to grow by slightly less than 4% each year to 2030, and then by 2.4% from 2030 to 2050.

The latest data for 2024 show a major slowdown in oil demand growth in China. Demand is projected to peak before 2030 in the STEPS, led by increasing electrification of the road transportation sector. Electric cars are projected to capture nearly 70% of new sales in 2030, up from nearly 40% in 2023, and to account for nearly one-third of cars on the road by 2030. When its oil demand peaks in the STEPS, oil demand per capita in China will be around half that of advanced economies. Nonetheless, in the STEPS, China surpasses the United States by 2030 to become the world's largest oil market. Once it has peaked, demand falls slowly in the STEPS, and is still close to the 2023 level in 2035. In the APS, it around 15% lower than in 2023 by 2035. The final energy consumption sectors account for nearly one-third of coal demand in China, largely due to its huge cement and steel industries. However, final consumption of coal peaked in 2014 and continues to decline slowly as the industrial sector restructures. Coal demand for electricity generation continues to rise in the STEPS before peaking in the next few years, leading to a peak in total coal demand.

China dominates global clean energy manufacturing. It accounts for over 80% of global solar PV module and EV battery cell production. Its solar PV manufacturing capacity was over 850 GW in 2023, compared with global installations of 425 GW that year, and its installed battery manufacturing capacity was 2 140 GWh, compared with annual global demand of around 870 GWh. China's huge manufacturing capacity for renewable power technologies provides the basis for continuing strong domestic deployment. In the STEPS, capacity additions of wind average around 75 GW and solar PV average around 350 GW through to 2030, adding on average around 500 TWh of clean electricity supply per year. Combined with expanding hydro and nuclear generation, growth in clean sources of electricity exceeds the annual average growth of electricity demand, which rises around 430 TWh per year to 2030. This is what leads coal-fired generation to peak by 2030.

The extraordinary consequences of simply maintaining the current expansion of solar PV capacity can be illustrated with one data point: by 2035 in the STEPS, solar PV generation in China exceeds the total electricity demand of the United States today. The biggest risk to this expansion is the challenge of grid integration. Concerns are arising about curtailment of variable renewables, though China is increasing the flexibility of its electricity system, adding 23 GW of "new energy storage", i.e. largely batteries, and 6 GW of pumped hydro storage in 2023.

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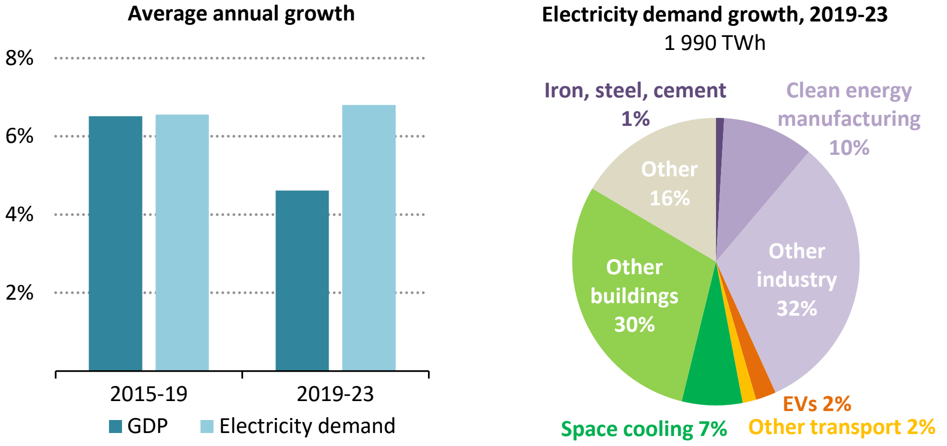
China is likely to miss its headline energy and carbon intensity targets for 2025, which aim for improvements of 13.5% and 18% respectively by 2025 relative to 2020 levels. On the other hand, China is on track to achieve its 2030 target of installing 1 200 GW of wind and solar already in 2024. The 15th Five-Year Plan is under preparation and will apply to the 2026-2030 period. It is likely to signal how China expects to meet its goal of securing a peak in emissions before 2030 and putting emissions on a downwards pathway towards net zero by 2060. The State Council's newly published work plan on the Dual Carbon Control System reinforces the government focus on controlling carbon emissions but maintains flexibility on the envisaged level of emissions before the peak date of 2030.

What is the outlook for electricity demand in China?

GDP growth has become more electricity intensive in China in recent years. In the pre-pandemic period, GDP and electricity consumption grew in lockstep, but since 2019 electricity consumption has increased nearly 50% faster than GDP (Figure 6.9). Between 2019 and 2023, electricity demand in industry increased around 860 TWh, of which about 200 TWh was in clean energy manufacturing. China's industrial production and exports also rose sharply during this period, while the structure of its industrial output shifted towards more electricity-intensive sectors. In the buildings sector, growth in cooling, heating and appliance ownership resulted in an increase of around 730 TWh in the same period, of which about 20% was for space cooling.

Figure 6.9 ▷ GDP and electricity demand growth in China, 2015-2023, and electricity demand growth by sector, 2019-2023



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Electricity demand has increased much faster than GDP in recent years, driven by the industry and buildings sectors

Notes: CAAGR = compound average annual growth rate; EVs = electric vehicles. Other sector includes own use, losses and electricity use in other energy transformation processes.

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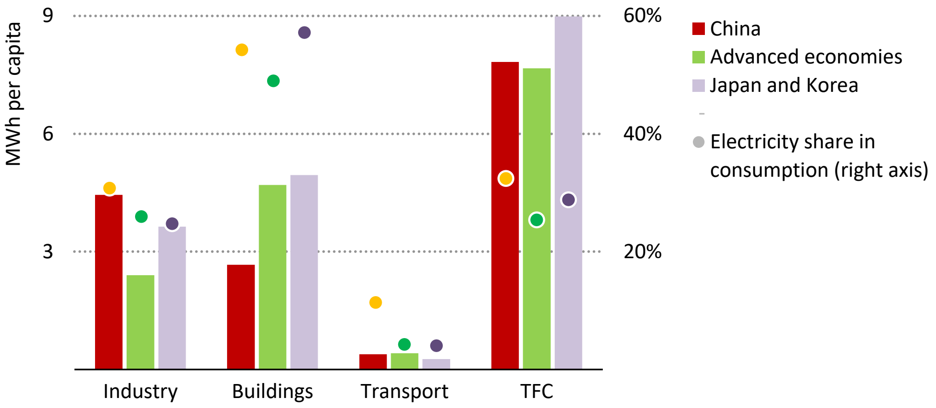
In the 2023-2030 period, total final electricity consumption grows around 420 TWh per year in China in the STEPS. Total growth amounts to 2 910 TWh in this period, roughly equivalent to the combined electricity consumption of the European Union and Korea today. By 2030, China's per capita electricity consumption overtakes that of advanced economies as a group (Figure 6.10). Its electricity consumption is dominated by the industry sector, and per capita industrial electricity consumption exceeds that of Japan and Korea by 2030. In contrast, electricity consumption per capita in its buildings sector is projected in the STEPS to remain below that of advanced economies in 2030.

Figure 6.10 ▷ Per capita electricity consumption by sector and region in the STEPS, 2030



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Economic growth and electrification push electricity consumption per capita in China to the level of advanced economies by 2030

Note: MWh = megawatt-hour; TFC = total final consumption.

Continued economic growth, rising incomes and manufacturing output all contribute to higher electricity demand. Electrification is also a major factor. Energy consumption in China is already more electrified than that of advanced economies as a group when measured as the share of electricity in total final consumption. The share of electricity in final consumption in China exceeded that of oil in 2023. By 2030 in the STEPS, almost one-third of its final energy consumption is from electricity, and China overtakes Japan to become the most electrified major economy in the world.

Clean electricity supply in China is more than able to keep pace with this rapid growth in electricity demand in the STEPS outlook. Of course, it is possible that demand growth will be even faster than projected or conversely that there will be a slowdown in the rate of clean electricity capacity additions. These sensitivities are explored in Chapter 4.

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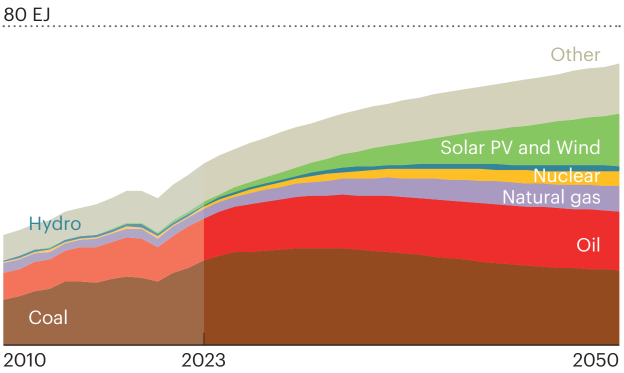
6.8 India

Population
Million people
2023 **1 429**
2050 **1 670**

GDP
Trillion USD (2023, PPP)
2023 **13.3**
2050 **47.8**

Energy demand in the Stated Policies Scenario



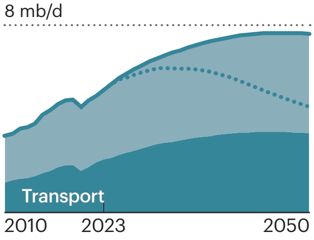
2070
Net zero emissions target

50%
Share of total power generation capacity targeted to be non-fossil by 2030

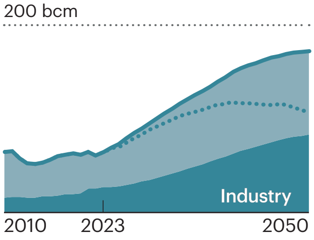
8.2 **Billion USD**
Earmarked for subsidies under the Production Linked Incentives (PLI) Scheme for low-carbon vehicles, solar PV and battery sectors

20 750 ckm
Intra-state Green Energy Corridor electricity transmission lines completed or planned to be completed by 2026.
ckm = circuit kilometres.

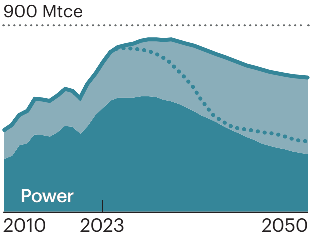
Oil demand



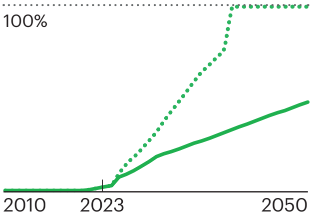
Natural gas demand



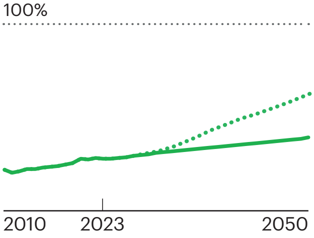
Coal demand



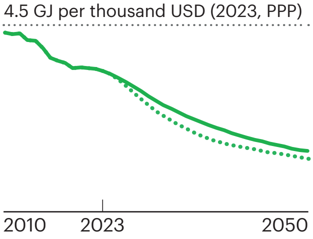
Zero-emissions vehicles in car sales



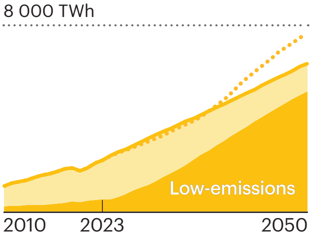
Low-emissions energy in industry



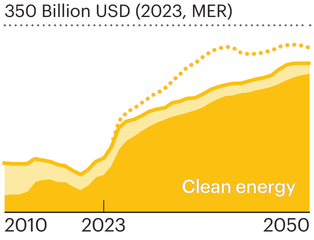
Energy intensity of GDP



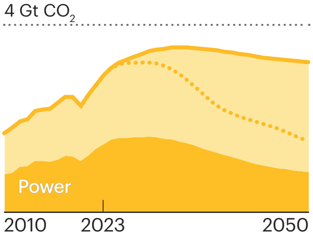
Electricity generation



Investment



CO_2 emissions



— Stated Policies Scenario ••• Announced Pledges Scenario

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India was the fastest growing major economy in 2023, with output increasing by 7.8%. It is on track to become the third-largest economy in the world by 2028. India overtook China in 2023 to become the most populous country in the world, even as its fertility rate dropped below replacement level. Looking ahead, India faces a range of challenges on the energy front, including ensuring universal clean cooking access, reducing fossil fuel import dependence, boosting the reliability of the power sector and the financial performance of distribution companies, addressing high levels of air pollution, and managing the impacts of climate extremes, especially heat waves and floods.

The population size and the scale of rising demand from all sectors mean that India is poised to experience more energy demand growth than any other country over the next decade. In the STEPS, India is on track to add over 12 000 cars every day to its roads over the period to 2035. Built space is set to increase by over 1 billion square metres annually, which is larger than the total built space in South Africa today. By 2035, iron and steel production are on track to grow by 70%; cement output is set to rise by nearly 55%; and the stock of air conditioners is projected to grow by over 4.5-times, resulting in electricity demand from air conditioners in 2035 that is more than Mexico's total expected electricity consumption that year. Total energy demand in India increases by nearly 35% by 2035 in the STEPS, and its electricity generation capacity nearly triples to 1 400 GW by 2035.

Coal is set to retain a strong position in the energy mix in India over the next decades. In the STEPS, nearly 60 GW of coal-fired capacity is added net of retirements by 2030, and electricity generation from coal rises by over 15%. Generation from coal remains over 30% higher than that from solar PV even in a decade in which solar PV accountings for twice as much capacity, owing to the lower capacity factor of solar installations. Coal has been playing a prominent role to meet energy demand in industry, providing 40% of its energy needs in 2023. By 2035, the consumption of coal in industry would have grown by 50%, with its share in total industry demand remaining at similar levels as today.

India has a range of ambitions that are set to shape its future energy use and emissions pathway, most notably is the commitment to achieve net zero emissions by 2070, which is reflected in the APS. In this scenario, clean power generation is nearly 20% higher than in the STEPS by 2035, and India has the world's third-largest installed battery storage capacity in place by 2030 to accommodate the rising share of variable renewables. There is also a rapid rise in electric mobility, and this contributes to oil consumption peaking in the 2030s. Coal use in industry also peaks in the 2030s as industrial use of electricity and hydrogen rises steadily. On its trajectory to net zero emissions by 2070, India's aggregate annual CO_2 emissions reach 2.5 billion tonnes in 2035, which is 25% below the level in the STEPS.

Two/three-wheelers and buses lead the EV revolution in India

India is one of the largest markets in the world for two/three-wheel vehicles, and the fourth-largest passenger car market. Over the next decade, India adds over 37 million cars and over 75 million two/three-wheelers to its roads in the STEPS. While an increasing share of vehicle

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sales are electric, the simultaneous growth of internal combustion engine vehicles results in oil demand from road transport rising 40% by 2035 in the STEPS, contributing to an increased dependence on oil imports. Adding over 12 000 additional cars every day in India places significant further demands on road infrastructure, exacerbates already poor air quality, and contributes to a 30% rise in CO_2 emissions from all road passenger transport by 2035. In response to these challenges, the government is planning to promote road transport electrification, scale up light urban rail and other public transport, strengthen regulations on fuel efficiency, step up the blending of biofuels in gasoline, and support compressed natural gas as an alternative fuel.

While many of these measures contribute to reductions in oil demand and emissions across the scenarios, the rapid scaling up of EVs is poised to have the biggest impact. India already has a range of policies in place that promote the electrification of road transport. Over the past few years, the Faster Adoption and Manufacturing of Electric Vehicles (FAME) scheme offered subsidies to support the electrification of over 1.3 million EVs of varying kinds, achieving between 55-84% of its original targets across a range of vehicle types, including buses, passenger cars, and two/three-wheelers (ICCT, 2024). The second phase of FAME ended in March 2024. In September 2024, the national government announced the PM Electric Drive Revolution in Innovative Vehicle Enhancement (PM e-DRIVE) programme which seeks to incentivise the uptake of 2.8 million electric two/three-wheelers and over 14 000 electric buses. It also supports the installation of over 22 000 fast chargers. In addition to the national government's incentives, several state governments in India have additional demand incentives in the form of subsidies, tax breaks and incentives to promote charging infrastructure. In addition, cities including Mumbai and Pune in Maharashtra and Amritsar in Punjab have created comprehensive mobility plans that explicitly include EVs within overall transport infrastructure planning (IEA, 2023).

India's stated objective to support the electrification of buses and two/three-wheelers is noteworthy, since many commuters rely on public transport and two/three-wheelers for transport. Passenger car ownership rates remain well below the global average. There are 35 cars for every 1 000 people in India, compared with a global average of 162 per 1 000 people and 480 per 1 000 people in advanced economies. On average, people living in India travel only one-eighth as far by car each year as those in advanced economies. Yet there are 157 two/three-wheelers per 1 000 people, 50% more than the global average and more than 2.5-times as many as in advanced economies.

Thanks partly to available incentives, 5% of two-wheelers, 50% of three-wheelers and 7% of buses sold in India today are electric. Over the next decade, two/three-wheelers and buses see faster rates of electrification in the STEPS than passenger cars because of existing government support, consumer preferences and the state of market development. With the net zero emissions by 2070 pathway in India, which is reflected in the APS, EVs account for a larger share of vehicle sales – especially for passenger cars – by 2035 than they do in the STEPS. Electric bus sales in the STEPS, on the other hand, are already similar to the APS trajectory as a result of existing government support and market activity. As a result of

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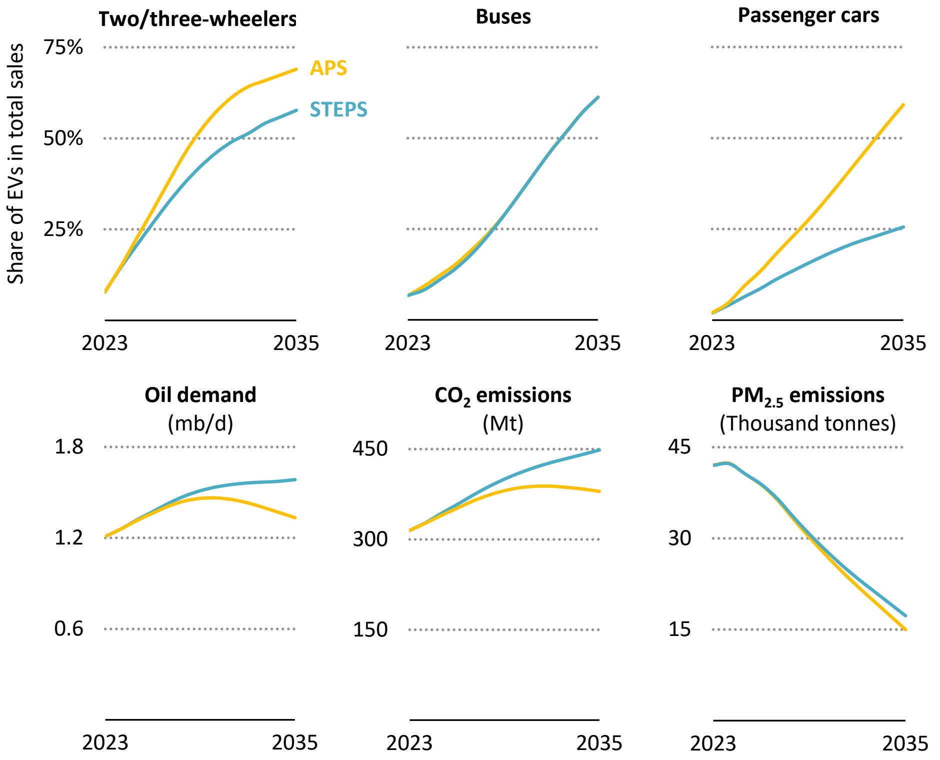
increased vehicle electrification, efficiency and uptake of biofuels in APS, both oil demand and CO_2 emissions from road passenger vehicles are around 17% lower in the APS by 2035 than in the STEPS. While they continue to rise in the coming years, both oil consumption and CO_2 emissions also begin to decline in the APS by the mid-2030s, while they keep rising in the STEPS. Combustion-related air pollutants such as fine particulate matter ($PM_{2.5}$) and nitrogen oxides (NO_X) in passenger road transport decline in both scenarios, with reductions stemming from improved fuel standards as well as vehicle electrification, but they decline further in the APS, where the level of these air pollutants is around 10% lower by 2035 than in the STEPS. Electrification of road transport in line with the net zero emissions by 2070 ambition therefore presents multiple benefits to India's environment and economy.

Figure 6.11 ⊳ EV sales, oil demand and emissions from passenger road transport in India in the STEPS and APS, 2023-2035



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Under India's net zero by 2070 pathway, reflected in the APS, the share of EVs in vehicle sales rises rapidly, and this contributes to reductions in oil demand and emissions

Notes: $PM_{2.5}$ = fine particulate matter. $PM_{2.5}$ emissions considered here relate only to emissions from combustion of fuels.

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6.9 Japan and Korea

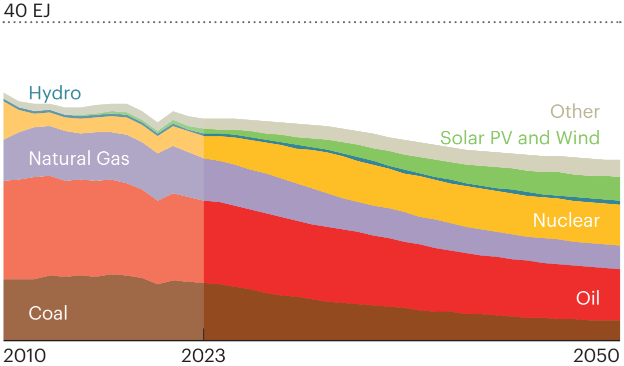
Population
Million people

2023 **176**
2050 **150**

GDP
Trillion USD
(2023, PPP)

2023 **9.4**
2050 **12.0**

Energy demand in the Stated Policies Scenario



2050

Net zero emissions target

3x

Declaration to Triple Nuclear Energy Capacity by 2050 endorsed by Japan and Korea

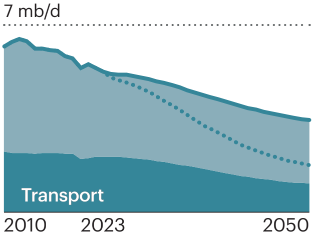
>150 **Trillion JPY**

Raising the funds for Japan Green Transformation through public and private financing over the next decade

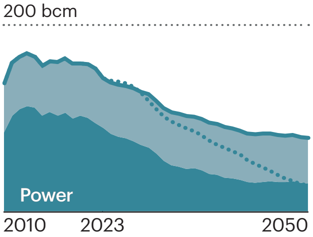
420 **Trillion KRW**

Providing policy loans to support Korean companies to reduce emissions until 2030

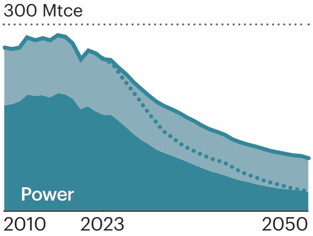
Oil demand



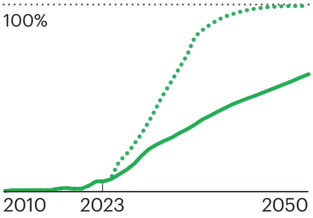
Natural gas demand



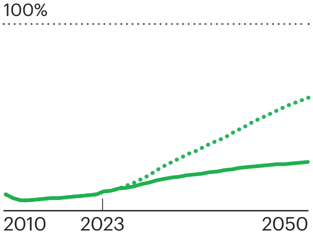
Coal demand



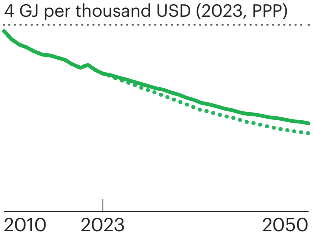
Zero-emissions vehicles in car sales



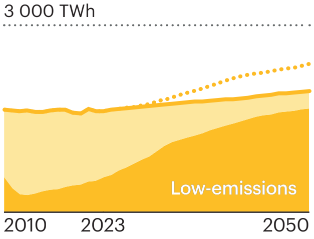
Low-emissions energy in industry



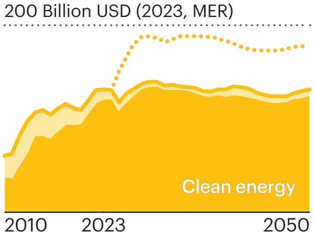
Energy intensity of GDP



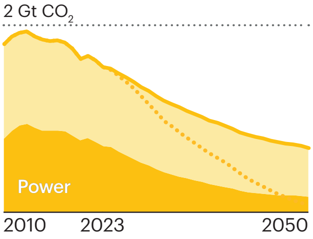
Electricity generation



Investment



CO_2 emissions



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Japan is the second-largest and Korea the fourth-largest economies in the Asia Pacific region. While there are many differences between these two countries, their economies and energy systems have some common features: relatively low and stable growth and inflation rates; ageing populations and falling birth rates; substantial capacity to generate electricity from nuclear power; and major hard-to-abate industrial sectors. Energy-intensive industries today account for 22% of total energy use in Japan and Korea, compared with 15% globally; 96% of energy for those industries is sourced from fossil fuels, nearly all of which are imported.

Fossil fuel demand is set to fall continuously as populations shrink and energy efficiency improves. Much has already been done to boost energy efficiency, which has improved by 30% since 2000. However, energy efficiency needs to improve by a further 25% by 2035, driving a total energy demand reduction of 5% to deliver the CO_2 reductions seen in the APS. Both countries are taking steps to bring about more gains in energy efficiency. In Korea, the Special Act on the Promotion of Distributed Energy took effect in June 2024 to complement the current centralised power system and prevent the unnecessary expansion of the transmission network. Japan's new energy efficiency technology strategy, approved in 2024, highlights important technologies for each energy sector, including non-fossil fuel sources such as hydrogen, ammonia and synthetic methane.

In the APS, the share of electricity generation from renewables in the two countries combined increases from 18% today to 48% in 2035, while the share of electricity generation from nuclear increases from 17% to 26%. Japan established the Basic Policy for the Realisation of Green Transformation to raise public and private investment and strengthen support for low-emissions technologies. In the wake of this policy, a new carbon capture and storage (CCS) law was adopted in 2024 to foster a business environment to spur CCS projects by 2030. The Hydrogen Society Promotion Act was also adopted to reduce the price gap between hydrogen and conventional fuels, with subsidies of Japanese yen (JPY) 3 trillion available over the next 15 years. In Korea, the 11th Basic Plan for Long-term Electricity Supply and Demand (11th Basic Plan) will be finalised in late 2024 to boost power generation from carbon-free sources. Korea launched the world's first clean hydrogen power bidding market in May 2024. In addition, Korea commissioned the 30 000 tonne per year Incheon Liquefied Hydrogen Plant. Recent policy changes are promoting nuclear expansion in Korea, witnessed by the commissioning of the Shin Hanul Unit 2 in 2024. Restarting existing reactors remains a priority for Japan to achieve its 2030 targets and energy security. It plans to restart two reactors in 2024 to add to the two restarted last year.

Meeting the goals of the APS requires a boost in annual clean energy investment in Japan and Korea from USD 120 billion to over USD 180 billion by 2035. Korea has announced Korean won (KRW) 420 trillion in policy loans to support clean energy technologies and to reduce emissions, together with a plan of KRW 9 trillion fund to finance green energy sources. In Japan, the world's first sovereign transition bonds were issued in 2024 as part of a plan to raise more than JPY 150 trillion through public and private financing over the next decade. In addition to accelerating decarbonisation of their economies, these measures to support new green energy investment help to reduce energy import dependence in Japan and Korea.

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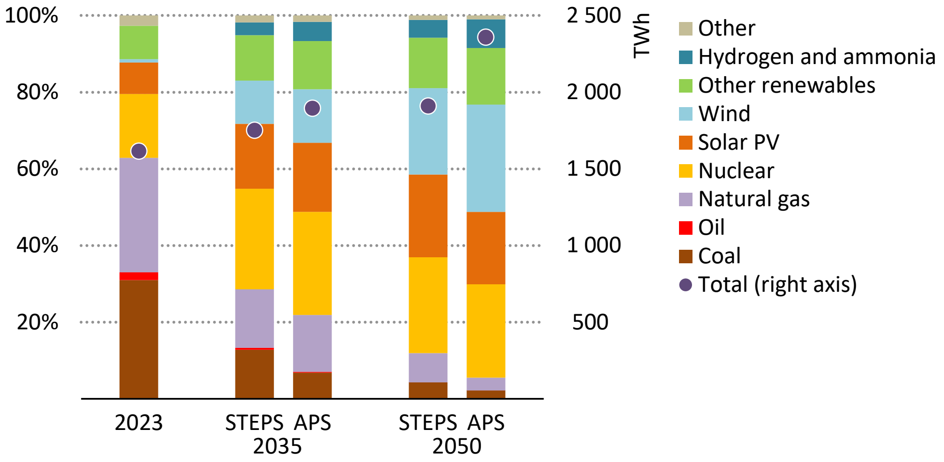
Conventional and innovative technologies advance energy security and clean energy transitions

Japan and Korea have significant energy- and carbon-intensive industry sectors which account for approximately 30% of GDP for each. Most energy used in industry is imported, which creates a priority for energy security during energy transitions. In the APS, energy supplies in Japan and Korea are underpinned by a variety of sources over the next decade as they pivot to increased use of clean energy sources – including renewables, nuclear and low-emissions fuels – to reduce emissions and secure supply (Figure 6.12). Although the share of fossil fuels in power generation decreases through to 2035 and beyond, natural gas continues to provide stable and flexible power for both countries in light of limited domestic supply options or interconnections with neighbouring countries. Natural gas is projected to remain an important energy source, accounting for nearly 12% of the power mix in 2035 in the APS, though gas-fired power drops to just 3% by 2050.

Figure 6.12 ⊳ Electricity generation by fuel in Japan and Korea in the STEPS and APS, 2023-2050



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Measures to reduce GHG emissions from natural gas use, decrease reliance on fossil fuels and increase use of clean energy are required to achieve the ambitions in the APS

Nuclear, an important clean energy source for stable electricity supply, accounts for over 15% of electricity generation in Japan and Korea today. In Korea, the draft of the 11th Basic Plan, which is due for adoption in late 2024, puts emphasis on more nuclear and less coal for power generation. Up to three new large-scale nuclear power units are being considered in the plan. In Japan, the Sixth Strategic Energy Plan and the Green Transformation bill support the role of nuclear to reduce CO_2 emissions from fossil fuels. Policy support in both countries is expected to increase the share of nuclear to over 25% by 2035 in the APS. Both countries have underlined the crucial importance of ensuring efficient and effective safety regulation.

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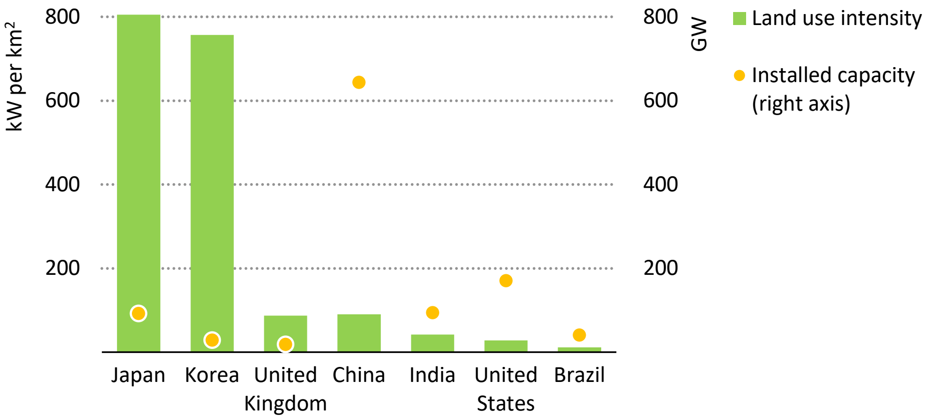
Beyond conventional energy sources, both countries need new technologies to decarbonise their economies and improve supply security. Hydrogen has a major part to play, enabled by ammonia, a derivative of hydrogen. Ammonia is relatively easy to transport long distances, so it can be used to supplement variable generation from renewables in which capacity is limited in both countries by land availability. Although hydrogen and ammonia only provide 4% of power in the APS by 2035, they have a key role as dispatchable low-carbon fuels. Japan and Korea are among the few countries with a stated policy to use hydrogen for power generation and are likely to have an important role in driving technological progress as the biggest consumers of hydrogen for power. In the APS, they account for 37% of electricity generated from hydrogen worldwide in 2035. Japan began co-firing ammonia in coal power plants in 2024 – a first step towards producing power from ammonia only.

Perovskite solar cells, which are derived from a non-silicon-based thin-film PV technology, are of particular interest in Japan and Korea. Both need to increase their deployment of solar PV, which more than doubles its share of electricity generation from 8% today to 21% by 2035 in the APS. However, both countries already have high levels of installed solar PV capacity relative to their non-forested land area (Figure 6.13), as their high population densities and specific geographies limit the amount of land available for panel installations. Perovskite solar cells can enable capacity expansion without increasing land use: because they are light and flexible, they can be installed on walls and roofs with low load-bearing capacity. To lower costs and raise efficiencies, both governments are funding research and development, and supporting new projects.

Figure 6.13 ▷ Installed solar PV capacity per non-forested land area in selected countries, 2023



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Korea and Japan have installed significant solar PV capacity and much more relative to their non-forested land area than other countries

Note: kW = kilowatt; km² = square kilometre; GW = gigawatt.

Source: Land-use data based on FAO (2020).

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6.10 Southeast Asia

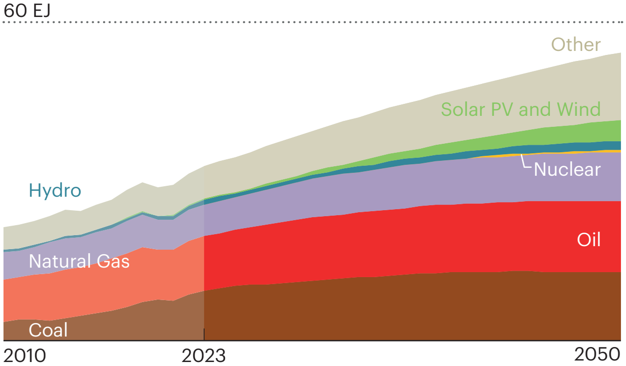
Population
Million people

2023 **685**
2050 **787**

GDP
Trillion USD
(2023, PPP)

2023 **11.2**
2050 **29.9**

Energy demand in the Stated Policies Scenario



8 out of 10

Countries with net zero or carbon neutrality targets by 2050-2065

2045-2056

Target phase-out of coal from power generation in Malaysia, Thailand, Indonesia and Viet Nam

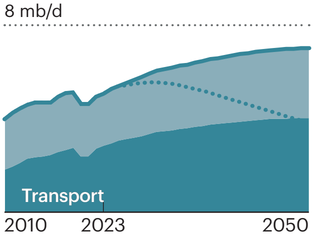
23%

Target share of renewable energy in total energy supply by 2025 under the ASEAN Plan of Action for Energy Cooperation

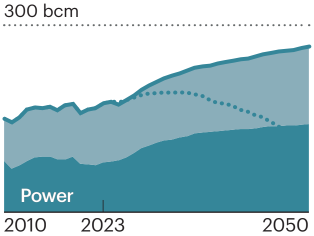
35.5 Billion USD

Total funding raised through Just Energy Transition Partnerships in Indonesia and Viet Nam to support their energy transitions

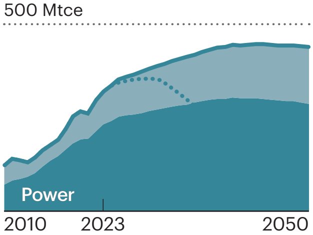
Oil demand



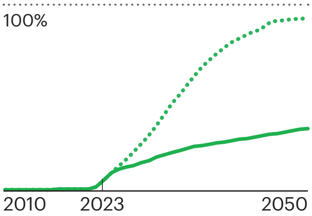
Natural gas demand



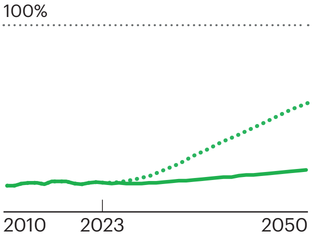
Coal demand



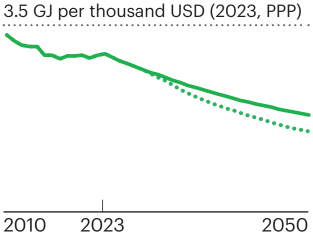
Zero-emissions vehicles in car sales



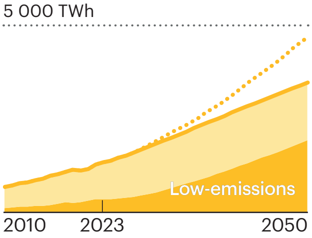
Low-emissions energy in industry



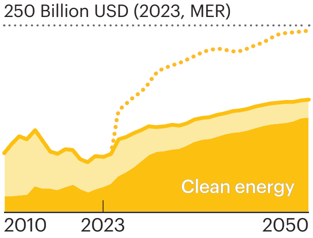
Energy intensity of GDP



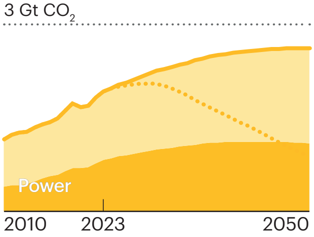
Electricity generation



Investment



CO_2 emissions



— Stated Policies Scenario ··· Announced Pledges Scenario

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Southeast Asia is one of the fastest growing economies in the world. It has an increasingly critical role in global energy security and clean energy transitions. Collectively the regional economy grew 4% in 2023, reflecting its continued post-pandemic recovery. Home to around 685 million people, Southeast Asia represents 9% of the global population and accounts for 6% of global GDP. GDP per capita in Southeast Asia is well below the global average.

Each of the ten countries[3] in Southeast Asia is distinctive in terms of development, industrial output, politics and geography. In Myanmar, energy demand per capita is just a fifth of the global average; in Singapore – where the first IEA Regional Cooperation Centre is to be established in 2024 – it is almost four-times the global average. Energy development priorities also vary across countries with different resource endowments, though common concerns include managing the impacts of climate change, investing in infrastructure and mobilising international investment, and cooperation via the Association of Southeast Asian Nations.

Rising demand from key sectors, notably power, transport and industry, drove a 5% increase in energy demand in 2023. This slows to an average of around 2.5% per year over the next decade. Major regional industries include manufacturing, tourism and the digital economy, all of which are likely to expand in the years ahead. Demand for data processing power and data centre capacity is rising across the region. Half of global mined nickel production in 2023 was in Indonesia, giving it a crucial link in the supply chain for EV batteries. VinFast, a Vietnamese automaker, is a leading EV manufacturer in Southeast Asia; around 15% of new car sales were electric in Viet Nam in 2023, the highest share of any country in the region.

Southeast Asia sees the second-fastest growth in energy demand after India, adding more than 20 EJ to demand by 2050 in the STEPS. While global energy demand is expected to increase around 6% by 2035 in the STEPS, it is set to increase by a third in Southeast Asia. In the STEPS, investment in renewables is on course to triple in the region by 2035, from a relatively low base, almost tripling installed renewables capacity from current levels, while spending on energy efficiency is also projected to rise strongly by 2035. In the APS, renewables capacity increases twice as fast as in the STEPS by 2035, and spending on energy efficiency is 30% higher, though in both scenarios improvements in energy intensity levels lag other regions, including India. Against a background of sharply rising overall energy demand, the measures in the STEPS are not enough to prevent demand for oil and natural gas from rising through to 2050, although coal demand flattens out in the 2040s. In the APS, by contrast, demand for all three fossil fuels starts to decline from mid-2030s.

Fossil fuels accounted for almost 75% of power sector inputs in 2023 in Southeast Asia. Dependence on imports is set to deepen, with the region on track to become a net importer of natural gas in the late 2020s. Affordability and energy security are priority considerations as the region considers its energy future, together with the role of the energy sector in economic development and emissions reductions.

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[3] Brunei Darussalam, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Singapore, Thailand and Viet Nam.

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How to tackle emissions from coal-fired power plants?

Coal is the primary power source in Southeast Asia today. Of the additional electricity generated over the past 20 years, 60% was from coal, and the region has nearly 110 GW of existing installed coal-fired capacity. Over 50% of this capacity is less than 10 years old, and over 80% is less than 20 years old. Since the technical lifetime of a coal plant is typically 40-50 years, many plants potentially have decades of operation ahead. Emissions from coal-fired power generation in Southeast Asia were 650 Mt CO_2 in 2023, equating to 35% of its total energy-related CO_2 emissions. Furthermore, new plants are still being commissioned: coal-fired generation capacity continues to increase until the 2040s in the STEPS, while in the APS it peaks around 2030.

The essential condition for reducing reliance on coal and cutting emissions from coal-fired power generation is to develop clean and affordable ways of providing the energy services that coal plants currently provide, both for generation and for electricity system reliability services. This is crucial to avoid trade-offs between the need to reduce coal use and the need to ensure electricity security and development objectives.

Building up clean sources of generation more quickly should allow for permitting of new coal plants to be halted, but measures are also needed to reduce emissions from operating plants or those at an advanced stage of development. Moving coal plants towards retirement typically requires funds to support their managed phase-out. The Energy Transition Mechanism arranged by the Asian Development Bank provides one financing route for early retirement, while a number of other initiatives are looking to develop solutions for transition credits to be utilised as a credible financing instrument.

Apart from retiring plants early, strategies to tackle emissions include repurposing to focus on system adequacy or flexibility services, co-firing with ammonia and biomass, and retrofitting with CCUS. Focussing operations on system adequacy or flexibility services means that coal plants operate at lower capacity factors, thereby producing less electricity and emissions, but they remain available for use when system needs are highest. Repurposing coal plants for flexibility is widely adopted in the APS because it enables the existing coal fleet to support and facilitate the integration of rapidly increasing shares of variable renewables. While some coal plants may require minor equipment upgrades to operate more flexibly, the main challenges generally arise from the need to adapt existing operational practices and contract structures.

Retrofitting coal-fired power plants with carbon capture or using low-emissions fuels like ammonia or biomass are other options to cut emissions from existing facilities. In the STEPS and APS, switching to use higher shares of low-emissions fuels gains some momentum. However, the higher fuel cost of ammonia means that these plants run at lower capacity factors than unabated coal plants today and primarily serve to provide flexibility and backup capacity, rather than baseload electricity (Figure 6.14).

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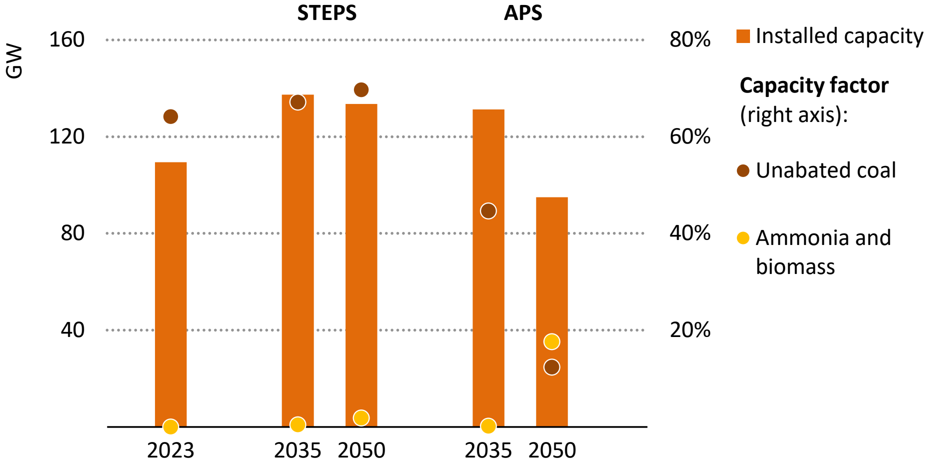
Figure 6.14 ▷ Installed coal-fired generation capacity and average capacity factor in Southeast Asia in the STEPS and APS, 2023-2050



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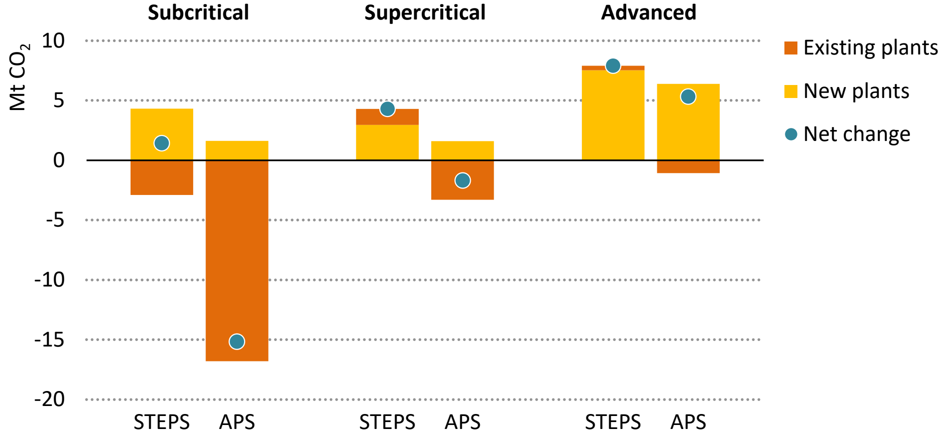
Coal capacity factors decrease as plants operate more flexibly and some are converted to co-fire with ammonia and biomass

Figure 6.15 ▷ Average annual change in coal-fired power plant emissions by technology type in Southeast Asia in the STEPS and APS, 2023-35



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Older and less efficient subcritical coal plants are increasingly repurposed to provide flexibility or retired, cutting emissions by around 15 Mt CO_2 per year on average in the APS

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In both the STEPS and APS, existing older and less efficient subcritical coal plants are the first to pivot to provide flexibility and adequacy services rather than bulk electricity, helping to cut emissions from this plant type by an average 3 Mt per year in the STEPS and nearly 17 Mt per year in the APS over the period to 2035. More efficient supercritical and other advanced coal plants continue to operate at high load factors in the STEPS, with additional plants of these types coming online and increasing aggregate emissions. In the APS, these plants also start operating more flexibly in response to changes in the rest of the power system, especially as wind and solar PV deployment accelerates after 2030, and this helps to cut emissions further (Figure 6.15).

As a result of the shift towards more flexible operations, early retirements and fewer new coal plants being commissioned, total annual CO_2 emissions from coal generation in Southeast Asia drop by 20% to 510 Mt CO_2 in 2035 in the APS. In the STEPS, by contrast, emissions continue to grow to nearly 820 Mt CO_2 in 2035 as new capacity comes online and existing supercritical and advanced coal power plants by and large continue to operate in baseload mode.

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ANNEXES

Box A.1 ▹ *World Energy Outlook* links

WEO homepage

WEO-2024 information **iea.li/weo24**

WEO-2024 datasets

Data in Annex A is available to download free in electronic format at:
iea.li/weo-data

An extended dataset, including the data behind figures, tables and the *WEO-2024* slide deck is available to purchase at:
iea.li/weo-extended-data

Modelling

Documentation and methodology / Investment costs
iea.li/model

Recent analysis

Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C Goal in Reach	iea.li/netzero
From Taking Stock to Taking Action How to implement the COP28 energy goals	iea.li/COP28-action
Global EV Outlook 2024	iea.li/gevo24
Batteries and Secure Energy Transitions	iea.li/batteries
World Energy Investment 2024	iea.li/wei24
State of Energy Policy 2024	iea.li/sep24
Strategies for Affordable and Fair Clean Energy Transitions	iea.li/affordability
Global Methane Tracker 2024	iea.li/methane-tracker24
Global Critical Minerals Outlook 2024	iea.li/critical-minerals24
Reducing the Cost of Capital	iea.li/capital

Databases

Policy Databases	iea.li/policies-database
Sustainable Development Goal 7	iea.li/SDG
Energy subsidies: Tracking the impact of fossil-fuel subsidies	iea.li/subsidies

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Tables for scenario projections

General note to the tables

This annex includes global historical and projected data by scenario for the following five datasets:

- A.1: World energy supply.
- A.2: World final energy consumption.
- A.3: World electricity sector: gross electricity generation and electrical capacity.
- A.4: World CO_2 emissions: carbon dioxide (CO_2) emissions from fossil fuel combustion and industrial processes.
- A.5: World economic and activity indicators: selected economic and activity indicators.

Each dataset is given for the following scenarios: (a) Stated Policies Scenario (STEPS) [Tables A.1a. to A.5a]; (b) Announced Pledges Scenario (APS) [Tables A.1b. to A.5b]; and (c) Net Zero Emissions by 2050 (NZE) Scenario [Tables A.1c. to A.5c].

This annex also includes regional historical and projected data for the STEPS and the APS for the following datasets:

- Tables A.6 – A.7: Total energy supply, renewables energy supply in exajoules (EJ).
- Tables A.8 – A.11: Oil production, oil demand, world liquids demand, and refining capacity and runs in million barrels per day (mb/d).
- Tables A.12 – A.13: Natural gas production, natural gas demand in billion cubic metres (bcm).
- Tables A.14 – A.15: Coal production, coal demand in million tonnes of coal equivalent (Mtce).
- Tables A.16 – A.22: Electricity generation total and by source (renewables, solar photovoltaics [PV], wind, nuclear, natural gas, coal) in terawatt-hours (TWh).
- Tables A.23 – A.26: Total final consumption and consumption by sector (industry, transport and buildings) in exajoules (EJ).
- Tables A.27 – A.28: Hydrogen demand (PJ) and the low-emissions hydrogen balance in million tonnes of hydrogen equivalent (Mt H_2 equivalent).
- Tables A.29 – A.31: Total carbon dioxide (CO_2) emissions, electricity and heat sectors CO_2 emissions, total final consumption CO_2 emissions in million tonnes of CO_2 emissions (Mt CO_2).

Tables A.6 to A.31 cover: World, North America, United States, Central and South America, Brazil, Europe, European Union, Africa, Middle East, Eurasia, Russia, Asia Pacific, China, India, Japan and Southeast Asia.

The definitions for regions, fuels and sectors are in Annex C.

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Abbreviations/acronyms used in the tables include: CAAGR = compound average annual growth rate; CCUS = carbon capture, utilisation and storage; EJ = exajoule; GJ = gigajoule; GW = gigawatt; Mt CO_2 = million tonnes of carbon dioxide; TWh = terawatt-hour. Fossil fuels used for energy purposes without carbon capture, utilisation and storage (CCUS) are classified as "unabated". Total fossil fuel use is equal to unabated fossil fuels plus fossil fuels with CCUS plus non-energy use of fossil fuels.

Both in the text of this report and in these annex tables, rounding may lead to minor differences between totals and the sum of their individual components. Growth rates are calculated on a compound average annual basis and are marked "n.a." when the base year is zero or the value exceeds 200%. Nil values are marked "-".

Box A.1 provides details on where to download the *World Energy Outlook (WEO)* tables in Excel format. In addition, Box A.1 lists the links relating to the main *WEO* website, documentation and methodology of the Global Energy and Climate Model, investment costs, policy databases and recent *WEO Special Reports*.

Data sources

The Global Energy and Climate Model is a very data-intensive model covering the whole global energy system. Detailed references on databases and publications used in the modelling and analysis may be found in Annex E.

The formal base year for this year's projections is 2022, as this is the most recent year for which a complete picture of energy demand and production is available. However, we have used more recent data wherever available, and we include our 2023 estimates for energy production and demand in this annex. Estimates for the year 2023 are based on the IEA *CO_2 Emissions in 2023* report in which data are derived from a number of sources, including the latest monthly data submissions to the IEA Energy Data Centre, other statistical releases from national administrations, and recent market data from the IEA *Market Report Series* that cover coal, oil, natural gas, renewables and power. Investment estimates include the year 2024 data, based on the IEA *World Energy Investment 2024* report. Historical data for gross power generation capacity (Table A.3) are drawn from the World Electric Power Plants Database (March 2023 edition) and Power Plant Units database both published by S&P Global Market Intelligence[1]; the International Atomic Energy Agency PRIS database; the Global Coal Plant Tracker, and the Global Oil and Gas Plant Tracker databases published by Global Energy Monitor.

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[1] The S&P World Electric Power Plants database has been discontinued with March 2023 the last published version. This product has been largely subsumed into the S&P Power Plant Units database which is published within the suite of datasets on the S&P Capital IQ Pro platform by S&P Global Market Intelligence. As a result of this migration, differences may be observed and in particular for fossil-fuelled power plants.

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Definitional note: Energy supply and transformation tables

Total energy supply (TES) is equivalent to electricity and heat generation plus the *other energy sector*, excluding electricity, heat and hydrogen, plus total final consumption, excluding electricity, heat and hydrogen. TES does not include ambient heat from heat pumps or electricity trade. *Solar* in TES includes solar PV generation, concentrating solar power (CSP) and final consumption of solar thermal. *Biofuels conversion losses* are the conversion losses to produce biofuels (mainly from modern solid bioenergy) used in the energy sector. *Low-emissions hydrogen production* is merchant low-emissions hydrogen production (excluding onsite production at industrial facilities and refineries), with inputs referring to total fuel inputs and outputs to produce hydrogen. While not itemised separately, *geothermal* and *marine* (tidal and wave) energy are included in the *renewables* category of TES and *electricity and heat sectors*. While not itemised separately, *non-renewable waste* and *other sources* are included in TES.

Definitional note: Energy demand tables

Sectors comprising total final consumption (TFC) include *industry* (energy use and feedstock), *transport* and *buildings* (residential, services and non-specified other). While not itemised separately, *agriculture* and *other non-energy use* are included in TFC. While not itemised separately, *non-renewable waste*, *solar thermal* and *geothermal* energy are included in *buildings*, *industry* and *TFC*. *Aviation* and *shipping* include both domestic and international energy demand. Energy demand from international marine and aviation bunkers are included in global transport totals and TFC.

Definitional note: Fossil fuel production and demand tables

Oil production and demand is expressed in million barrels per day (mb/d). Tight oil includes tight crude oil and condensate production except for the United States, which includes tight crude oil only (US tight condensate volumes are included in natural gas liquids). Processing gains cover volume increases that occur during crude oil refining. Biofuels and their inclusion in liquids demand is expressed in energy-equivalent volumes of gasoline and diesel. Natural gas production and demand is expressed in billion cubic metres (bcm). Coal production and demand is expressed in million tonnes of coal equivalent (Mtce). Differences between historical production and demand volumes for oil, gas and coal are due to changes in stocks. Bunkers include both international marine and aviation fuels. Refining capacity at risk is defined as the difference between refinery capacity and refinery runs, with the latter including a 14% allowance for downtime. Projected shutdowns beyond those publicly announced are also counted as capacity at risk.

Definitional note: Electricity tables

Electricity generation expressed in terawatt-hours (TWh) and installed electrical capacity data expressed in gigawatts (GW) are both provided on a gross basis, i.e. includes own use by the generator. Projected gross electrical capacity is the sum of existing capacity and additions, less retirements. While not itemised separately, *other sources* are included in total

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electricity generation. Hydrogen and ammonia are fuels that can provide a low-emissions alternative to natural gas- and coal-fired electricity generation – either through co-firing or full conversion of facilities. Blending levels of hydrogen in gas-fired plants and ammonia in coal-fired plants are represented in the scenarios and reported in the tables. The electricity generation outputs in the tables are based on fuel input shares, while the hydrogen and ammonia capacity is derived based on a typical capacity factor.

Definitional note: CO_2 emissions tables

Total CO_2 includes carbon dioxide emissions from the combustion of fossil fuels and non-renewable wastes; from industrial and fuel transformation processes (process emissions); and from flaring and CO_2 removal. CO_2 removal includes: captured and stored emissions from the combustion of bioenergy and renewable wastes; from biofuels production; and from direct air capture. *Aviation* and *shipping* include both domestic and international emissions.

The first two entries are often reported as bioenergy with carbon capture and storage (BECCS). Note that some of the CO_2 captured from biofuels production and direct air capture is used to produce synthetic fuels, which is not included as CO_2 removal.

Total CO_2 captured includes the carbon dioxide captured from CCUS facilities, such as electricity generation or industry, and atmospheric CO_2 captured through direct air capture, but excludes that captured and used for urea production.

Definitional note: Economic and activity indicators

The emissions intensity expressed in grammes of carbon dioxide per kilowatt-hour (g CO_2 per kWh) is calculated based on electricity-only plants and the electricity component of combined heat and power (CHP) plants.[2] *Primary chemicals* include ethylene, propylene, aromatics, methanol and ammonia. Industrial production data for *aluminium* excludes production based on internally generated scrap. Heavy-duty trucks activity includes freight activity of medium freight trucks and heavy freight trucks. *Aviation* activity includes both domestic and international flight activity. *Shipping* activity refers to international shipping activity.

Abbreviations used include: GDP = gross domestic product; GJ = gigajoule; m^2 = square metres; Mt = million tonnes; pkm = passenger-kilometres; PPP = purchasing power parity; tkm = tonnes-kilometres.

Definitional note: Hydrogen tables

Total hydrogen demand includes merchant (or offsite) hydrogen demand and hydrogen demand in industry and refineries covered by onsite production. It also includes hydrogen used in the production of hydrogen-based fuels (ammonia, synthetic hydrocarbon fuels). The

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[2] To derive the associated electricity-only emissions from CHP plants, we assume that the heat production of a CHP plant is 90% efficient and the remainder of the fuel input is allocated to electricity generation.

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hydrogen balance table A.28 is expressed in million tonnes of hydrogen equivalent, which means for hydrogen-based fuels the mass of hydrogen feedstock needed to produce them. Hydrogen demand in end-use sectors includes total final consumption of hydrogen and hydrogen-based fuels as well as hydrogen demand in industry covered by onsite production within industrial facilities. Low-emissions hydrogen trade as a share of production represents the percentage of produced low-emissions hydrogen (including merchant hydrogen and that which is produced onsite in industry and refining) which is exported from the region as hydrogen or as an energy product.

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Table A.1a: World energy supply

				Stated Policies (EJ)				Shares (%)			CAAGR (%) 2023 to:	
	2010	2022	2023	2030	2035	2040	2050	2023	2030	2050	2030	2050
Total energy supply	**536**	**629**	**642**	**676**	**682**	**691**	**722**	**100**	**100**	**100**	**0.7**	**0.4**
Renewables	43	74	78	120	153	185	241	12	18	33	6.4	4.3
Solar	1	6	8	26	42	58	84	1	4	12	19	9.3
Wind	1	8	8	18	27	34	44	1	3	6	12	6.4
Hydro	12	16	15	17	19	20	23	2	3	3	1.9	1.5
Modern solid bioenergy	23	34	36	44	46	49	56	6	6	8	2.9	1.7
Modern liquid bioenergy	2	4	5	6	6	7	8	1	1	1	3.4	2.2
Modern gaseous bioenergy	1	1	1	2	3	5	8	0	0	1	7.7	7.2
Traditional use of biomass	21	19	19	15	13	12	10	3	2	1	-3.8	-2.5
Nuclear	30	29	30	36	41	45	49	5	5	7	2.5	1.8
Natural gas	115	144	145	153	153	152	152	23	23	21	0.8	0.2
Unabated	109	136	137	144	142	140	139	21	21	19	0.7	0.0
With CCUS	0	1	1	1	2	2	3	0	0	0	11	6.3
Oil	173	187	192	195	189	182	176	30	29	24	0.2	-0.3
Non-energy use	26	30	31	36	38	40	41	5	5	6	2.3	1.1
Coal	153	172	175	156	131	114	94	27	23	13	-1.7	-2.3
Unabated	151	169	172	151	126	109	89	27	22	12	-1.8	-2.4
With CCUS	-	0	0	0	0	0	1	0	0	0	46	15
Electricity and heat sectors	**200**	**249**	**255**	**275**	**286**	**302**	**334**	**100**	**100**	**100**	**1.1**	**1.0**
Renewables	20	41	43	78	108	136	182	17	28	54	8.8	5.5
Solar PV	0	5	6	23	38	54	78	2	8	23	22	10
Wind	1	8	8	18	27	34	44	3	7	13	12	6.4
Hydro	12	16	15	17	19	20	23	6	6	7	1.9	1.5
Bioenergy	4	9	10	14	16	17	21	4	5	6	5.1	3.0
Hydrogen	-	-	-	0	0	0	0	-	0	0	n.a.	n.a.
Ammonia	-	-	-	0	0	0	0	-	0	0	n.a.	n.a.
Nuclear	30	29	30	36	41	45	49	12	13	15	2.5	1.8
Unabated natural gas	47	56	57	58	56	54	52	22	21	16	0.1	-0.3
Natural gas with CCUS	-	-	-	0	0	0	1	-	0	0	n.a.	n.a.
Oil	11	9	8	4	3	3	2	3	2	0	-8.9	-6.1
Unabated coal	91	112	115	98	76	63	47	45	36	14	-2.2	-3.3
Coal with CCUS	-	0	0	0	0	0	0	0	0	0	32	16
Other energy sector	**51**	**67**	**69**	**70**	**70**	**71**	**79**	**100**	**100**	**100**	**0.3**	**0.5**
Biofuels conversion losses	-	6	6	8	8	9	10	100	100	100	3.4	1.9
Low-emissions hydrogen (offsite)												
Production inputs	-	0	0	1	2	3	7	100	100	100	n.a.	n.a.
Production outputs	-	0	0	1	1	2	5	100	100	100	106	30
For hydrogen-based fuels	-	-	-	0	0	1	2	-	25	44	n.a.	n.a.

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Table A.2a: World final energy consumption

				Stated Policies (EJ)				Shares (%)			CAAGR (%) 2023 to:	
	2010	2022	2023	2030	2035	2040	2050	2023	2030	2050	2030	2050
Total final consumption	**377**	**437**	**445**	**485**	**499**	**509**	**533**	**100**	**100**	**100**	**1.3**	**0.7**
Electricity	64	88	91	114	129	143	168	20	23	32	3.3	2.3
Liquid fuels	153	173	176	187	183	179	177	40	38	33	0.8	0.0
Biofuels	2	4	5	6	6	7	8	1	1	2	3.4	2.2
Ammonia	-	-	-	0	0	0	0	-	0	0	n.a.	n.a.
Synthetic oil	-	-	-	0	0	0	1	-	0	0	n.a.	n.a.
Oil	151	168	172	181	177	171	167	39	37	31	0.7	-0.1
Gaseous fuels	57	72	71	80	82	85	89	16	16	17	1.6	0.8
Biomethane	0	0	0	1	1	2	5	0	0	1	14	11
Hydrogen	-	0	0	0	0	1	2	0	0	0	51	22
Synthetic methane	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.
Natural gas	57	71	70	78	80	81	82	16	16	15	1.5	0.5
Solid fuels	90	87	88	84	82	80	75	20	17	14	-0.7	-0.6
Solid bioenergy	33	34	35	33	33	33	33	8	7	6	-0.8	-0.3
Coal	56	51	52	50	48	46	42	12	10	8	-0.6	-0.8
Heat	12	15	15	18	18	18	18	3	4	3	1.9	0.5
Industry	**143**	**170**	**173**	**193**	**200**	**204**	**209**	**100**	**100**	**100**	**1.6**	**0.7**
Electricity	27	38	39	47	50	53	58	22	25	28	3.0	1.5
Liquid fuels	29	34	34	40	41	42	43	20	20	20	2.1	0.8
Oil	29	34	34	40	41	42	42	20	20	20	2.1	0.8
Gaseous fuels	24	32	33	36	38	40	42	19	19	20	1.6	0.9
Biomethane	0	0	0	0	1	1	2	0	0	1	16	12
Hydrogen	-	0	0	0	0	0	0	0	0	0	44	20
Unabated natural gas	21	28	29	32	33	34	34	17	17	16	1.4	0.6
Natural gas with CCUS	0	0	0	0	0	0	0	0	0	0	13	8.0
Solid fuels	58	58	59	60	60	59	57	34	31	27	0.3	-0.1
Modern solid bioenergy	8	11	11	13	14	15	16	6	7	8	2.3	1.5
Unabated coal	48	44	45	44	43	41	38	26	23	18	-0.3	-0.6
Coal with CCUS	-	0	0	0	0	0	0	0	0	0	29	8.8
Heat	5	8	8	10	10	10	9	5	5	4	1.8	0.3
Chemicals	37	49	50	58	61	63	63	29	30	30	2.1	0.9
Iron and steel	31	36	37	37	37	37	36	21	19	17	0.2	-0.1
Cement	9	12	12	12	12	12	12	7	6	6	0.0	0.0
Aluminium	5	7	7	7	8	8	8	4	4	4	0.7	0.3

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Table A.2a: World final energy consumption (continued)

				Stated Policies (EJ)				Shares (%)			CAAGR (%) 2023 to:	
	2010	2022	2023	2030	2035	2040	2050	2023	2030	2050	2030	2050
Transport	**101**	**118**	**122**	**132**	**133**	**134**	**140**	**100**	**100**	**100**	**1.1**	**0.5**
Electricity	1	2	2	5	10	14	21	1	4	15	16	9.5
Liquid fuels	96	111	115	120	115	111	110	94	91	78	0.6	-0.2
Biofuels	2	4	5	6	6	7	8	4	4	6	3.4	2.1
Oil	94	107	110	114	109	104	101	90	87	72	0.5	-0.3
Gaseous fuels	4	5	5	7	7	8	10	4	5	7	3.3	2.2
Biomethane	0	0	0	0	0	1	1	0	0	1	12	9.7
Hydrogen	-	0	0	0	0	1	2	0	0	1	50	23
Natural gas	4	5	5	6	7	7	7	4	5	5	2.8	0.9
Road	75	90	92	97	96	94	97	75	74	69	0.8	0.2
Passenger cars	39	46	47	47	45	43	43	39	36	31	-0.0	-0.4
Heavy-duty trucks	22	28	28	33	35	36	40	23	25	28	2.1	1.3
Aviation	10	11	13	17	18	20	24	11	13	17	3.3	2.2
Shipping	10	11	11	12	13	13	14	9	9	10	1.5	0.7
Buildings	**111**	**125**	**124**	**132**	**137**	**141**	**153**	**100**	**100**	**100**	**0.9**	**0.8**
Electricity	35	46	46	56	63	70	82	37	43	54	2.8	2.1
Liquid fuels	13	13	13	12	10	9	9	10	9	6	-1.2	-1.4
Biofuels	-	-	-	0	0	0	0	-	0	0	n.a.	n.a.
Oil	13	13	13	12	10	9	9	10	9	6	-1.3	-1.4
Gaseous fuels	26	30	29	31	31	31	32	23	24	21	1.3	0.4
Biomethane	0	0	0	0	0	0	1	0	0	1	13	11
Hydrogen	-	-	-	0	0	0	0	-	0	0	n.a.	n.a.
Natural gas	25	29	28	31	30	30	30	23	23	20	1.2	0.2
Solid fuels	31	27	27	21	20	18	16	22	16	10	-3.1	-1.9
Modern solid bioenergy	4	4	4	5	5	5	6	3	4	4	2.1	1.2
Traditional use of biomass	21	19	19	15	13	12	10	15	11	6	-3.8	-2.5
Coal	6	3	3	2	1	1	0	3	1	0	-8.2	-8.6
Heat	6	7	7	8	8	8	8	5	6	5	2.0	0.7
Residential	78	87	86	87	88	90	96	69	66	63	0.3	0.4
Services	33	38	39	45	48	51	57	31	34	37	2.3	1.5

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Table A.3a: World electricity sector

				Stated Policies (TWh)				Shares (%)			CAAGR (%) 2023 to:	
	2010	2022	2023	2030	2035	2040	2050	2023	2030	2050	2030	2050
Total generation	**21 511**	**29 145**	**29 863**	**37 489**	**42 766**	**48 409**	**58 352**	**100**	**100**	**100**	**3.3**	**2.5**
Renewables	4 209	8 567	9 029	17 577	24 930	31 802	42 770	30	47	73	10.0	5.9
Solar PV	32	1 294	1 612	6 452	10 689	14 912	21 557	5	17	37	22	10
Wind	342	2 120	2 336	5 024	7 535	9 492	12 347	8	13	21	12	6.4
Hydro	3 455	4 350	4 249	4 846	5 190	5 572	6 399	14	13	11	1.9	1.5
Bioenergy	309	691	714	1 081	1 237	1 402	1 758	2	3	3	6.1	3.4
of which BECCS	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.
CSP	2	14	18	25	58	115	238	0	0	0	5.1	10
Geothermal	68	97	100	147	206	271	384	0	0	1	5.7	5.1
Marine	1	1	1	3	15	38	87	0	0	0	25	21
Nuclear	2 756	2 684	2 765	3 266	3 746	4 059	4 460	9	9	8	2.4	1.8
Hydrogen and ammonia	-	-	-	21	58	80	89	-	0	0	n.a.	n.a.
Fossil fuels with CCUS	-	1	1	8	39	79	111	0	0	0	41	21
Coal with CCUS	-	1	1	4	17	28	29	0	0	0	28	15
Natural gas with CCUS	-	-	-	4	22	52	82	-	0	0	n.a.	n.a.
Unabated fossil fuels	14 458	17 765	17 941	16 503	13 886	12 276	10 806	60	44	19	-1.2	-1.9
Coal	8 671	10 451	10 648	9 213	6 969	5 650	4 256	36	25	7	-2.0	-3.3
Natural gas	4 819	6 515	6 540	6 910	6 622	6 405	6 425	22	18	11	0.8	-0.1
Oil	968	800	753	379	295	221	126	3	1	0	-9.3	-6.4

				Stated Policies (GW)				Shares (%)			CAAGR (%) 2023 to:	
	2010	2022	2023	2030	2035	2040	2050	2023	2030	2050	2030	2050
Total capacity	**5 259**	**8 768**	**9 436**	**15 922**	**20 934**	**25 400**	**31 436**	**100**	**100**	**100**	**7.8**	**4.6**
Renewables	1 334	3 684	4 246	9 768	14 095	17 974	23 218	45	61	74	13	6.5
Solar PV	40	1 185	1 610	5 838	9 203	12 333	16 445	17	37	52	20	9.0
Wind	181	899	1 015	2 079	2 862	3 419	4 189	11	13	13	11	5.4
Hydro	1 028	1 398	1 411	1 576	1 689	1 808	2 031	15	10	6	1.6	1.4
Bioenergy	74	180	188	242	283	323	394	2	2	1	3.6	2.8
of which BECCS	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.
CSP	1	6	7	10	21	35	68	0	0	0	5.0	8.8
Geothermal	10	15	15	22	31	40	56	0	0	0	5.8	5.1
Marine	0	1	1	1	7	16	34	0	0	0	8.6	16
Nuclear	403	417	416	478	534	586	647	4	3	2	2.0	1.7
Hydrogen and ammonia	-	-	-	7	17	24	20	-	0	0	n.a.	n.a.
Fossil fuels with CCUS	-	0	0	2	13	25	37	0	0	0	50	24
Coal with CCUS	-	0	0	1	6	11	14	0	0	0	39	20
Natural gas with CCUS	-	-	-	1	7	14	23	-	0	0	n.a.	n.a.
Unabated fossil fuels	3 510	4 602	4 665	4 798	4 630	4 438	4 064	49	30	13	0.4	-0.5
Coal	1 613	2 204	2 243	2 236	2 038	1 845	1 385	24	14	4	-0.0	-1.8
Natural gas	1 468	1 981	2 007	2 262	2 323	2 366	2 528	21	14	8	1.7	0.9
Oil	429	417	414	300	269	227	151	4	2	0	-4.5	-3.7
Battery storage	1	45	89	853	1 630	2 339	3 438	1	5	11	38	14

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Table A.4a: World CO_2 emissions

				Stated Policies (Mt CO_2)				CAAGR (%) 2023 to:	
	2010	2022	2023	2030	2035	2040	2050	2030	2050
Total CO_2*	**32 805**	**37 230**	**37 723**	**36 170**	**33 285**	**31 185**	**28 636**	**-0.6**	**-1.0**
Combustion activities (+)	**30 566**	**34 290**	**34 789**	**33 232**	**30 292**	**28 163**	**25 617**	**-0.7**	**-1.1**
Coal	13 840	15 285	15 667	13 797	11 473	9 974	8 055	-1.8	-2.4
Oil	10 479	11 219	11 334	11 239	10 679	10 123	9 593	-0.1	-0.6
Natural gas	6 062	7 516	7 520	7 945	7 904	7 830	7 737	0.8	0.1
Bioenergy and waste	186	270	267	251	236	236	231	-0.9	-0.5
Other removals (-)**	**-**	**1**	**1**	**20**	**23**	**27**	**45**	**47**	**14**
Biofuels production	-	1	1	1	1	1	1	0.0	0.0
Direct air capture	-	-	0	19	21	26	44	194	36
Electricity and heat sectors	**12 513**	**14 943**	**15 262**	**13 311**	**10 968**	**9 469**	**7 757**	**-1.9**	**-2.5**
Coal	8 952	10 944	11 269	9 607	7 460	6 134	4 583	-2.3	-3.3
Oil	826	677	638	333	262	199	117	-8.9	-6.1
Natural gas	2 621	3 177	3 211	3 239	3 126	3 012	2 929	0.1	-0.3
Bioenergy and waste	115	146	144	131	120	124	128	-1.3	-0.4
Other energy sector**	**1 441**	**1 616**	**1 579**	**1 585**	**1 567**	**1 539**	**1 490**	**0.1**	**-0.2**
Final consumption**	**18 590**	**20 410**	**20 604**	**21 106**	**20 601**	**20 043**	**19 288**	**0.3**	**-0.2**
Coal	4 686	4 243	4 302	4 096	3 927	3 760	3 400	-0.7	-0.9
Oil	9 020	9 909	10 108	10 359	9 893	9 421	9 008	0.4	-0.4
Natural gas	2 854	3 559	3 521	3 888	3 952	3 995	3 991	1.4	0.5
Bioenergy and waste	71	123	124	120	116	112	103	-0.5	-0.7
Industry**	8 313	9 183	9 207	9 491	9 532	9 468	9 098	0.4	-0.0
Chemicals**	1 163	1 344	1 343	1 449	1 457	1 421	1 306	1.1	-0.1
Iron and steel**	2 111	2 730	2 800	2 774	2 737	2 686	2 509	-0.1	-0.4
Cement**	1 916	2 408	2 356	2 366	2 417	2 452	2 458	0.1	0.2
Aluminium**	175	248	250	263	266	265	266	0.7	0.2
Transport	6 965	7 944	8 213	8 537	8 198	7 840	7 557	0.6	-0.3
Road	5 181	6 028	6 137	6 221	5 799	5 378	5 027	0.2	-0.7
Passenger cars	2 658	3 083	3 168	3 011	2 668	2 376	2 137	-0.7	-1.4
Heavy-duty trucks	1 518	1 873	1 898	2 136	2 168	2 154	2 190	1.7	0.5
Aviation	746	800	941	1 158	1 266	1 363	1 491	3.0	1.7
Shipping	792	836	856	900	883	854	806	0.7	-0.2
Buildings	2 873	2 842	2 747	2 666	2 468	2 345	2 275	-0.4	-0.7
Residential	1 961	1 974	1 904	1 772	1 611	1 500	1 380	-1.0	-1.2
Services	912	867	842	894	857	846	895	0.9	0.2
Total CO_2 removals**	**-**	**1**	**1**	**21**	**24**	**30**	**50**	**48**	**14**
Total CO_2 captured**	**16**	**43**	**40**	**122**	**192**	**261**	**395**	**17**	**8.8**

*Includes industrial process and flaring emissions.

**Includes industrial process emissions.

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Table A.5a: World economic and activity indicators

				Stated Policies				CAAGR (%) 2023 to:	
	2010	2022	2023	2030	2035	2040	2050	2030	2050
Indicators									
Population (million)	6 966	7 948	8 018	8 518	8 851	9 160	9 680	0.9	0.7
GDP (USD 2023 billion, PPP)	118 823	170 644	175 981	217 526	250 591	284 660	357 510	3.1	2.7
GDP per capita (USD 2023, PPP)	17 057	21 471	21 948	25 537	28 312	31 078	36 931	2.2	1.9
TES/GDP (GJ per USD 1 000, PPP)	4.5	3.7	3.7	3.1	2.7	2.4	2.0	-2.3	-2.2
TFC/GDP (GJ per USD 1 000, PPP)	3.0	2.4	2.4	2.1	1.9	1.7	1.5	-1.7	-1.8
CO_2 intensity of electricity generation (g CO_2 per kWh)	528	460	458	312	219	164	111	-5.4	-5.1
Industrial production (Mt)									
Primary chemicals	510	721	736	866	925	961	1 002	2.3	1.1
Steel	1 435	1 890	1 892	2 049	2 157	2 255	2 424	1.1	0.9
Cement	3 280	4 156	4 072	4 206	4 395	4 548	4 735	0.5	0.6
Aluminium	60	104	108	123	133	143	167	1.9	1.6
Transport									
Passenger cars (billion pkm)	16 889	24 181	25 381	31 073	36 015	41 115	49 671	2.9	2.5
Heavy-duty trucks (billion tkm)	24 022	32 017	32 792	41 787	48 408	54 686	67 520	3.5	2.7
Aviation (billion pkm)	4 923	5 441	7 676	11 857	13 777	16 070	20 588	6.4	3.7
Shipping (billion tkm)	80 335	109 679	111 106	119 188	126 037	134 006	155 031	1.0	1.2
Buildings									
Households (million)	1 800	2 171	2 196	2 396	2 538	2 674	2 916	1.3	1.1
Residential floor area (million m^2)	154 190	200 926	204 412	230 630	250 933	271 510	311 590	1.7	1.6
Services floor area (million m^2)	39 439	54 920	56 342	64 233	69 562	74 529	83 188	1.9	1.5

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Table A.1b: World energy supply

				Announced Pledges (EJ)				Shares (%)			CAAGR (%) 2023 to:	
	2010	2022	2023	2030	2035	2040	2050	2023	2030	2050	2030	2050
Total energy supply	**536**	**629**	**642**	**641**	**624**	**620**	**635**	**100**	**100**	**100**	**-0.0**	**-0.0**
Renewables	43	74	78	140	197	251	336	12	22	53	8.7	5.6
Solar	1	6	8	31	55	81	120	1	5	19	22	11
Wind	1	8	8	21	34	46	66	1	3	10	14	7.9
Hydro	12	16	15	18	20	22	25	2	3	4	2.4	1.9
Modern solid bioenergy	23	34	36	48	56	64	73	6	7	11	4.3	2.7
Modern liquid bioenergy	2	4	5	10	12	14	14	1	2	2	11	4.2
Modern gaseous bioenergy	1	1	1	4	6	8	12	0	1	2	17	8.6
Traditional use of biomass	21	19	19	6	5	3	2	3	1	0	-14	-7.7
Nuclear	30	29	30	39	49	59	69	5	6	11	3.6	3.1
Natural gas	115	144	145	138	121	106	86	23	22	14	-0.7	-1.9
Unabated	109	136	137	128	108	90	65	21	20	10	-1.0	-2.7
With CCUS	0	1	1	2	5	7	13	0	0	2	25	13
Oil	173	187	192	178	156	133	100	30	28	16	-1.1	-2.4
Non-energy use	26	30	31	34	35	35	34	5	5	5	1.6	0.3
Coal	153	172	175	138	95	66	40	27	22	6	-3.4	-5.3
Unabated	151	169	172	134	87	56	28	27	21	4	-3.5	-6.5
With CCUS	-	0	0	0	4	6	10	0	0	2	63	28
Electricity and heat sectors	**200**	**249**	**255**	**271**	**285**	**314**	**378**	**100**	**100**	**100**	**0.9**	**1.5**
Renewables	20	41	43	88	134	180	255	17	33	68	11	6.8
Solar PV	0	5	6	27	49	71	104	2	10	28	25	11
Wind	1	8	8	21	34	46	66	3	8	17	14	7.9
Hydro	12	16	15	18	20	22	25	6	7	7	2.4	1.9
Bioenergy	4	9	10	15	20	25	32	4	6	9	6.6	4.5
Hydrogen	-	-	-	0	1	2	2	-	0	1	n.a.	n.a.
Ammonia	-	-	-	0	0	0	2	-	0	0	n.a.	n.a.
Nuclear	30	29	30	39	49	59	69	12	14	18	3.6	3.1
Unabated natural gas	47	56	57	53	43	36	26	22	19	7	-1.1	-2.9
Natural gas with CCUS	-	-	-	0	0	1	1	-	0	0	n.a.	n.a.
Oil	11	9	8	4	2	2	1	3	1	0	-12	-8.1
Unabated coal	91	112	115	86	50	29	13	45	32	4	-4.0	-7.6
Coal with CCUS	-	0	0	0	3	4	7	0	0	2	60	30
Other energy sector	**51**	**67**	**69**	**71**	**79**	**87**	**109**	**100**	**100**	**100**	**0.4**	**1.7**
Biofuels conversion losses	-	6	6	12	15	18	18	100	100	100	9.8	4.2
Low-emissions hydrogen (offsite)												
Production inputs	-	0	0	3	11	19	34	100	100	100	n.a.	n.a.
Production outputs	-	0	0	2	8	13	25	100	100	100	148	38
For hydrogen-based fuels	-	-	-	1	4	6	13	-	38	53	n.a.	n.a.

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Table A.2b: World final energy consumption

				Announced Pledges (EJ)				Shares (%)			CAAGR (%) 2023 to:	
	2010	2022	2023	2030	2035	2040	2050	2023	2030	2050	2030	2050
Total final consumption	**377**	**437**	**445**	**457**	**450**	**441**	**434**	**100**	**100**	**100**	**0.4**	**-0.1**
Electricity	64	88	91	115	132	151	184	20	25	42	3.4	2.7
Liquid fuels	153	173	176	176	162	145	117	40	39	27	-0.0	-1.5
Biofuels	2	4	5	10	12	14	14	1	2	3	11	4.2
Ammonia	-	-	-	0	2	2	3	-	0	1	n.a.	n.a.
Synthetic oil	-	-	-	0	0	1	3	-	0	1	n.a.	n.a.
Oil	151	168	172	166	147	126	96	39	36	22	-0.5	-2.1
Gaseous fuels	57	72	71	73	68	65	61	16	16	14	0.3	-0.6
Biomethane	0	0	0	2	3	4	6	0	0	1	29	12
Hydrogen	-	0	0	1	2	4	9	0	0	2	84	30
Synthetic methane	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.
Natural gas	57	71	70	70	63	55	45	16	15	10	-0.1	-1.7
Solid fuels	90	87	88	72	64	57	48	20	16	11	-2.9	-2.2
Solid bioenergy	33	34	35	27	27	26	28	8	6	6	-3.7	-0.8
Coal	56	51	52	44	37	30	19	12	10	4	-2.3	-3.6
Heat	12	15	15	17	16	15	13	3	4	3	1.0	-0.6
Industry	**143**	**170**	**173**	**185**	**185**	**183**	**177**	**100**	**100**	**100**	**1.0**	**0.1**
Electricity	27	38	39	50	56	62	72	22	27	41	3.8	2.3
Liquid fuels	29	34	34	37	36	34	30	20	20	17	1.0	-0.5
Oil	29	34	34	36	35	33	29	20	20	16	0.9	-0.6
Gaseous fuels	24	32	33	34	33	32	29	19	18	16	0.4	-0.4
Biomethane	0	0	0	1	1	2	3	0	0	2	31	13
Hydrogen	-	0	0	0	1	2	3	0	0	2	108	34
Unabated natural gas	21	28	29	29	26	23	17	17	16	9	-0.1	-2.0
Natural gas with CCUS	0	0	0	0	1	1	3	0	0	2	25	17
Solid fuels	58	58	59	55	51	46	37	34	30	21	-0.8	-1.7
Modern solid bioenergy	8	11	11	14	16	17	19	6	7	11	3.4	2.1
Unabated coal	48	44	45	39	31	25	13	26	21	8	-2.1	-4.3
Coal with CCUS	-	0	0	0	1	2	3	0	0	2	51	25
Heat	5	8	8	9	8	7	6	5	5	3	0.5	-1.4
Chemicals	37	49	50	56	57	56	55	29	30	31	1.4	0.3
Iron and steel	31	36	37	35	34	32	30	21	19	17	-0.6	-0.8
Cement	9	12	12	11	11	11	11	7	6	6	-0.5	-0.2
Aluminium	5	7	7	7	7	7	7	4	4	4	0.7	-0.3

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Table A.2b: World final energy consumption (continued)

				Announced Pledges (EJ)				Shares (%)			CAAGR (%) 2023 to:	
	2010	2022	2023	2030	2035	2040	2050	2023	2030	2050	2030	2050
Transport	**101**	**118**	**122**	**125**	**121**	**115**	**109**	**100**	**100**	**100**	**0.4**	**-0.4**
Electricity	1	2	2	6	12	19	31	1	5	29	18	11
Liquid fuels	96	111	115	114	104	90	70	94	91	64	-0.1	-1.8
Biofuels	2	4	5	9	11	13	12	4	7	11	11	3.8
Oil	94	107	110	104	90	73	50	90	83	45	-0.8	-2.9
Gaseous fuels	4	5	5	6	5	6	8	4	4	8	0.8	1.6
Biomethane	0	0	0	0	1	1	1	0	0	1	20	6.9
Hydrogen	-	0	0	0	1	2	6	0	0	5	71	28
Natural gas	4	5	5	5	4	3	2	4	4	2	-0.7	-3.6
Road	75	90	92	94	88	81	73	75	75	67	0.3	-0.8
Passenger cars	39	46	47	46	41	36	31	39	36	28	-0.6	-1.6
Heavy-duty trucks	22	28	28	32	32	32	31	23	25	29	1.7	0.4
Aviation	10	11	13	16	18	19	22	11	13	20	2.9	2.0
Shipping	10	11	11	10	10	10	9	9	8	8	-1.7	-0.8
Buildings	**111**	**125**	**124**	**120**	**117**	**117**	**123**	**100**	**100**	**100**	**-0.5**	**-0.0**
Electricity	35	46	46	55	60	66	76	37	46	62	2.4	1.8
Liquid fuels	13	13	13	11	8	6	5	10	9	4	-2.2	-3.3
Biofuels	-	-	-	0	0	0	0	-	0	0	n.a.	n.a.
Oil	13	13	13	11	8	6	5	10	9	4	-2.3	-3.3
Gaseous fuels	26	30	29	29	25	22	19	23	24	15	-0.0	-1.6
Biomethane	0	0	0	1	1	2	3	0	1	2	34	14
Hydrogen	-	-	-	0	0	0	0	-	0	0	n.a.	n.a.
Natural gas	25	29	28	27	23	19	15	23	23	12	-0.5	-2.4
Solid fuels	31	27	27	14	11	9	8	22	12	7	-8.8	-4.2
Modern solid bioenergy	4	4	4	6	6	5	6	3	5	5	4.6	1.3
Traditional use of biomass	21	19	19	6	5	3	2	15	5	2	-14	-7.7
Coal	6	3	3	2	1	0	0	3	1	0	-9.4	-11
Heat	6	7	7	8	8	8	7	5	6	6	1.7	0.2
Residential	78	87	86	77	74	72	76	69	64	62	-1.5	-0.4
Services	33	38	39	43	44	45	47	31	36	38	1.6	0.7

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Table A.3b: World electricity sector

				Announced Pledges (TWh)				Shares (%)			CAAGR (%) 2023 to:	
	2010	2022	2023	2030	2035	2040	2050	2023	2030	2050	2030	2050
Total generation	**21 511**	**29 145**	**29 863**	**38 285**	**45 759**	**54 638**	**70 564**	**100**	**100**	**100**	**3.6**	**3.2**
Renewables	4 209	8 567	9 029	19 897	30 828	41 505	58 611	30	52	83	12	7.2
Solar PV	32	1 294	1 612	7 512	13 673	19 816	28 996	5	20	41	25	11
Wind	342	2 120	2 336	5 938	9 548	12 734	18 289	8	16	26	14	7.9
Hydro	3 455	4 350	4 249	5 003	5 501	6 061	7 032	14	13	10	2.4	1.9
Bioenergy	309	691	714	1 231	1 652	2 084	2 782	2	3	4	8.1	5.2
of which BECCS	-	-	-	24	184	326	481	-	0	1	n.a.	n.a.
CSP	2	14	18	40	174	410	844	0	0	1	13	15
Geothermal	68	97	100	169	261	355	567	0	0	1	7.9	6.7
Marine	1	1	1	3	20	46	100	0	0	0	28	21
Nuclear	2 756	2 684	2 765	3 462	4 332	5 156	6 055	9	9	9	3.3	2.9
Hydrogen and ammonia	-	-	-	78	227	324	560	-	0	1	n.a.	n.a.
Fossil fuels with CCUS	-	1	1	24	292	502	832	0	0	1	66	30
Coal with CCUS	-	1	1	15	235	390	634	0	0	1	56	29
Natural gas with CCUS	-	-	-	9	57	112	198	-	0	0	n.a.	n.a.
Unabated fossil fuels	14 458	17 765	17 941	14 718	9 982	7 047	4 400	60	38	6	-2.8	-5.1
Coal	8 671	10 451	10 648	8 019	4 580	2 499	1 193	36	21	2	-4.0	-7.8
Natural gas	4 819	6 515	6 540	6 408	5 212	4 426	3 146	22	17	4	-0.3	-2.7
Oil	968	800	753	292	190	122	61	3	1	0	-13	-8.9

				Announced Pledges (GW)				Shares (%)			CAAGR (%) 2023 to:	
	2010	2022	2023	2030	2035	2040	2050	2023	2030	2050	2030	2050
Total capacity	**5 259**	**8 768**	**9 436**	**16 969**	**23 440**	**29 423**	**37 593**	**100**	**100**	**100**	**8.7**	**5.3**
Renewables	1 334	3 684	4 246	10 918	16 654	21 965	29 355	45	64	78	14	7.4
Solar PV	40	1 185	1 610	6 544	10 793	14 801	20 059	17	39	53	22	9.8
Wind	181	899	1 015	2 410	3 553	4 487	6 032	11	14	16	13	6.8
Hydro	1 028	1 398	1 411	1 626	1 788	1 945	2 200	15	10	6	2.0	1.7
Bioenergy	74	180	188	296	414	541	713	2	2	2	6.7	5.1
of which BECCS	-	-	-	6	37	60	85	-	0	0	n.a.	n.a.
CSP	1	6	7	16	57	120	230	0	0	1	12	14
Geothermal	10	15	15	26	40	53	83	0	0	0	8.2	6.6
Marine	0	1	1	1	8	19	39	0	0	0	12	17
Nuclear	403	417	416	508	627	748	874	4	3	2	2.9	2.8
Hydrogen and ammonia	-	-	-	29	122	202	273	-	0	1	n.a.	n.a.
Fossil fuels with CCUS	-	0	0	6	66	113	183	0	0	0	79	32
Coal with CCUS	-	0	0	3	48	84	137	0	0	0	62	30
Natural gas with CCUS	-	-	-	3	18	29	46	-	0	0	n.a.	n.a.
Unabated fossil fuels	3 510	4 602	4 665	4 479	3 978	3 444	2 512	49	26	7	-0.6	-2.3
Coal	1 613	2 204	2 243	2 119	1 817	1 490	782	24	12	2	-0.8	-3.8
Natural gas	1 468	1 981	2 007	2 078	1 929	1 759	1 613	21	12	4	0.5	-0.8
Oil	429	417	414	281	232	194	117	4	2	0	-5.4	-4.6
Battery storage	1	45	89	1 015	1 981	2 939	4 386	1	6	12	42	16

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Table A.4b: World CO_2 emissions

				Announced Pledges (Mt CO_2)				CAAGR (%) 2023 to:	
	2010	2022	2023	2030	2035	2040	2050	2030	2050
Total CO_2*	**32 805**	**37 230**	**37 723**	**32 056**	**24 678**	**18 820**	**11 711**	**-2.3**	**-4.2**
Combustion activities (+)	**30 566**	**34 290**	**34 789**	**29 477**	**22 383**	**16 932**	**10 576**	**-2.3**	**-4.3**
Coal	13 840	15 285	15 667	12 093	7 847	5 104	2 602	-3.6	-6.4
Oil	10 479	11 219	11 334	10 121	8 537	6 904	4 681	-1.6	-3.2
Natural gas	6 062	7 516	7 520	7 065	5 967	5 039	3 621	-0.9	-2.7
Bioenergy and waste	186	270	267	198	33	- 115	- 328	-4.2	n.a.
Other removals (-)**	**-**	**1**	**1**	**97**	**159**	**224**	**307**	**84**	**22**
Biofuels production	-	1	1	79	131	188	246	79	21
Direct air capture	-	-	0	19	28	36	61	194	38
Electricity and heat sectors	**12 513**	**14 943**	**15 262**	**11 760**	**7 516**	**4 894**	**2 640**	**-3.7**	**-6.3**
Coal	8 952	10 944	11 269	8 425	4 917	2 831	1 330	-4.1	-7.6
Oil	826	677	638	267	182	122	66	-12	-8.1
Natural gas	2 621	3 177	3 211	2 965	2 437	2 053	1 461	-1.1	-2.9
Bioenergy and waste	115	146	144	104	- 19	- 112	- 216	-4.5	n.a.
Other energy sector**	**1 441**	**1 616**	**1 579**	**1 256**	**960**	**688**	**292**	**-3.2**	**-6.1**
Final consumption**	**18 590**	**20 410**	**20 604**	**19 003**	**16 185**	**13 239**	**8 817**	**-1.1**	**-3.1**
Coal	4 686	4 243	4 302	3 584	2 861	2 224	1 256	-2.6	-4.5
Oil	9 020	9 909	10 108	9 390	7 971	6 452	4 376	-1.0	-3.1
Natural gas	2 854	3 559	3 521	3 439	2 992	2 551	1 877	-0.3	-2.3
Bioenergy and waste	71	123	124	94	52	- 3	- 112	-3.9	-200
Industry**	8 313	9 183	9 207	8 520	7 384	6 119	3 861	-1.1	-3.2
Chemicals**	1 163	1 344	1 343	1 295	1 112	867	495	-0.5	-3.6
Iron and steel**	2 111	2 730	2 800	2 526	2 181	1 832	1 157	-1.5	-3.2
Cement**	1 916	2 408	2 356	2 170	1 954	1 670	1 117	-1.2	-2.7
Aluminium**	175	248	250	253	236	186	72	0.2	-4.5
Transport	6 965	7 944	8 213	7 731	6 626	5 370	3 632	-0.9	-3.0
Road	5 181	6 028	6 137	5 804	4 908	3 879	2 426	-0.8	-3.4
Passenger cars	2 658	3 083	3 168	2 776	2 199	1 639	934	-1.9	-4.4
Heavy-duty trucks	1 518	1 873	1 898	2 017	1 893	1 643	1 164	0.9	-1.8
Aviation	746	800	941	1 090	1 102	1 083	971	2.1	0.1
Shipping	792	836	856	619	431	254	131	-4.5	-6.7
Buildings	2 873	2 842	2 747	2 401	1 883	1 510	1 163	-1.9	-3.1
Residential	1 961	1 974	1 904	1 613	1 253	987	700	-2.3	-3.6
Services	912	867	842	789	629	523	463	-0.9	-2.2
Total CO_2 removals**	**-**	**1**	**1**	**119**	**315**	**515**	**788**	**89**	**27**
Total CO_2 captured**	**16**	**43**	**40**	**410**	**1 261**	**2 143**	**3 731**	**39**	**18**

*Includes industrial process and flaring emissions.

**Includes industrial process emissions.

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Table A.5b: World economic and activity indicators

				Announced Pledges				CAAGR (%) 2023 to:	
	2010	2022	2023	2030	2035	2040	2050	2030	2050
Indicators									
Population (million)	6 966	7 948	8 018	8 518	8 851	9 160	9 680	0.9	0.7
GDP (USD 2023 billion, PPP)	118 823	170 644	175 981	217 526	250 591	284 660	357 510	3.1	2.7
GDP per capita (USD 2023, PPP)	17 057	21 471	21 948	25 537	28 312	31 078	36 931	2.2	1.9
TES/GDP (GJ per USD 1 000, PPP)	4.5	3.7	3.7	3.0	2.5	2.2	1.8	-3.0	-2.6
TFC/GDP (GJ per USD 1 000, PPP)	3.0	2.4	2.4	2.0	1.7	1.5	1.2	-2.5	-2.6
CO_2 intensity of electricity generation (g CO_2 per kWh)	528	460	458	270	140	73	29	-7.3	-9.7
Industrial production (Mt)									
Primary chemicals	510	721	736	838	879	899	897	1.9	0.7
Steel	1 435	1 890	1 892	2 012	2 054	2 089	2 132	0.9	0.4
Cement	3 280	4 156	4 072	4 110	4 204	4 261	4 302	0.1	0.2
Aluminium	60	104	108	126	135	144	164	2.2	1.6
Transport									
Passenger cars (billion pkm)	16 889	24 181	25 381	30 786	35 554	40 794	50 200	2.8	2.6
Heavy-duty trucks (billion tkm)	24 022	32 017	32 792	41 371	47 853	54 156	66 847	3.4	2.7
Aviation (billion pkm)	4 923	5 441	7 676	11 734	13 553	15 822	20 396	6.3	3.7
Shipping (billion tkm)	80 335	109 679	111 106	114 613	117 931	122 224	135 603	0.4	0.7
Buildings									
Households (million)	1 800	2 171	2 196	2 396	2 538	2 674	2 916	1.3	1.1
Residential floor area (million m^2)	154 190	200 926	204 412	230 630	250 933	271 510	311 590	1.7	1.6
Services floor area (million m^2)	39 439	54 920	56 342	64 233	69 562	74 529	83 188	1.9	1.5

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Table A.1c: World energy supply

				Net Zero Emissions by 2050 (EJ)				Shares (%)			CAAGR (%) 2023 to:	
	2010	2022	2023	2030	2035	2040	2050	2023	2030	2050	2030	2050
Total energy supply	**536**	**629**	**642**	**588**	**544**	**538**	**564**	**100**	**100**	**100**	**-1.3**	**-0.5**
Renewables	43	74	78	165	245	312	399	12	28	71	11	6.2
Solar	1	6	8	38	72	104	145	1	6	26	26	11
Wind	1	8	8	26	45	62	86	1	4	15	17	9.0
Hydro	12	16	15	19	22	25	28	2	3	5	3.5	2.2
Modern solid bioenergy	23	34	36	53	64	71	76	6	9	13	5.8	2.8
Modern liquid bioenergy	2	4	5	12	14	14	12	1	2	2	15	3.5
Modern gaseous bioenergy	1	1	1	6	9	11	12	0	1	2	26	8.8
Traditional use of biomass	21	19	19	-	-	-	-	3	-	-	n.a.	n.a.
Nuclear	30	29	30	44	59	70	78	5	7	14	5.5	3.6
Natural gas	115	144	145	126	79	53	31	23	21	5	-2.0	-5.6
Unabated	109	136	137	113	62	32	7	21	19	1	-2.7	-10
With CCUS	0	1	1	5	9	13	17	0	1	3	39	14
Oil	173	187	192	151	109	77	40	30	26	7	-3.4	-5.6
Non-energy use	26	30	31	33	32	31	28	5	6	5	0.9	-0.3
Coal	153	172	175	101	51	25	15	27	17	3	-7.6	-8.8
Unabated	151	169	172	95	41	13	2	27	16	0	-8.1	-15
With CCUS	-	0	0	2	7	9	11	0	0	2	106	28
Electricity and heat sectors	**200**	**249**	**255**	**266**	**286**	**329**	**408**	**100**	**100**	**100**	**0.6**	**1.8**
Renewables	20	41	43	104	172	232	311	17	39	76	13	7.6
Solar PV	0	5	6	33	64	89	123	2	12	30	28	12
Wind	1	8	8	26	45	62	86	3	10	21	17	9.0
Hydro	12	16	15	19	22	25	28	6	7	7	3.5	2.2
Bioenergy	4	9	10	16	24	30	36	4	6	9	7.2	5.0
Hydrogen	-	-	-	2	4	5	5	-	1	1	n.a.	n.a.
Ammonia	-	-	-	1	1	2	2	-	0	0	n.a.	n.a.
Nuclear	30	29	30	44	59	70	78	12	17	19	5.5	3.6
Unabated natural gas	47	56	57	53	26	11	2	22	20	0	-1.0	-12
Natural gas with CCUS	-	-	-	0	1	2	3	-	0	1	n.a.	n.a.
Oil	11	9	8	2	1	0	0	3	1	0	-17	-25
Unabated coal	91	112	115	58	17	0	0	45	22	0	-9.4	-35
Coal with CCUS	-	0	0	1	4	6	7	0	1	2	117	30
Other energy sector	**51**	**67**	**69**	**74**	**82**	**98**	**131**	**100**	**100**	**100**	**0.9**	**2.4**
Biofuels conversion losses	-	6	6	14	16	16	14	100	100	100	13	3.0
Low-emissions hydrogen (offsite)												
Production inputs	-	0	0	9	21	33	52	100	100	100	n.a.	n.a.
Production outputs	-	0	0	6	14	23	38	100	100	100	185	40
For hydrogen-based fuels	-	-	-	2	6	11	18	-	30	47	n.a.	n.a.

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Table A.2c: World final energy consumption

				Net Zero Emissions by 2050 (EJ)				Shares (%)			CAAGR (%) 2023 to:	
	2010	2022	2023	2030	2035	2040	2050	2023	2030	2050	2030	2050
Total final consumption	**377**	**437**	**445**	**415**	**382**	**361**	**344**	**100**	**100**	**100**	**-1.0**	**-0.9**
Electricity	64	88	91	116	136	157	188	20	28	55	3.6	2.7
Liquid fuels	153	173	176	152	119	93	61	40	37	18	-2.1	-3.9
Biofuels	2	4	5	12	14	14	12	1	3	3	15	3.5
Ammonia	-	-	-	0	1	2	3	-	0	1	n.a.	n.a.
Synthetic oil	-	-	-	0	1	3	6	-	0	2	n.a.	n.a.
Oil	151	168	172	139	103	74	39	39	34	11	-2.9	-5.3
Gaseous fuels	57	72	71	65	54	45	40	16	16	12	-1.3	-2.2
Biomethane	0	0	0	4	6	7	7	0	1	2	47	13
Hydrogen	-	0	0	2	4	7	14	0	0	4	118	32
Synthetic methane	-	-	-	0	0	0	0	-	0	0	n.a.	n.a.
Natural gas	57	71	70	58	42	30	16	16	14	5	-2.8	-5.4
Solid fuels	90	87	88	60	52	43	34	20	15	10	-5.2	-3.5
Solid bioenergy	33	34	35	22	24	25	27	8	5	8	-6.4	-1.0
Coal	56	51	52	38	27	18	7	12	9	2	-4.4	-7.0
Heat	12	15	15	15	13	11	7	3	4	2	-0.7	-2.7
Industry	**143**	**170**	**173**	**178**	**173**	**167**	**157**	**100**	**100**	**100**	**0.4**	**-0.4**
Electricity	27	38	39	53	62	69	78	22	30	50	4.7	2.6
Liquid fuels	29	34	34	34	31	28	23	20	19	15	-0.2	-1.5
Oil	29	34	34	33	30	27	22	20	19	14	-0.4	-1.7
Gaseous fuels	24	32	33	32	29	26	21	19	18	13	-0.3	-1.6
Biomethane	0	0	0	1	2	3	4	0	1	3	45	15
Hydrogen	-	0	0	1	2	3	5	0	0	3	164	37
Unabated natural gas	21	28	29	25	19	13	4	17	14	2	-1.9	-7.4
Natural gas with CCUS	0	0	0	1	2	3	5	0	0	3	48	19
Solid fuels	58	58	59	51	43	36	28	34	28	18	-2.1	-2.8
Modern solid bioenergy	8	11	11	15	17	19	21	6	8	13	4.5	2.4
Unabated coal	48	44	45	32	21	12	1	26	18	1	-4.5	-12
Coal with CCUS	-	0	0	1	2	3	4	0	0	3	92	27
Heat	5	8	8	7	6	5	3	5	4	2	-1.7	-4.0
Chemicals	37	49	50	54	54	53	50	29	30	32	1.0	-0.1
Iron and steel	31	36	37	33	30	28	25	21	19	16	-1.5	-1.4
Cement	9	12	12	11	11	10	10	7	6	6	-1.2	-0.7
Aluminium	5	7	7	7	7	6	5	4	4	3	0.2	-1.1

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Table A.2c: World final energy consumption (continued)

				Net Zero Emissions by 2050 (EJ)				Shares (%)			CAAGR (%) 2023 to:	
	2010	**2022**	**2023**	**2030**	**2035**	**2040**	**2050**	**2023**	**2030**	**2050**	**2030**	**2050**
Transport	**101**	**118**	**122**	**109**	**91**	**81**	**76**	**100**	**100**	**100**	**-1.7**	**-1.7**
Electricity	1	2	2	8	16	25	39	1	7	51	23	12
Liquid fuels	96	111	115	96	70	51	27	94	88	36	-2.6	-5.2
Biofuels	2	4	5	11	12	12	9	4	10	12	14	2.6
Oil	94	107	110	84	55	34	9	90	77	11	-3.9	-9.0
Gaseous fuels	4	5	5	5	5	5	10	4	5	13	-0.6	2.3
Biomethane	0	0	0	0	0	0	0	0	0	0	22	4.6
Hydrogen	-	0	0	1	2	3	9	0	1	12	97	30
Natural gas	4	5	5	4	2	1	0	4	4	0	-4.1	-11
Road	75	90	92	80	64	54	49	75	74	64	-1.9	-2.3
Passenger cars	39	46	47	37	25	20	18	39	34	24	-3.5	-3.5
Heavy-duty trucks	22	28	28	29	27	25	23	23	27	30	0.4	-0.8
Aviation	10	11	13	15	14	14	15	11	13	20	1.4	0.6
Shipping	10	11	11	9	9	8	8	9	9	10	-2.8	-1.3
Buildings	**111**	**125**	**124**	**103**	**94**	**90**	**92**	**100**	**100**	**100**	**-2.7**	**-1.1**
Electricity	35	46	46	51	54	59	67	37	50	72	1.3	1.4
Liquid fuels	13	13	13	9	5	3	1	10	9	2	-4.5	-7.7
Biofuels	-	-	-	0	0	0	1	-	0	1	n.a.	n.a.
Oil	13	13	13	9	5	2	1	10	9	1	-4.6	-10
Gaseous fuels	26	30	29	23	15	10	5	23	23	5	-3.0	-6.5
Biomethane	0	0	0	2	3	3	3	0	2	3	61	14
Hydrogen	-	-	-	0	0	0	0	-	0	0	n.a.	n.a.
Natural gas	25	29	28	20	11	5	0	23	19	0	-4.9	-23
Solid fuels	31	27	27	8	7	5	5	22	8	6	-16	-5.9
Modern solid bioenergy	4	4	4	6	6	5	5	3	6	6	6.1	0.7
Traditional use of biomass	21	19	19	-	-	-	-	15	-	-	n.a.	n.a.
Coal	6	3	3	1	0	0	0	3	1	0	-13	-26
Heat	6	7	7	7	7	6	5	5	7	5	0.5	-1.5
Residential	78	87	86	65	58	55	57	69	64	61	-3.8	-1.5
Services	33	38	39	37	36	35	36	31	36	39	-0.5	-0.3

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Table A.3c: World electricity sector

				Net Zero Emissions by 2050 (TWh)				Shares (%)			CAAGR (%) 2023 to:	
	2010	2022	2023	2030	2035	2040	2050	2023	2030	2050	2030	2050
Total generation	**21 511**	**29 145**	**29 863**	**39 783**	**50 084**	**61 965**	**80 194**	**100**	**100**	**100**	**4.2**	**3.7**
Renewables	4 209	8 567	9 029	23 337	39 128	52 821	70 963	30	59	88	15	7.9
Solar PV	32	1 294	1 612	9 212	17 645	24 846	34 069	5	23	42	28	12
Wind	342	2 120	2 336	7 114	12 608	17 293	23 940	8	18	30	17	9.0
Hydro	3 455	4 350	4 249	5 404	6 226	6 920	7 722	14	14	10	3.5	2.2
Bioenergy	309	691	714	1 256	1 889	2 445	3 054	2	3	4	8.4	5.5
of which BECCS	-	-	-	55	330	538	731	-	0	1	n.a.	n.a.
CSP	2	14	18	93	332	731	1 327	0	0	2	27	17
Geothermal	68	97	100	246	398	529	739	0	1	1	14	7.7
Marine	1	1	1	10	30	57	112	0	0	0	52	22
Nuclear	2 756	2 684	2 765	3 887	5 138	6 092	6 969	9	10	9	5.0	3.5
Hydrogen and ammonia	-	-	-	349	672	878	987	-	1	1	n.a.	n.a.
Fossil fuels with CCUS	-	1	1	161	566	833	979	0	0	1	119	31
Coal with CCUS	-	1	1	122	386	523	605	0	0	1	110	29
Natural gas with CCUS	-	-	-	38	180	310	374	-	0	0	n.a.	n.a.
Unabated fossil fuels	14 458	17 765	17 941	11 951	4 502	1 258	206	60	30	0	-5.6	-15
Coal	8 671	10 451	10 648	5 357	1 551	0	0	36	13	0	-9.3	-35
Natural gas	4 819	6 515	6 540	6 419	2 899	1 256	206	22	16	0	-0.3	-12
Oil	968	800	753	174	52	2	0	3	0	0	-19	-25

				Net Zero Emissions by 2050 (GW)				Shares (%)			CAAGR (%) 2023 to:	
	2010	2022	2023	2030	2035	2040	2050	2023	2030	2050	2030	2050
Total capacity	**5 259**	**8 768**	**9 436**	**17 093**	**25 490**	**32 510**	**41 298**	**100**	**100**	**100**	**8.9**	**5.6**
Renewables	1 334	3 684	4 246	11 495	19 152	25 446	33 179	45	67	80	15	7.9
Solar PV	40	1 185	1 610	6 699	12 044	16 455	21 618	17	39	52	23	10
Wind	181	899	1 015	2 731	4 542	5 945	7 901	11	16	19	15	7.9
Hydro	1 028	1 398	1 411	1 697	1 943	2 161	2 419	15	10	6	2.7	2.0
Bioenergy	74	180	188	292	438	556	696	2	2	2	6.5	5.0
of which BECCS	-	-	-	13	65	98	128	-	0	0	n.a.	n.a.
CSP	1	6	7	35	112	226	390	0	0	1	26	16
Geothermal	10	15	15	39	61	80	111	0	0	0	15	7.7
Marine	0	1	1	4	12	23	43	0	0	0	32	17
Nuclear	403	417	416	554	750	896	1 017	4	3	2	4.2	3.4
Hydrogen and ammonia	-	-	-	118	358	458	443	-	1	1	n.a.	n.a.
Fossil fuels with CCUS	-	0	0	47	140	202	235	0	0	1	137	33
Coal with CCUS	-	0	0	33	92	127	146	0	0	0	126	31
Natural gas with CCUS	-	-	-	14	48	75	89	-	0	0	n.a.	n.a.
Unabated fossil fuels	3 510	4 602	4 665	3 605	2 499	1 696	904	49	21	2	-3.6	-5.9
Coal	1 613	2 204	2 243	1 543	926	526	213	24	9	1	-5.2	-8.4
Natural gas	1 468	1 981	2 007	1 827	1 419	1 095	657	21	11	2	-1.3	-4.1
Oil	429	417	414	235	155	75	34	4	1	0	-7.8	-8.8
Battery storage	1	45	89	1 260	2 580	3 802	5 512	1	7	13	46	17

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Table A.4c: World CO$_2$ emissions

				Net Zero Emissions by 2050 (Mt CO$_2$)				CAAGR (%) 2023 to:	
	2010	2022	2023	2030	2035	2040	2050	2030	2050
Total CO$_2$*	**32 805**	**37 230**	**37 723**	**25 112**	**13 485**	**6 221**	**-**	**-5.6**	**n.a.**
Combustion activities (+)	**30 566**	**34 290**	**34 789**	**23 082**	**12 143**	**5 678**	**777**	**-5.7**	**-13**
Coal	13 840	15 285	15 667	8 590	3 587	1 086	158	-8.2	-16
Oil	10 479	11 219	11 334	8 149	5 334	3 208	878	-4.6	-9.0
Natural gas	6 062	7 516	7 520	6 232	3 417	1 811	391	-2.6	-10
Bioenergy and waste	186	270	267	111	- 195	- 428	- 650	-12	n.a.
Other removals (-)**	**-**	**1**	**1**	**182**	**361**	**586**	**1 069**	**101**	**28**
Biofuels production	-	1	1	114	191	264	289	88	22
Direct air capture	-	-	0	68	170	322	780	n.a.	52
Electricity and heat sectors	**12 513**	**14 943**	**15 262**	**8 861**	**3 054**	**384**	**- 299**	**-7.5**	**-186**
Coal	8 952	10 944	11 269	5 646	1 709	35	20	-9.4	-21
Oil	826	677	638	169	66	18	0	-17	-25
Natural gas	2 621	3 177	3 211	2 992	1 442	635	111	-1.0	-12
Bioenergy and waste	115	146	144	55	- 163	- 304	- 430	-13	n.a.
Other energy sector**	**1 441**	**1 616**	**1 579**	**770**	**259**	**74**	**- 72**	**-9.7**	**-189**
Final consumption**	**18 590**	**20 410**	**20 604**	**15 539**	**10 335**	**6 082**	**1 149**	**-4.0**	**-10**
Coal	4 686	4 243	4 302	2 909	1 853	1 035	127	-5.4	-12
Oil	9 020	9 909	10 108	7 601	5 005	2 994	756	-4.0	-9.2
Natural gas	2 854	3 559	3 521	2 770	1 814	1 053	196	-3.4	-10
Bioenergy and waste	71	123	124	56	- 32	- 124	- 220	-11	n.a.
Industry**	8 313	9 183	9 207	7 204	5 059	3 067	458	-3.4	-11
Chemicals**	1 163	1 344	1 343	1 162	846	516	80	-2.0	-9.9
Iron and steel**	2 111	2 730	2 800	2 153	1 520	961	224	-3.7	-8.9
Cement**	1 916	2 408	2 356	1 796	1 260	736	65	-3.8	-12
Aluminium**	175	248	250	225	184	116	9	-1.5	-12
Transport	6 965	7 944	8 213	6 202	4 097	2 474	632	-3.9	-9.1
Road	5 181	6 028	6 137	4 585	2 904	1 655	338	-4.1	-10
Passenger cars	2 658	3 083	3 168	2 078	1 091	525	96	-5.8	-12
Heavy-duty trucks	1 518	1 873	1 898	1 725	1 357	924	220	-1.4	-7.7
Aviation	746	800	941	922	749	561	210	-0.3	-5.4
Shipping	792	836	856	524	328	184	63	-6.8	-9.2
Buildings	2 873	2 842	2 747	1 832	974	418	43	-5.6	-14
Residential	1 961	1 974	1 904	1 295	689	299	38	-5.4	-14
Services	912	867	842	538	285	118	6	-6.2	-17
Total CO$_2$ removals**	**-**	**1**	**1**	**243**	**671**	**1 110**	**1 797**	**110**	**30**
Total CO$_2$ captured**	**16**	**43**	**40**	**1 023**	**2 540**	**4 001**	**5 924**	**59**	**20**

*Includes industrial process and flaring emissions.

**Includes industrial process emissions.

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Table A.5c: World economic and activity indicators

				Net Zero Emissions by 2050				CAAGR (%) 2023 to:	
	2010	2022	2023	2030	2035	2040	2050	2030	2050
Indicators									
Population (million)	6 966	7 948	8 018	8 518	8 851	9 160	9 680	0.9	0.7
GDP (USD 2023 billion, PPP)	118 823	170 644	175 981	217 526	250 591	284 660	357 510	3.1	2.7
GDP per capita (USD 2023, PPP)	17 057	21 471	21 948	25 537	28 312	31 078	36 931	2.2	1.9
TES/GDP (GJ per USD 1 000, PPP)	4.5	3.7	3.7	2.7	2.2	1.9	1.6	-4.2	-3.1
TFC/GDP (GJ per USD 1 000, PPP)	3.0	2.4	2.4	1.8	1.5	1.2	1.0	-3.9	-3.4
CO_2 intensity of electricity generation (g CO_2 per kWh)	528	460	458	195	50	3	- 4	-12	-184
Industrial production (Mt)									
Primary chemicals	510	721	736	826	855	860	823	1.7	0.4
Steel	1 435	1 890	1 892	1 950	1 954	1 928	1 925	0.4	0.1
Cement	3 280	4 156	4 072	3 984	3 969	3 904	3 812	-0.3	-0.2
Aluminium	60	104	108	126	136	143	151	2.3	1.3
Transport									
Passenger cars (billion pkm)	16 889	24 181	25 381	28 634	31 485	36 204	45 487	1.7	2.2
Heavy-duty trucks (billion tkm)	24 022	32 017	32 792	41 241	47 686	53 764	65 387	3.3	2.6
Aviation (billion pkm)	4 923	5 441	7 676	10 867	11 499	12 915	16 433	5.1	2.9
Shipping (billion tkm)	80 335	109 679	111 106	107 747	106 338	106 743	118 663	-0.4	0.2
Buildings									
Households (million)	1 800	2 171	2 196	2 396	2 538	2 674	2 916	1.3	1.1
Residential floor area (million m^2)	154 190	200 926	204 412	230 630	250 933	271 510	311 590	1.7	1.6
Services floor area (million m^2)	39 439	54 920	56 342	64 233	69 562	74 529	83 188	1.9	1.5

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Table A.6: Total energy supply (EJ)

				Stated Policies			Announced Pledges		
	2010	2022	2023	2030	2035	2050	2030	2035	2050
World	**536.3**	**629.0**	**642.1**	**676.5**	**681.6**	**721.9**	**640.8**	**624.0**	**634.7**
North America	112.6	113.7	112.3	108.8	103.6	99.3	103.7	96.3	89.1
United States	94.1	93.4	91.9	88.2	83.0	78.0	84.7	78.5	72.9
Central and South America	26.6	29.3	29.8	32.7	35.2	43.5	32.3	34.7	40.0
Brazil	12.1	13.9	14.4	16.1	17.2	21.3	16.2	17.8	20.4
Europe	89.0	77.0	74.4	73.0	70.2	65.5	70.4	65.1	59.3
European Union	64.2	55.4	53.0	50.9	48.0	42.8	49.2	44.9	40.2
Africa	25.4	33.5	33.9	36.9	39.8	51.7	30.8	32.9	46.9
Middle East	26.1	35.0	35.6	40.6	44.3	55.9	39.6	44.1	54.1
Eurasia	35.8	42.2	42.7	43.1	43.3	44.1	40.5	39.1	37.5
Russia	29.1	33.9	34.4	34.0	33.7	32.7	32.2	30.8	28.4
Asia Pacific	205.9	283.1	297.0	321.9	324.5	338.0	306.9	296.0	293.8
China	107.3	160.1	170.4	178.0	171.4	162.0	171.1	157.8	141.2
India	27.7	42.7	45.4	55.8	60.7	70.5	50.6	52.0	61.9
Japan	20.9	16.4	16.4	15.0	14.0	12.3	14.7	13.4	10.9
Southeast Asia	21.5	31.5	33.0	39.6	43.8	54.2	38.9	40.6	45.2

Table A.7: Renewables energy supply (EJ)

				Stated Policies			Announced Pledges		
	2010	2022	2023	2030	2035	2050	2030	2035	2050
World	**43.2**	**74.4**	**77.9**	**120.1**	**152.9**	**240.6**	**139.5**	**196.5**	**336.3**
North America	8.8	12.7	12.6	17.9	22.1	33.3	24.2	34.6	51.9
United States	6.6	10.0	10.1	14.4	18.2	28.1	19.9	29.4	43.8
Central and South America	7.7	9.9	10.3	12.7	14.4	21.6	14.5	18.2	29.2
Brazil	5.6	6.9	7.4	9.0	9.8	13.4	9.9	11.9	16.7
Europe	9.9	14.4	15.1	21.5	25.5	31.9	24.4	30.3	37.8
European Union	7.8	10.7	11.2	16.0	19.1	23.6	18.0	22.3	26.9
Africa	3.6	5.6	5.8	7.7	9.5	15.8	6.9	10.2	25.6
Middle East	0.1	0.2	0.3	1.3	2.4	6.4	1.9	5.1	15.4
Eurasia	1.0	1.2	1.2	1.5	1.7	2.5	1.8	2.4	4.4
Russia	0.7	0.9	0.9	1.1	1.2	1.7	1.2	1.5	2.3
Asia Pacific	12.1	30.4	32.6	57.1	76.6	126.3	64.8	93.6	167.8
China	4.6	15.0	16.1	31.8	43.5	67.9	35.3	50.9	80.4
India	2.7	6.3	6.6	11.0	14.7	27.0	11.4	16.5	35.7
Japan	0.8	1.2	1.4	2.0	2.5	3.5	2.3	3.3	4.8
Southeast Asia	2.8	5.8	6.2	8.2	10.3	17.6	10.4	14.8	29.5

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Table A.8: Oil production (mb/d)

				Stated Policies			Announced Pledges		
	2010	2022	2023	2030	2035	2050	2030	2035	2050
World supply	**85.1**	**97.4**	**99.2**	**101.7**	**99.1**	**93.1**	**92.8**	**82.0**	**53.7**
Processing gains	2.1	2.3	2.4	2.5	2.6	2.8	2.4	2.2	1.6
World production	**83.2**	**95.1**	**96.9**	**99.2**	**96.5**	**90.3**	**90.4**	**79.9**	**52.1**
Conventional crude oil	66.8	62.9	62.7	59.4	57.0	54.3	54.9	46.6	28.9
Tight oil	0.7	8.2	9.1	11.2	11.8	10.7	10.8	10.4	7.2
Natural gas liquids	12.7	19.3	20.2	23.1	22.1	19.2	19.8	18.4	13.1
Extra-heavy oil & bitumen	2.6	3.8	3.9	4.6	4.6	5.1	3.9	3.6	2.7
Non-OPEC	51.7	61.8	63.9	66.8	63.9	54.2	60.0	51.5	30.8
OPEC	31.5	33.3	33.0	32.4	32.6	36.1	30.4	28.3	21.3
North America	14.0	25.7	27.4	29.5	28.5	23.8	26.3	23.5	14.8
Central and South America	7.4	6.4	7.0	8.8	9.4	9.1	8.1	7.3	5.0
Europe	4.4	3.3	3.4	2.9	2.2	1.2	2.6	1.8	0.5
European Union	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.1
Africa	10.3	7.2	7.4	6.6	5.9	5.3	5.7	4.5	2.7
Middle East	25.4	31.1	30.4	31.2	32.1	35.8	29.4	27.8	21.5
Eurasia	13.4	13.9	13.8	13.8	12.6	11.1	12.4	10.2	5.4
Asia Pacific	8.4	7.5	7.5	6.4	5.8	4.1	5.9	4.7	2.2
Southeast Asia	2.6	1.8	1.8	1.4	1.2	1.0	1.3	1.0	0.5

Table A.9: Oil demand (mb/d)

				Stated Policies			Announced Pledges		
	2010	2022	2023	2030	2035	2050	2030	2035	2050
World	**87.2**	**97.1**	**99.1**	**101.7**	**99.1**	**93.1**	**92.8**	**82.0**	**53.7**
North America	22.2	22.0	22.1	21.0	18.6	14.5	18.8	14.7	6.3
United States	17.8	18.1	18.2	17.2	15.1	11.3	15.6	12.1	4.8
Central and South America	5.5	5.5	5.6	5.8	6.0	6.6	5.2	4.8	2.9
Brazil	2.2	2.4	2.5	2.5	2.6	2.8	2.3	2.1	1.2
Europe	13.6	12.4	12.1	10.7	9.0	5.3	9.6	7.0	2.4
European Union	10.3	9.3	9.0	7.8	6.3	3.0	6.9	4.9	1.4
Africa	3.3	4.3	4.2	4.9	5.6	7.9	4.8	5.1	5.8
Middle East	7.0	8.1	8.1	8.1	8.5	10.2	7.7	7.8	7.4
Eurasia	3.5	4.3	4.4	4.6	4.7	5.0	4.3	4.2	3.9
Russia	3.0	3.5	3.5	3.6	3.6	3.6	3.4	3.3	2.9
Asia Pacific	25.1	33.3	34.8	38.1	37.9	34.4	35.2	32.0	20.2
China	8.8	14.8	16.2	17.4	16.4	11.8	16.1	14.1	7.8
India	3.3	5.0	5.2	6.6	7.1	7.6	6.2	6.1	4.5
Japan	4.2	3.1	3.1	2.6	2.3	1.7	2.3	1.7	0.7
Southeast Asia	4.0	4.9	5.0	6.0	6.4	7.0	5.5	5.2	3.8
International bunkers	7.0	7.1	7.7	8.6	8.9	9.3	7.1	6.4	4.9

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Table A.10: World liquids demand (mb/d)

			Stated Policies			Announced Pledges		
	2022	**2023**	**2030**	**2035**	**2050**	**2030**	**2035**	**2050**
Total liquids	**99.3**	**101.4**	**104.6**	**102.4**	**97.8**	**97.9**	**89.3**	**64.7**
Biofuels	2.2	2.3	2.9	3.2	4.1	4.9	6.3	7.0
Hydrogen based fuels	-	-	-	0.1	0.6	0.2	1.0	4.0
Total oil	97.1	99.1	101.7	99.1	93.1	92.8	82.0	53.7
CTL, GTL and additives	0.9	1.0	0.9	1.0	0.9	0.9	0.7	0.3
Direct use of crude oil	1.0	0.9	0.4	0.3	0.1	0.3	0.2	0.1
Oil products	95.2	97.2	100.4	97.8	92.1	91.6	81.1	53.3
LPG and ethane	14.0	14.0	16.4	17.3	17.8	13.9	13.5	11.3
Naphtha	6.8	7.0	7.7	8.3	9.2	6.0	6.2	6.0
Gasoline	24.4	25.0	23.9	21.3	17.1	22.2	17.7	7.6
Kerosene	6.2	7.1	8.5	9.1	10.6	7.9	7.9	6.8
Diesel	27.3	27.3	28.5	27.8	25.5	25.4	22.2	12.5
Fuel oil	6.5	6.5	5.7	5.4	4.5	4.1	3.0	1.1
Other products	10.0	10.3	9.7	8.6	7.4	12.1	10.6	8.0
Products from NGLs	12.2	12.8	14.3	13.3	11.1	12.5	11.5	8.2
Refinery products	83.0	84.4	86.1	84.5	81.0	79.1	69.6	45.1
Refinery market share	*84%*	*83%*	*82%*	*83%*	*83%*	*81%*	*78%*	*70%*

Note: CTL = coal-to-liquids; GTL = gas-to-liquids; LPG = liquefied petroleum gas; NGLs = natural gas liquids.

Table A.11: Refining capacity and runs (mb/d)

	Refining capacity							Refinery runs						
		STEPS			APS				STEPS			APS		
	2023	**2030**	**2035**	**2050**	**2030**	**2035**	**2050**	**2023**	**2030**	**2035**	**2050**	**2030**	**2035**	**2050**
North America	21.9	21.5	20.8	20.6	21.0	18.8	9.6	18.6	17.8	16.9	16.0	16.5	14.4	7.0
Europe	15.8	14.8	13.7	13.0	13.4	9.7	6.3	12.5	11.2	9.8	8.2	9.5	6.3	3.5
Asia Pacific	38.2	39.9	40.1	39.9	39.8	37.9	26.1	31.0	32.0	32.0	30.9	30.2	28.3	19.0
Japan and Korea	6.8	6.5	6.2	5.7	6.3	5.5	3.7	5.3	5.0	4.7	4.2	4.7	3.9	2.4
China	18.3	18.9	18.9	18.9	18.9	17.8	10.0	15.0	15.0	14.6	13.5	14.3	12.9	6.7
India	5.8	6.8	7.1	7.3	6.8	6.9	5.4	5.2	6.1	6.4	6.6	5.7	5.7	4.4
Southeast Asia	5.4	5.8	5.9	5.9	5.8	5.7	5.1	4.1	4.5	4.7	5.0	4.2	4.4	4.1
Middle East	11.2	11.8	12.6	12.6	11.3	10.4	8.4	8.8	10.2	10.7	10.5	8.9	8.0	6.2
Russia	7.0	7.0	6.5	6.5	6.5	5.8	4.0	5.5	5.7	4.9	4.2	4.8	3.9	2.3
Africa	3.0	3.7	4.0	4.0	3.7	3.9	3.5	1.6	2.3	2.7	3.0	2.2	2.3	2.3
Brazil	2.2	2.4	2.4	2.4	2.2	2.1	1.5	2.0	2.2	2.2	2.2	1.9	1.8	1.3
World	**104.2**	**106.1**	**105.1**	**103.9**	**102.9**	**93.1**	**62.9**	**82.5**	**84.1**	**81.9**	**78.1**	**76.6**	**67.3**	**43.6**
Atlantic Basin	54.6	54.1	52.1	51.2	51.6	44.5	28.2	42.6	41.8	39.1	36.7	37.4	30.9	18.4
East of Suez	49.6	52.0	53.0	52.7	51.3	48.6	34.7	39.9	42.3	42.8	41.5	39.2	36.4	25.3

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Table A.12: Natural gas production (bcm)

				Stated Policies			Announced Pledges		
	2010	2022	2023	2030	2035	2050	2030	2035	2050
World	**3 286**	**4 210**	**4 218**	**4 430**	**4 422**	**4 377**	**4 003**	**3 493**	**2 466**
Conventional gas	2 781	2 941	2 908	2 982	2 996	3 076	2 818	2 560	1 969
Tight gas	274	312	314	242	195	120	213	138	39
Shale gas	154	861	896	1 106	1 128	1 082	890	728	429
Coalbed methane	77	85	86	77	78	73	58	49	29
North America	815	1 272	1 323	1 319	1 241	1 073	1 153	863	409
Central and South America	163	161	160	164	170	176	150	139	102
Europe	341	253	236	198	181	133	172	127	57
European Union	148	47	37	31	29	23	17	9	2
Africa	210	254	262	284	298	314	261	240	211
Middle East	464	687	698	903	962	1 152	849	860	777
Eurasia	807	896	851	891	896	873	793	715	577
Asia Pacific	487	686	688	671	675	655	625	549	332
Southeast Asia	215	196	193	172	152	122	156	130	81

Table A.13: Natural gas demand (bcm)

				Stated Policies			Announced Pledges		
	2010	2022	2023	2030	2035	2050	2030	2035	2050
World	**3 312**	**4 166**	**4 186**	**4 430**	**4 422**	**4 377**	**4 003**	**3 493**	**2 466**
North America	838	1 167	1 175	1 121	1 028	811	957	674	367
United States	678	939	940	883	791	578	760	506	260
Central and South America	150	156	156	168	180	183	158	152	102
Brazil	28	32	30	34	35	32	27	26	20
Europe	697	544	507	462	407	301	409	281	86
European Union	446	358	331	296	257	166	264	167	29
Africa	107	176	182	203	219	290	181	180	185
Middle East	370	566	578	702	750	880	674	692	678
Eurasia	573	652	660	671	671	669	617	575	490
Russia	467	515	523	521	513	485	479	444	371
Asia Pacific	577	904	928	1 075	1 131	1 191	992	928	559
China	110	370	398	499	522	523	448	397	213
India	64	60	64	99	125	172	91	107	107
Japan	95	94	85	61	49	41	57	45	22
Southeast Asia	149	167	175	209	231	265	191	189	115
International bunkers	-	-	-	27	36	51	16	11	-

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Table A.14: Coal production (Mtce)

				Stated Policies			Announced Pledges		
	2010	2022	2023	2030	2035	2050	2030	2035	2050
World	**5 243**	**6 060**	**6 278**	**5 308**	**4 454**	**3 191**	**4 702**	**3 231**	**1 370**
Steam coal	4 076	4 848	5 079	4 262	3 479	2 398	3 743	2 423	985
Coking coal	867	961	970	911	861	711	851	724	346
Lignite and peat	300	251	229	135	114	82	107	84	39
North America	818	453	444	214	139	89	132	83	34
Central and South America	81	67	58	32	33	18	20	19	4
Europe	331	196	163	74	54	33	45	23	5
European Union	220	137	109	36	20	6	23	8	1
Africa	211	204	206	180	162	138	153	114	35
Middle East	1	1	1	1	1	1	1	-	-
Eurasia	309	426	422	355	343	273	318	281	194
Asia Pacific	3 493	4 714	4 985	4 451	3 723	2 639	4 035	2 713	1 098
Southeast Asia	318	564	626	573	523	437	481	352	182

Table A.15: Coal demand (Mtce)

				Stated Policies			Announced Pledges		
	2010	2022	2023	2030	2035	2050	2030	2035	2050
World	**5 216**	**5 879**	**5 986**	**5 307**	**4 453**	**3 191**	**4 702**	**3 231**	**1 370**
North America	769	366	308	137	68	26	69	32	16
United States	717	342	284	125	58	16	59	25	11
Central and South America	38	41	38	37	38	42	26	24	15
Brazil	21	20	20	22	23	25	16	15	10
Europe	539	352	299	195	155	125	142	85	40
European Union	361	238	188	94	61	36	62	28	9
Africa	155	150	147	124	108	89	106	80	30
Middle East	3	5	5	6	7	8	6	6	4
Eurasia	203	250	257	232	214	179	213	186	134
Russia	151	191	197	173	159	123	167	149	106
Asia Pacific	3 509	4 715	4 931	4 576	3 863	2 724	4 139	2 818	1 129
China	2 565	3 329	3 469	3 029	2 358	1 413	2 748	1 731	572
India	392	665	721	832	800	645	761	590	336
Japan	165	156	151	107	93	60	99	75	24
Southeast Asia	122	297	320	388	418	438	353	280	103

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Table A.16: Electricity generation (TWh)

				Stated Policies			Announced Pledges		
	2010	2022	2023	2030	2035	2050	2030	2035	2050
World	**21 511**	**29 145**	**29 863**	**37 489**	**42 766**	**58 352**	**38 285**	**45 759**	**70 564**
North America	5 230	5 468	5 390	5 979	6 704	8 955	6 137	7 403	11 361
United States	4 354	4 473	4 412	4 854	5 446	7 365	4 994	6 046	9 384
Central and South America	1 129	1 372	1 419	1 691	1 951	2 921	1 805	2 228	4 003
Brazil	516	677	710	809	900	1 260	835	985	1 573
Europe	4 119	3 980	3 885	4 719	5 508	6 893	5 027	6 059	8 174
European Union	2 955	2 793	2 705	3 291	3 871	4 858	3 518	4 242	5 688
Africa	687	901	913	1 203	1 460	2 459	1 360	1 837	3 877
Middle East	829	1 342	1 370	1 773	2 087	3 236	1 836	2 623	4 721
Eurasia	1 251	1 457	1 477	1 593	1 688	1 949	1 576	1 682	2 047
Russia	1 036	1 149	1 163	1 223	1 279	1 397	1 201	1 247	1 404
Asia Pacific	8 265	14 625	15 409	20 531	23 368	31 940	20 544	23 925	36 381
China	4 236	8 947	9 566	12 967	14 495	18 956	12 914	14 559	19 713
India	972	1 814	1 943	2 881	3 511	5 555	2 744	3 418	6 704
Japan	1 164	1 010	1 016	1 035	1 052	1 141	1 056	1 130	1 347
Southeast Asia	685	1 284	1 337	1 827	2 249	3 470	1 901	2 444	4 716

Table A.17: Renewables generation (TWh)

				Stated Policies			Announced Pledges		
	2010	2022	2023	2030	2035	2050	2030	2035	2050
World	**4 209**	**8 567**	**9 029**	**17 577**	**24 930**	**42 770**	**19 897**	**30 828**	**58 611**
North America	856	1 493	1 450	2 695	3 898	6 931	3 333	5 345	9 603
United States	441	960	958	2 037	3 137	5 882	2 615	4 418	7 990
Central and South America	752	998	1 052	1 327	1 570	2 596	1 498	1 928	3 845
Brazil	437	594	633	725	804	1 163	789	928	1 522
Europe	954	1 609	1 757	3 118	4 178	5 673	3 540	4 888	6 846
European Union	653	1 085	1 208	2 227	3 039	4 116	2 522	3 503	4 794
Africa	116	211	223	472	725	1 616	730	1 296	3 459
Middle East	18	38	48	270	481	1 326	336	1 013	3 168
Eurasia	226	273	277	330	371	482	360	465	760
Russia	167	206	207	234	255	312	242	280	366
Asia Pacific	1 287	3 946	4 223	9 365	13 707	24 146	10 099	15 893	30 929
China	782	2 687	2 923	6 737	9 650	15 511	7 047	10 418	16 951
India	161	400	405	1 022	1 741	4 185	1 055	2 083	5 780
Japan	106	219	238	384	491	679	398	541	803
Southeast Asia	104	355	351	525	819	1 882	726	1 432	4 180

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Table A.18: Solar PV generation (TWh)

				Stated Policies			Announced Pledges		
	2010	2022	2023	2030	2035	2050	2030	2035	2050
World	**32**	**1 294**	**1 612**	**6 452**	**10 689**	**21 557**	**7 512**	**13 673**	**28 996**
North America	3	210	247	904	1 549	3 633	1 157	2 117	4 282
United States	3	184	212	833	1 447	3 434	1 075	1 939	3 697
Central and South America	0	55	78	216	274	588	358	562	1 327
Brazil	0	30	49	129	155	253	197	277	440
Europe	23	250	293	871	1 226	1 638	1 021	1 438	1 863
European Union	22	206	240	705	989	1 303	827	1 136	1 352
Africa	0	15	19	136	271	645	294	624	1 835
Middle East	0	16	23	213	377	967	275	857	2 298
Eurasia	0	5	6	20	27	40	26	45	101
Russia	0	3	3	5	6	10	8	12	27
Asia Pacific	6	742	946	4 092	6 965	14 047	4 380	8 030	17 290
China	1	427	584	3 001	5 107	9 800	3 092	5 494	10 688
India	0	105	125	539	1 015	2 552	557	1 225	3 450
Japan	4	93	100	168	208	250	171	212	263
Southeast Asia	0	40	45	108	212	640	215	516	1 681

Table A.19: Wind generation (TWh)

				Stated Policies			Announced Pledges		
	2010	2022	2023	2030	2035	2050	2030	2035	2050
World	**342**	**2 120**	**2 336**	**5 024**	**7 535**	**12 347**	**5 938**	**9 548**	**18 289**
North America	105	497	488	954	1 462	2 259	1 286	2 170	4 028
United States	95	439	430	843	1 301	1 942	1 143	1 933	3 555
Central and South America	3	117	135	263	379	775	304	452	1 116
Brazil	2	82	95	161	209	428	167	233	534
Europe	154	556	613	1 209	1 844	2 687	1 441	2 297	3 540
European Union	140	421	479	921	1 424	2 064	1 072	1 713	2 623
Africa	2	25	25	72	127	327	120	223	596
Middle East	0	4	4	25	58	241	25	104	646
Eurasia	0	8	9	20	35	86	33	86	224
Russia	0	6	6	9	17	51	15	35	86
Asia Pacific	77	913	1 060	2 480	3 631	5 973	2 728	4 216	8 139
China	45	763	886	1 998	2 715	3 629	2 086	2 839	3 800
India	20	81	94	163	341	1 049	176	393	1 259
Japan	4	9	10	66	121	225	72	147	313
Southeast Asia	0	14	20	69	162	495	120	369	1 549

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Table A.20: Nuclear generation (TWh)

				Stated Policies			Announced Pledges		
	2010	2022	2023	2030	2035	2050	2030	2035	2050
World	**2 756**	**2 684**	**2 765**	**3 266**	**3 746**	**4 460**	**3 462**	**4 332**	**6 055**
North America	935	902	908	919	948	997	944	1 003	1 250
United States	839	804	808	820	831	863	831	878	1 101
Central and South America	22	23	24	33	51	70	34	54	77
Brazil	15	15	15	24	37	45	24	37	41
Europe	1 032	749	766	779	765	834	795	802	1 172
European Union	854	609	616	617	564	630	617	600	860
Africa	12	10	9	24	44	68	29	52	103
Middle East	0	29	40	46	80	108	48	113	220
Eurasia	173	226	223	219	246	315	219	255	401
Russia	170	223	220	216	239	305	216	247	383
Asia Pacific	582	746	796	1 245	1 612	2 067	1 393	2 054	2 832
China	74	418	435	623	898	1 159	737	1 258	1 720
India	26	46	48	128	201	337	128	206	345
Japan	288	56	88	202	210	206	226	242	289
Southeast Asia	0	0	0	0	0	41	0	24	98

Table A.21: Natural gas generation (TWh)

				Stated Policies			Announced Pledges		
	2010	2022	2023	2030	2035	2050	2030	2035	2050
World	**4 819**	**6 515**	**6 540**	**6 914**	**6 643**	**6 507**	**6 416**	**5 269**	**3 344**
North America	1 217	2 008	2 145	2 006	1 694	984	1 660	901	343
United States	1 018	1 739	1 858	1 673	1 339	596	1 375	623	167
Central and South America	170	211	203	235	257	220	226	220	72
Brazil	36	42	36	42	43	41	20	17	9
Europe	946	838	715	495	331	206	476	251	73
European Union	589	535	452	313	219	104	311	122	19
Africa	235	377	391	471	501	685	395	346	263
Middle East	524	930	943	1 298	1 406	1 758	1 326	1 411	1 316
Eurasia	603	676	685	765	794	888	751	739	709
Russia	521	519	529	582	593	609	575	563	528
Asia Pacific	1 125	1 476	1 458	1 644	1 660	1 767	1 583	1 401	568
China	92	288	305	438	443	494	439	346	188
India	107	55	64	84	107	164	77	96	46
Japan	332	343	323	203	134	106	185	132	73
Southeast Asia	336	336	349	526	607	715	457	461	172

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Table A.22: Coal generation (TWh)

				Stated Policies			Announced Pledges		
	2010	2022	2023	2030	2035	2050	2030	2035	2050
World	**8 671**	**10 451**	**10 648**	**9 217**	**6 986**	**4 284**	**8 034**	**4 814**	**1 827**
North America	2 103	964	794	313	123	7	124	30	25
United States	1 994	913	744	301	118	7	116	29	24
Central and South America	41	53	50	33	28	19	10	5	1
Brazil	11	14	16	12	10	4	0	0	0
Europe	1 068	687	554	281	201	167	180	97	56
European Union	755	482	349	97	27	0	39	3	3
Africa	259	237	229	173	127	49	152	93	17
Middle East	0	1	1	3	3	3	3	3	3
Eurasia	235	267	276	273	272	260	240	218	172
Russia	166	188	196	186	187	166	162	153	124
Asia Pacific	4 963	8 243	8 745	8 139	6 233	3 779	7 325	4 368	1 553
China	3 263	5 537	5 886	5 151	3 484	1 756	4 669	2 478	757
India	658	1 307	1 419	1 640	1 457	865	1 479	1 029	503
Japan	317	312	303	198	168	92	192	151	43
Southeast Asia	185	568	615	760	808	815	703	514	103

Table A.23: Total final consumption (EJ)

				Stated Policies			Announced Pledges		
	2010	2022	2023	2030	2035	2050	2030	2035	2050
World	**377.4**	**437.3**	**444.7**	**485.4**	**498.5**	**533.3**	**457.3**	**449.6**	**434.4**
North America	76.6	79.4	78.6	78.3	74.9	71.0	74.3	67.3	55.5
United States	63.8	66.5	65.7	65.2	61.9	57.4	61.9	55.7	44.7
Central and South America	19.2	21.2	21.4	23.6	25.3	30.4	22.7	23.4	24.5
Brazil	9.1	10.4	10.6	11.5	12.2	14.5	11.2	11.6	12.4
Europe	62.6	56.9	55.2	55.5	53.0	47.6	53.0	48.2	38.6
European Union	45.4	41.5	39.9	39.3	36.8	31.0	37.6	33.9	25.9
Africa	17.6	23.0	23.1	26.3	28.8	38.5	22.9	24.2	31.6
Middle East	18.3	23.9	24.2	29.1	32.1	42.0	28.3	30.5	36.5
Eurasia	24.1	28.8	29.1	30.8	31.3	32.2	29.4	28.7	27.1
Russia	19.5	23.2	23.5	24.3	24.3	23.8	23.2	22.5	20.0
Asia Pacific	144.2	189.0	196.6	222.3	232.2	246.6	209.5	209.1	200.1
China	76.3	105.3	110.8	122.5	123.7	117.7	117.2	113.1	96.9
India	18.9	29.2	31.0	38.7	43.6	54.5	34.4	37.4	44.0
Japan	14.1	11.6	11.4	10.7	10.2	9.0	10.2	9.2	7.1
Southeast Asia	14.8	20.2	21.0	25.8	28.6	35.5	24.6	26.1	28.6

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Table A.24: Industry consumption (EJ)

				Stated Policies			Announced Pledges		
	2010	2022	2023	2030	2035	2050	2030	2035	2050
World	**143.2**	**169.7**	**172.8**	**193.1**	**199.7**	**209.5**	**185.2**	**184.6**	**176.9**
North America	17.8	19.2	19.0	20.4	20.9	22.2	19.7	19.7	18.8
United States	14.1	15.3	15.1	16.0	16.3	17.2	15.5	15.4	14.4
Central and South America	7.2	7.1	7.1	7.8	8.3	9.7	7.7	8.0	9.0
Brazil	4.0	4.0	4.0	4.4	4.6	5.4	4.3	4.5	5.1
Europe	19.6	17.4	16.7	17.2	17.1	16.5	16.5	15.9	14.1
European Union	14.3	13.2	12.4	12.6	12.4	11.3	12.1	11.5	9.7
Africa	3.9	4.5	4.5	5.2	5.8	8.0	5.1	5.5	7.2
Middle East	8.2	10.2	10.5	12.3	13.2	15.1	12.0	12.6	13.5
Eurasia	8.6	9.8	10.0	10.8	10.9	10.7	10.5	10.4	9.6
Russia	7.0	8.3	8.4	9.0	8.9	8.3	8.8	8.7	7.7
Asia Pacific	77.9	101.5	104.9	119.3	123.5	127.3	113.8	112.7	104.7
China	49.2	64.0	66.4	73.3	73.0	66.6	69.8	66.2	53.7
India	7.8	13.6	14.6	19.4	22.3	29.3	18.1	19.9	23.9
Japan	6.1	5.0	4.8	4.5	4.3	4.0	4.3	4.0	3.3
Southeast Asia	6.2	9.2	9.7	11.9	13.2	16.0	11.6	12.4	13.9

Table A.25: Transport consumption (EJ)

				Stated Policies			Announced Pledges		
	2010	2022	2023	2030	2035	2050	2030	2035	2050
World	**101.1**	**117.7**	**122.0**	**131.7**	**132.6**	**139.9**	**125.2**	**120.8**	**109.1**
North America	29.6	30.3	30.6	29.3	25.9	21.3	27.6	23.1	16.4
United States	25.0	25.9	26.3	25.2	22.2	17.8	23.8	19.8	13.9
Central and South America	6.1	7.6	7.7	8.8	9.6	12.0	8.5	8.7	8.0
Brazil	2.9	3.8	3.9	4.3	4.6	5.4	4.2	4.3	4.0
Europe	15.2	16.0	15.9	14.9	13.3	9.6	14.3	12.1	7.9
European Union	11.2	11.7	11.6	10.6	9.1	5.6	10.2	8.5	5.2
Africa	3.7	5.4	5.3	6.3	7.2	11.0	6.2	7.0	9.2
Middle East	4.8	6.0	6.1	7.0	7.7	10.8	7.0	7.5	8.3
Eurasia	4.7	5.4	5.5	5.7	5.9	6.5	5.5	5.5	5.3
Russia	4.0	4.3	4.4	4.4	4.4	4.3	4.3	4.2	3.6
Asia Pacific	22.1	31.8	34.3	40.1	42.0	43.7	38.7	38.5	33.4
China	8.3	13.5	15.5	17.5	17.3	14.5	17.0	16.3	12.8
India	2.7	4.7	5.0	6.8	7.7	9.1	6.6	7.0	6.5
Japan	3.3	2.7	2.7	2.4	2.1	1.7	2.3	1.9	1.2
Southeast Asia	3.7	5.9	6.1	7.5	8.3	10.0	7.3	7.6	7.4

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Table A.26: Buildings consumption (EJ)

				Stated Policies			Announced Pledges		
	2010	2022	2023	2030	2035	2050	2030	2035	2050
World	**111.2**	**125.0**	**124.1**	**132.5**	**136.7**	**152.6**	**120.0**	**117.2**	**122.9**
North America	23.7	24.9	23.9	23.4	22.8	22.3	22.0	19.8	16.2
United States	20.5	21.4	20.4	19.9	19.3	18.4	18.8	16.8	13.3
Central and South America	4.4	5.1	5.1	5.5	5.8	6.8	5.0	5.1	5.9
Brazil	1.4	1.8	1.9	1.9	2.1	2.7	1.9	2.0	2.5
Europe	24.3	20.7	19.9	20.7	20.0	18.9	19.6	17.7	14.6
European Union	17.6	14.8	14.1	14.4	13.7	12.5	13.7	12.4	9.9
Africa	9.2	12.1	12.3	13.6	14.4	17.7	10.5	10.4	13.5
Middle East	4.4	6.2	6.3	8.5	9.9	14.8	8.1	9.2	13.6
Eurasia	8.4	10.3	10.3	10.8	10.8	11.1	10.1	9.5	8.8
Russia	6.2	7.6	7.6	7.7	7.6	7.5	7.1	6.5	5.5
Asia Pacific	36.9	45.8	46.2	50.0	53.0	61.0	44.8	45.6	50.3
China	15.7	22.7	22.9	25.0	26.6	30.3	24.1	24.4	25.5
India	6.9	8.6	8.9	9.3	9.9	11.1	6.7	7.2	9.5
Japan	4.3	3.7	3.5	3.5	3.3	3.0	3.3	3.0	2.4
Southeast Asia	3.9	4.2	4.3	5.2	6.0	8.2	4.7	5.0	6.2

Table A.27: Hydrogen demand (PJ)

			Stated Policies			Announced Pledges		
	2022	2023	2030	2035	2050	2030	2035	2050
World	**11 129**	**11 425**	**13 335**	**14 628**	**18 665**	**14 254**	**19 743**	**37 994**
North America	1 901	1 931	2 134	2 349	3 387	2 538	3 607	8 218
United States	1 574	1 613	1 739	1 917	2 902	2 157	3 107	7 361
Central and South America	370	386	533	690	1 269	720	1 078	2 663
Brazil	54	59	87	102	137	145	277	682
Europe	884	916	986	1 061	1 635	1 217	1 658	2 912
European Union	695	715	777	845	1 400	965	1 289	2 086
Africa	363	373	463	536	817	561	803	1 858
Middle East	1 551	1 649	2 053	2 360	2 903	2 065	3 311	6 042
Eurasia	810	814	914	927	946	903	954	1 014
Russia	729	723	801	806	805	792	835	861
Asia Pacific	5 250	5 355	6 363	7 074	8 236	6 358	8 520	15 383
China	3 015	3 087	3 571	3 651	3 644	3 586	4 731	6 866
India	1 028	1 083	1 350	1 593	2 148	1 276	1 585	3 211
Japan	228	229	216	238	278	258	409	814
Southeast Asia	451	434	528	632	855	527	649	2 424
International bunkers	-	-	6	17	78	92	210	580

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Table A.28: Low-emissions hydrogen balance (Mt H_2 equivalent)

		Stated Policies			Announced Pledges			Net Zero Emissions by 2050		
	2023	2030	2035	2050	2030	2035	2050	2030	2035	2050
Low-emissions hydrogen production	1	7	15	46	25	78	260	66	152	401
Water electrolysis	0	5	11	37	18	61	203	49	118	326
Fossil fuels with CCUS	1	2	4	9	7	17	57	17	33	74
Bioenergy and other	0	0	0	0	0	0	0	0	0	1
Transformation of hydrogen	0	4	9	26	16	48	140	41	91	201
To power generation	-	1	2	3	4	11	20	17	30	44
To hydrogen-based fuels	0	1	4	17	7	30	109	16	50	148
In oil refining	0	2	2	5	3	5	7	6	8	5
To biofuels	0	0	0	1	2	2	3	2	3	4
Hydrogen demand for end-use sectors	0	2	6	20	9	29	117	24	59	191
Low-emissions hydrogen-based fuels	-	1	3	17	7	29	108	15	48	145
Total final consumption	-	0	2	15	6	27	91	10	33	127
Power generation	-	0	1	2	0	2	17	5	14	18
Trade	0	2	7	22	7	22	59	18	32	71
Trade as share of demand	0%	30%	48%	50%	27%	28%	23%	28%	21%	18%

Table A.29: Total CO_2 emissions* (Mt CO_2)

				Stated Policies			Announced Pledges		
	2010	2022	2023	2030	2035	2050	2030	2035	2050
World	**32 805**	**37 230**	**37 723**	**36 170**	**33 285**	**28 636**	**32 056**	**24 678**	**11 711**
North America	6 485	5 728	5 571	4 778	4 056	2 878	3 837	2 458	374
United States	5 470	4 738	4 579	3 843	3 152	2 016	3 086	1 857	101
Central and South America	1 149	1 200	1 189	1 221	1 278	1 384	1 078	982	558
Brazil	412	452	446	455	470	505	384	345	174
Europe	4 679	3 832	3 573	2 919	2 434	1 609	2 461	1 610	350
European Union	3 277	2 682	2 446	1 872	1 470	746	1 576	972	106
Africa	1 161	1 428	1 420	1 472	1 543	1 971	1 329	1 288	1 233
Middle East	1 639	2 158	2 197	2 326	2 423	2 814	2 185	2 166	1 878
Eurasia	2 141	2 339	2 388	2 380	2 356	2 286	2 162	2 008	1 659
Russia	1 684	1 798	1 841	1 795	1 749	1 582	1 647	1 526	1 211
Asia Pacific	14 436	19 417	20 171	19 682	17 752	14 182	17 879	13 183	4 953
China	8 770	12 087	12 636	11 598	9 607	6 356	10 523	6 951	1 745
India	1 667	2 702	2 902	3 458	3 497	3 184	3 172	2 685	1 509
Japan	1 189	1 024	978	741	633	430	677	488	50
Southeast Asia	1 165	1 833	1 925	2 258	2 423	2 617	2 057	1 794	886

*Includes industrial process and flaring emissions.

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Table A.30: Electricity and heat sectors CO_2 emissions (Mt CO_2)

				Stated Policies			Announced Pledges		
	2010	2022	2023	2030	2035	2050	2030	2035	2050
World	**12 513**	**14 943**	**15 262**	**13 311**	**10 968**	**7 757**	**11 760**	**7 516**	**2 640**
North America	2 596	1 809	1 704	1 113	797	387	769	280	- 31
United States	2 346	1 610	1 495	955	644	240	639	164	- 93
Central and South America	235	224	216	179	168	117	130	113	35
Brazil	46	50	47	40	36	30	10	9	4
Europe	1 728	1 185	1 008	594	431	298	460	214	70
European Union	1 188	807	649	302	175	66	225	66	2
Africa	419	495	491	426	384	338	366	283	146
Middle East	548	754	758	699	686	690	683	654	493
Eurasia	1 034	1 021	1 050	1 029	1 027	991	937	873	740
Russia	892	806	833	808	799	726	754	709	594
Asia Pacific	5 953	9 455	10 036	9 270	7 475	4 936	8 415	5 100	1 187
China	3 509	6 095	6 576	5 854	4 311	2 528	5 322	2 860	533
India	785	1 327	1 424	1 579	1 402	838	1 442	982	329
Japan	499	469	444	265	203	112	252	170	- 11
Southeast Asia	398	773	829	998	1 075	1 095	916	720	174

Table A.31: Total final consumption CO_2 emissions* (Mt CO_2)

				Stated Policies			Announced Pledges		
	2010	2022	2023	2030	2035	2050	2030	2035	2050
World	**18 590**	**20 410**	**20 604**	**21 106**	**20 601**	**19 288**	**19 003**	**16 185**	**8 817**
North America	3 470	3 475	3 416	3 219	2 813	2 072	2 799	2 019	459
United States	2 865	2 868	2 818	2 638	2 265	1 561	2 302	1 622	253
Central and South America	803	884	885	957	1 019	1 172	880	818	490
Brazil	343	382	386	402	419	461	366	331	171
Europe	2 776	2 498	2 424	2 215	1 907	1 235	1 928	1 366	280
European Union	1 975	1 772	1 700	1 498	1 232	629	1 303	886	97
Africa	556	760	755	894	1 014	1 487	851	911	1 057
Middle East	926	1 137	1 163	1 351	1 460	1 827	1 293	1 324	1 277
Eurasia	913	1 192	1 207	1 228	1 214	1 191	1 155	1 076	884
Russia	668	896	908	895	867	785	847	779	595
Asia Pacific	8 032	9 337	9 541	9 851	9 729	8 791	8 973	7 690	3 663
China	4 998	5 610	5 702	5 402	4 966	3 558	4 896	3 859	1 198
India	848	1 298	1 398	1 791	2 005	2 263	1 653	1 640	1 143
Japan	662	537	517	464	421	329	413	310	74
Southeast Asia	691	980	1 017	1 206	1 295	1 470	1 101	1 039	689

* Includes industrial process emissions.

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Design of the scenarios

The *World Energy Outlook-2024* (*WEO-2024)* explores three main scenarios in the analysis in the chapters. These scenarios are not predictions – the IEA does not have a single view on the future of the energy system. The scenario descriptions are:

- The **Stated Policies Scenario** (STEPS) explores how energy systems evolve under today's policies and private sector momentum. The scenario is not developed with a particular outcome in mind, but rather explores where current efforts are likely to lead global energy systems. The STEPS does not take for granted that all government targets will be achieved. Instead, it takes a granular, sector-by-sector look at the concrete policies and measures in effect as of August 2024, and assesses their impact on energy demand and supply. The STEPS also takes into account private sector action, including fuel production and manufacturing capacity of clean energy technologies, and assesses how these market dynamics impact future trends. A snapshot of the major policies considered in the STEPS is presented in Tables B.6 to B.11. These tables also include key national targets that are met or exceeded as a result of this bottom-up assessment.
- The **Announced Pledges Scenario** (APS) assumes that governments will meet all climate commitments, including their Nationally Determined Contributions and longer-term net zero emissions targets. The APS starts from the policies and trends in the STEPS and identifies additional efforts needed to reach national climate and energy targets. In some cases, one national target may require other targets to not be achieved exactly by the date or in the manner specified. In most cases, national long-term net zero emissions targets are achieved in the APS. Still, other interim targets have a strong influence on the pathways in which countries achieve their long-term targets. Countries without ambitious long-term pledges are assumed to benefit in this scenario from the accelerated cost reductions and wider availability of clean energy technologies. The list of climate and energy targets considered in the APS is in Tables B.6 to B.11, and can be explored in more detail through the IEA Climate Pledges Explorer.[1]
- The **Net Zero Emissions by 2050** (NZE) **Scenario** depicts a narrow but achievable pathway for the global energy sector to reach net zero energy-related CO_2 emissions by 2050 by deploying a wide portfolio of clean energy technologies and without offsets from land-use measures. It recognises that achieving net zero energy sector CO_2 emissions by 2050 depends on fair and effective global co-operation, with advanced economies taking the lead and reaching net zero emissions earlier in the NZE Scenario than emerging market and developing economies. This scenario also achieves universal modern energy access by 2030, consistent with the energy-related targets of the United Nations Sustainable Development Goals. The NZE Scenario is consistent with limiting the global temperature rise to 1.5 °C (with at least a 50% probability) with limited overshoot.

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[1] The IEA Climate Pledges Explorer is available at: http://www.iea.org/data-and-statistics/data-tools/climate-pledges-explorer.

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B.1 Population

Table B.1 ▷ Population assumptions by region

	Compound average annual growth rate (%)				Population (million)				Urbanisation (share of population, %)			
	2000-23	2023-30	2023-35	2023-50	2023	2030	2035	2050	2023	2030	2035	2050
North America	0.9	0.6	0.5	0.4	509	529	542	566	83	84	86	89
United States	0.7	0.5	0.5	0.4	338	350	358	373	83	85	86	89
C & S America	1.0	0.7	0.6	0.5	532	559	574	601	82	83	85	88
Brazil	0.9	0.5	0.4	0.2	216	224	228	231	88	89	90	92
Europe	0.3	0.0	0.0	-0.1	691	693	692	679	76	78	80	84
European Union	0.2	-0.2	-0.2	-0.2	449	444	441	425	76	78	79	84
Africa	2.5	2.3	2.2	2.0	1 458	1 708	1 897	2 482	45	48	51	59
Middle East	2.1	1.4	1.3	1.1	269	297	315	364	73	75	76	81
Eurasia	0.4	0.3	0.2	0.2	240	244	247	255	65	67	68	73
Russia	-0.1	-0.3	-0.3	-0.3	143	140	138	132	75	77	79	83
Asia Pacific	1.0	0.5	0.5	0.3	4 319	4 489	4 584	4 734	51	55	57	64
China	0.5	-0.1	-0.2	-0.3	1 419	1 409	1 393	1 307	65	71	74	80
India	1.3	0.8	0.8	0.6	1 429	1 515	1 568	1 670	36	40	43	53
Japan	-0.1	-0.6	-0.6	-0.6	124	119	116	105	92	93	93	95
Southeast Asia	1.2	0.8	0.7	0.5	685	723	745	787	52	56	58	66
World	**1.2**	**0.9**	**0.8**	**0.7**	**8 018**	**8 518**	**8 851**	**9 680**	**57**	**60**	**62**	**68**

Notes: C & S America = Central and South America. See Annex C for composition of regional groupings.

Sources: OECD (2024); UN DESA (2018 and 2022); World Bank (2024a); IEA databases and analysis.

- Population is a major determinant of many of the trends in the *Outlook*. We use the medium variant of the United Nations projections as the basis for population growth in all scenarios, but this is naturally subject to a degree of uncertainty.
- On average, the rate of population growth is assumed to slow over time, but the global population approaches 9.7 billion by 2050 (Table B.1).
- Around three-fifths of the increase over the projection period to 2050 is in Africa and around a further quarter is in the Asia Pacific region.
- The share of the world's population living in towns and cities has been rising steadily, a trend that is projected to continue over the period to 2050. In aggregate, this means that virtually all of the 1.7 billion increase in global population over the period is added to cities and towns.

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B.2 CO_2 prices

Table B.2 ⊳ CO_2 prices for electricity, industry and energy production in selected regions by scenario

USD (2023, MER) per tonne of CO_2	2030	2035	2040	2050
Stated Policies Scenario				
Canada	126	126	126	126
Chile and Colombia	21	24	28	28
China	39	43	46	52
European Union	140	145	149	158
Korea	56	65	73	89
Announced Pledges Scenario				
Advanced economies with net zero emissions pledges*	135	160	175	200
Selected emerging market and developing economies with net zero emissions pledges**	40	65	110	160
Other emerging market and developing economies	-	6	17	47
Net Zero Emissions by 2050 Scenario				
Advanced economies with net zero emissions pledges*	140	180	205	250
Selected emerging market and developing economies with net zero emissions pledges**	90	125	160	200
Selected emerging market and developing economies without net zero emissions pledges	25	50	85	180
Other emerging market and developing economies	15	25	35	55

* Includes all OECD countries except Mexico. ** Includes China, India, Indonesia, Brazil and South Africa. *** Regions excluding OECD countries, selected emerging market and developing economies with net zero emissions pledges, developing Asia and sub-Saharan Africa.

Note: MER = market exchange rate. Values are rounded.

- There are 75 direct carbon pricing instruments in place today, covering around 50 countries and 40 sub-national jurisdictions. Global carbon pricing revenues in 2023 increased by 7% from 2022 levels, to around USD 105 billion (World Bank, 2024b).
- Existing and scheduled CO_2 pricing schemes are reflected in the STEPS, covering electricity generation, industry, energy production sectors and other end-use sectors, e.g. aviation, road transport and buildings, where applicable.
- In the APS, higher CO_2 prices are introduced across all regions with net zero emissions pledges. No explicit pricing is assumed in sub-Saharan Africa (excluding South Africa) and developing Asia. Instead, these regions rely on direct policy interventions to drive decarbonisation in the APS.
- In the NZE Scenario, CO_2 prices cover all regions and rise rapidly across all advanced economies as well as in prominent emerging market economies with net zero emissions pledges, including China, India, Indonesia, Brazil and South Africa. CO_2 prices are lower, but nevertheless rising in other emerging market and developing economies such as

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North Africa, Middle East, Russia and Southeast Asia (excluding Indonesia). CO_2 prices are lower in the remaining emerging market and developing economies, as it is assumed they pursue more direct policies to adapt and transform their energy systems.

- All scenarios consider the effects of other policy measures alongside CO_2 pricing, such as coal phase out plans, efficiency standards and renewable targets (Tables B.6 - B.11). These policies interact with carbon pricing; therefore, CO_2 pricing is not the marginal cost of abatement as is often the case in other modelling approaches.

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B.3 Fossil fuel resources

Table B.3 ⊳ Remaining technically recoverable fossil fuel resources, 2023

Oil (billion barrels)	Proven reserves	Resources	Conventional crude oil	Tight oil	NGLs	EHOB	Kerogen oil
North America	222	2 440	232	212	200	796	1 000
Central and South America	305	851	250	57	49	493	3
Europe	14	110	55	19	28	3	6
Africa	125	448	309	54	83	2	-
Middle East	902	1 114	870	29	171	14	30
Eurasia	146	946	232	85	59	552	18
Asia Pacific	51	272	117	72	64	3	16
World	**1 765**	**6 181**	**2 064**	**528**	**654**	**1 862**	**1 073**

Natural gas (trillion cubic metres)	Proven reserves	Resources	Conventional gas	Tight gas	Shale gas	Coalbed methane
North America	19	146	50	10	80	7
Central and South America	9	84	28	15	41	-
Europe	5	46	18	5	18	5
Africa	19	100	50	10	40	0
Middle East	83	120	100	9	11	-
Eurasia	69	167	129	11	10	17
Asia Pacific	21	137	43	21	53	20
World	**225**	**800**	**418**	**80**	**252**	**49**

Coal (billion tonnes)	Proven reserves	Resources	Coking coal	Steam coal	Lignite
North America	257	8 387	1 031	5 838	1 519
Central and South America	14	60	3	32	25
Europe	137	980	163	415	402
Africa	15	343	44	298	-
Middle East	1	41	36	5	-
Eurasia	191	2 015	388	995	632
Asia Pacific	460	8 950	1 721	5 815	1 413
World	**1 074**	**20 776**	**3 387**	**13 398**	**3 991**

Notes: NGLs = natural gas liquids; EHOB = extra-heavy oil and bitumen. The breakdown of coal resources by type is an IEA estimate. Coal world resources exclude Antarctica.

Sources: BGR (2023); CEDIGAZ (2024); Energy Institute (2024); OGJ (2023); US EIA (2023); USGS (2012a and 2012b); IEA databases and analysis.

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- The *World Energy Outlook* supply modelling relies on estimates of the remaining technically recoverable resources, rather than the (often more widely quoted) numbers for proven reserves. Resource estimates are subject to a considerable degree of uncertainty, as well as the distinction in the analysis between conventional and unconventional resource types.
- Overall, the remaining technical recoverable resources of fossil fuels remain similar to the *World Energy Outlook-2023*. All fuels are at a level comfortably sufficient to meet the projections of global energy demand growth to 2050 in all scenarios. Remaining technically recoverable resources of US tight oil (crude plus condensate) total more than 190 billion barrels.
- Overall, the gradual depletion of resources (at a pace that varies by scenario) means that operators have to develop more difficult and complex reservoirs. This tends to push up production costs over time, although this effect is offset by the assumed continuous adoption of new, more efficient production technologies and practices.
- World coal resources are made up of various types of coal: around 80% is steam and coking coal and the remainder is lignite. Close to 85% of coal resources are located in Asia and North America.

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B.4 Electricity generation technology costs

Table B.4a ▹ Technology costs in selected regions in the Stated Policies Scenario

	Capital costs (USD/kW)			Capacity factor (%)			Fuel, CO_2, O&M (USD/MWh)			LCOE (USD/MWh)			VALCOE (USD/MWh)		
	2023	2030	2050	2023	2030	2050	2023	2030	2050	2023	2030	2050	2023	2030	2050
United States															
Nuclear	5 000	4 800	4 500	90	90	85	30	30	30	110	110	110	110	110	110
Coal	2 100	2 100	2 100	40	20	n.a.	35	35	35	105	165	n.a.	105	160	n.a.
Gas CCGT	1 000	1 000	1 000	55	40	15	35	40	40	60	70	120	55	70	75
Solar PV	1 110	690	480	20	22	23	10	10	10	55	35	25	65	60	60
Wind onshore	1 500	1 430	1 370	42	43	44	10	10	10	40	35	35	45	50	50
Wind offshore	4 060	2 760	1 980	41	46	49	35	25	15	125	80	55	130	90	65
Electricity generation costs										60	70	70			
European Union															
Nuclear	6 600	5 100	4 500	70	75	75	35	35	35	170	135	125	160	120	110
Coal	2 000	2 000	2 000	20	n.a.	n.a.	155	170	180	290	n.a.	n.a.	245	n.a.	n.a.
Gas CCGT	1 000	1 000	1 000	20	10	n.a.	130	110	120	205	260	n.a.	150	155	n.a.
Solar PV	750	480	340	14	14	14	10	10	10	50	35	25	60	65	70
Wind onshore	1 630	1 550	780	29	30	30	15	15	10	60	55	25	70	75	50
Wind offshore	3 120	2 280	1 660	50	55	56	15	10	10	70	45	35	70	65	60
Electricity generation costs										130	110	80			
China															
Nuclear	2 800	2 800	2 500	80	70	70	30	30	30	75	80	75	75	80	75
Coal	800	800	800	55	35	15	55	50	50	70	80	120	70	70	90
Gas CCGT	560	560	560	30	20	15	80	70	75	100	105	115	85	70	60
Solar PV	670	410	280	13	13	13	10	10	10	50	30	25	70	70	70
Wind onshore	990	940	900	24	25	26	10	10	10	45	40	40	55	50	55
Wind offshore	2 380	1 720	1 260	32	37	40	20	15	10	90	60	40	95	60	40
Electricity generation costs										80	80	65			
India															
Nuclear	2 800	2 800	2 800	75	85	90	30	30	30	75	70	70	75	70	70
Coal	1 200	1 200	1 200	70	70	65	40	35	35	60	55	55	60	50	45
Gas CCGT	700	700	700	30	35	45	120	85	80	150	110	100	145	90	70
Solar PV	710	450	300	20	21	22	5	5	5	45	25	20	50	35	40
Wind onshore	1 210	1 150	1 090	26	28	30	15	10	10	60	55	45	65	65	60
Wind offshore	2 620	1 960	1 360	33	36	39	25	15	10	115	80	55	115	90	65
Electricity generation costs										85	70	55			

Notes: O&M = operation and maintenance; LCOE = levelised cost of electricity; VALCOE = value-adjusted LCOE; kW = kilowatt; MWh = megawatt-hour; CCGT = combined-cycle gas turbine; n.a. = not applicable. Cost components, LCOE and VALCOE figures are rounded. Lower values for VALCOE indicate improved competitiveness.

Sources: IEA analysis; IRENA (2024).

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Table B.4b ⊳ Technology costs in selected regions in the Announced Pledges Scenario

	Capital costs (USD/kW)			Capacity factor (%)			Fuel, CO_2 and O&M (USD/MWh)			LCOE (USD/MWh)		
	2023	2030	2050	2023	2030	2050	2023	2030	2050	2023	2030	2050
United States												
Nuclear	5 000	4 800	4 500	90	90	85	30	30	30	110	110	110
Coal	2 100	2 100	2 100	30	n.a.	n.a.	90	150	180	185	n.a.	n.a.
Gas CCGT	1 000	1 000	1 000	50	30	n.a.	55	80	95	80	130	n.a.
Solar PV	1 110	660	460	20	22	23	10	10	10	55	35	25
Wind onshore	1 500	1 420	1 340	42	43	44	10	10	10	40	35	35
Wind offshore	4 060	2 660	1 800	41	46	49	35	25	15	125	75	50
Electricity generation costs										60	90	70
European Union												
Nuclear	6 600	5 100	4 500	70	75	75	35	35	35	170	140	120
Coal	2 000	2 000	2 000	15	n.a.	n.a.	155	175	210	315	n.a.	n.a.
Gas CCGT	1 000	1 000	1 000	25	15	n.a.	120	100	110	175	185	n.a.
Solar PV	750	460	330	14	14	14	10	10	10	50	35	25
Wind onshore	1 630	1 540	770	29	30	30	15	15	10	60	55	30
Wind offshore	3 120	2 200	1 500	50	55	56	15	10	10	70	45	30
Electricity generation costs										130	105	80
China												
Nuclear	2 800	2 800	2 500	80	70	70	30	30	30	75	80	75
Coal	800	800	800	55	30	10	60	85	150	80	120	250
Gas CCGT	560	560	560	35	25	10	80	80	105	100	105	170
Solar PV	670	400	270	13	13	13	10	10	5	50	30	25
Wind onshore	990	930	880	24	25	26	10	10	10	45	40	35
Wind offshore	2 380	1 660	1 140	32	37	40	20	15	10	90	55	35
Electricity generation costs										80	85	65
India												
Nuclear	2 800	2 800	2 800	75	85	90	30	30	30	75	70	70
Coal	1 200	1 200	1 200	70	70	45	40	65	165	60	85	200
Gas CCGT	700	700	700	25	30	20	110	75	115	140	105	160
Solar PV	710	430	290	20	21	22	5	5	5	45	25	20
Wind onshore	1 210	1 140	1 060	26	28	30	15	10	10	60	55	45
Wind offshore	2 620	1 900	1 220	33	36	39	25	15	10	115	80	50
Electricity generation costs										85	90	65

Notes: O&M = operation and maintenance; LCOE = levelised cost of electricity; kW = kilowatt; MWh = megawatt-hour; CCGT = combined-cycle gas turbine; n.a. = not applicable. Cost components and LCOE figures are rounded.

Sources: IEA analysis; IRENA (2024).

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Table B.4c ⊳ Technology costs in selected regions in the Net Zero Emissions by 2050 Scenario

	Capital costs (USD/kW)			Capacity factor (%)			Fuel, CO_2 and O&M (USD/MWh)			LCOE (USD/MWh)		
	2023	2030	2050	2023	2030	2050	2023	2030	2050	2023	2030	2050
United States												
Nuclear	5 000	4 800	4 500	90	90	85	30	30	30	110	110	110
Coal	2 100	2 100	2 100	30	n.a.	n.a.	95	160	220	195	n.a.	n.a.
Gas CCGT	1 000	1 000	1 000	60	35	n.a.	55	85	110	75	120	n.a.
Solar PV	1 110	640	440	20	22	23	10	10	10	55	30	25
Wind onshore	1 500	1 420	1 320	42	43	44	10	10	10	40	35	35
Wind offshore	4 060	2 560	1 740	41	46	49	35	25	15	125	75	50
Electricity generation costs										60	80	65
European Union												
Nuclear	6 600	5 100	4 500	70	75	75	35	35	35	170	135	125
Coal	2 000	2 000	2 000	15	n.a.	n.a.	160	185	250	320	n.a.	n.a.
Gas CCGT	1 000	1 000	1 000	20	10	n.a.	120	95	120	195	230	n.a.
Solar PV	750	460	320	14	14	14	10	10	10	50	35	25
Wind onshore	1 630	1 530	750	29	30	30	15	15	10	60	55	30
Wind offshore	3 120	2 140	1 440	50	55	56	15	10	10	70	45	30
Electricity generation costs										130	95	80
China												
Nuclear	2 800	2 800	2 500	80	75	80	30	30	30	75	80	70
Coal	800	800	800	50	n.a.	n.a.	80	120	180	100	n.a.	n.a.
Gas CCGT	560	560	560	40	30	n.a.	85	90	115	100	115	n.a.
Solar PV	670	400	270	13	13	13	10	10	5	50	30	25
Wind onshore	990	920	860	24	25	26	10	10	10	45	40	35
Wind offshore	2 380	1 600	1 100	32	37	40	20	15	10	90	55	35
Electricity generation costs										80	85	60
India												
Nuclear	2 800	2 800	2 800	75	85	90	30	30	30	75	75	70
Coal	1 200	1 200	1 200	70	n.a.	n.a.	40	105	200	60	n.a.	n.a.
Gas CCGT	700	700	700	30	25	n.a.	100	80	120	130	115	n.a.
Solar PV	710	430	280	20	21	22	5	5	5	45	25	20
Wind onshore	1 210	1 130	1 040	26	28	30	15	10	10	60	50	45
Wind offshore	2 620	1 740	1 160	33	36	39	25	15	10	115	70	45
Electricity generation costs										85	100	45

Notes: O&M = operation and maintenance; LCOE = levelised cost of electricity; kW = kilowatt; MWh = megawatt-hour; CCGT = combined-cycle gas turbine; n.a. = not applicable. Cost components and LCOE figures are rounded.

Sources: IEA analysis; IRENA (2024).

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- All costs are expressed in year-2023 market exchange rate US dollars.
- Major contributors to the levelised cost of electricity (LCOE) include: overnight capital costs; capacity factor that describes the average output over the year relative to the maximum rated capacity (typical values provided); cost of fuel inputs; plus operation and maintenance. Economic lifetime assumptions are 25 years for solar PV, and onshore and offshore wind.
- Weighted average cost of capital (WACC) assumptions reflect market data and survey information provided through the *Cost of Capital Observatory* (IEA, 2023), updated analysis for utility-scale solar PV in the *World Energy Outlook-2020* (IEA, 2020), with a range of 4-7%, and for offshore wind analysis from the *Offshore Wind Outlook 2019* (IEA, 2019) with a range of 5-8%. Onshore wind was assumed to have the same WACC as utility-scale solar PV. A standard WACC was assumed for nuclear power, coal-fired and gas-fired power plants (8-9% based on the stage of economic development).
- The value-adjusted levelised cost of electricity (VALCOE) incorporates information on both costs and the value provided to the system. Based on the LCOE, estimates of energy, capacity and flexibility value are incorporated to provide a more complete metric of competitiveness for power generation technologies.
- Fuel, CO_2 and operation and maintenance costs reflect the average over the ten years following the indicated date in the projections (and therefore vary by scenario in 2023).
- Solar PV and wind costs do not include the cost of energy storage technologies, such as utility-scale batteries.
- The capital costs for nuclear power represent the "nth-of-a-kind" costs for new reactor designs, with substantial cost reductions from the first-of-a-kind projects.
- Electricity generation costs reflect all costs related to power plants and storage, expressed per unit of electricity generation. This includes capital recovery, fuel, CO_2 and operation and maintenance costs, but excludes electricity grid costs.

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B.5 Other key technology costs

Table B.5 ▷ Costs for selected technologies by scenario

		Stated Policies			Announced Pledges			Net Zero Emissions by 2050		
	2023	2030	2035	2050	2030	2035	2050	2030	2035	2050
Levelised cost of iron-based steel production (USD/t)										
Conventional										
Lower range	510	470	470	470	500	530	590	550	600	730
Upper range	630	560	560	560	690	730	770	750	770	850
Innovative										
Lower range	n.a	650	660	650	680	700	650	730	670	680
Upper range	n.a	870	880	850	960	880	820	910	760	830
Vehicles (USD/vehicle)										
Hybrid cars	17 500	15 100	15 000	15 000	15 100	15 000	14 900	15 100	15 000	14 900
Battery electric cars	18 900	15 800	14 700	13 700	15 100	14 200	13 300	14 800	13 600	12 900
Batteries and hydrogen										
Hydrogen electrolysers (USD/kW)										
Lower range	1 300	850	810	710	750	620	550	640	560	520
Upper range	2 160	1 320	1 180	1 010	1 050	940	820	960	860	780
Fuel cells (USD/kW)	90	65	55	45	55	45	35	50	40	30
Utility-scale stationary batteries (USD/kWh)	250	175	155	130	170	150	125	165	145	120

Notes: t = tonne; kW = kilowatt; kWh = kilowatt-hour. All values are in USD (2023, MER).

Sources: IEA analysis; BNEF (2023); Cole et al. (2021); Financial Times (2020); James et al. (2018); JATO (2021); Thompson, et al. (2018); Tsiropoulos et al. (2018).

- All costs represent fully installed/delivered technologies, not solely the module cost, unless otherwise noted. Installed/delivered costs include engineering, procurement and construction costs to install the module.
- Iron-based steel production costs display a range considering technology and regional differences, e.g. capital expenditure, operating expenditure and learning rate, and differentiate between conventional and innovative production routes. Levelised cost of production includes estimated iron ore prices, carbon prices and fuel subsidies differentiated by region and scenario, and are weighted by regional deployment. Conventional routes are blast furnace-basic oxygen furnace (BF-BOF) and direct reduced iron-electric arc furnace (DRI-EAF). The innovative routes are BF-BOFs with carbon capture, utilisation and storage (CCUS), DRI-EAF with CCUS, and 100% electrolytic hydrogen-based DRI-EAF.
- Vehicle costs reflect production costs, not retail prices, to better reflect the cost declines in total cost of manufacturing, which move independently of final market prices for electric vehicles to customers.

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- Electrolyser costs reflect a weighted average among different electrolysis technologies. The lower value for hydrogen electrolysers refers to China and the upper one to the rest of the world.
- Fuel cell costs are based on stack manufacturing costs only, not installed/delivered costs. The costs provided are for automotive fuel cell stacks for light-duty vehicles.
- Utility-scale stationary battery costs reflect the global average installed costs of all battery systems rated to provide maximum power output for a four-hour period.

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B.6 Policies

The policy actions taken by governments are key inputs in the *World Energy Outlook*. An overview of the policies and measures that are considered in the various scenarios is included in Tables B.6 to B.11. The tables do not include all policies and measures, but rather highlight those most prominent in shaping global energy demand today, derived from an exhaustive examination of policies, announcements, plans and pledges made by countries around the world. A more comprehensive assessment of the latest energy policies by country can be explored in the IEA *State of Energy Policy Report* published in September 2024 (IEA, 2024). This new report tracks key energy policies enacted in G20 and IEA member countries, and synthesises a more complete policy dataset that can be accessed through the publicly available Energy Policy Inventory.[2]

The tables begin with broad cross-cutting policy frameworks, followed by more detailed policies by sector: power, industry, buildings and transport. The tables highlight policies and targets considered in the Stated Policies Scenario (STEPS). The aims of these policies are not automatically assumed to be met; they are incorporated in the scenario only to the extent that they are underpinned by adequate provisions for their implementation. The tables also highlight the key national targets and pledged policy frameworks considered in the Announced Pledges Scenario (APS). Targets included in the APS still can inform trends in the STEPS. Even if those targets are not achieved in full or on time in the STEPS, they establish a clear direction of travel that does influence the overall policy landscape, private sector decision making, and more. These priorities and momentum shape the pathways that individual regions take across all scenarios. Table B.11 provides a list of key industry and intergovernmental initiatives considered fully or partially implemented in the STEPS, APS and NZE Scenario. In the NZE Scenario, these initiatives are often met globally, not just by current signatories.

Some regional policies have been included in the tables if they play a significant role in shaping the energy landscape at a global scale, e.g. regional carbon markets, efficiency standards in very large provinces or states.

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[2] The IEA Energy Policy Inventory is available at: https://www.iea.org/data-and-statistics/data-tools/energy-policy-inventory

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Table B.6 ▻ Cross-cutting policy assumptions for selected regions/countries by scenario

Region/ country	Scenario	Policies and targets
United States	STEPS	• Energy provisions in: Creating Helpful Incentives to Produce Semiconductors and Science Act (2022); Inflation Reduction Act (2022); Consolidated Appropriations Act (2021); and Infrastructure and Jobs Act (2021). • Defence Production Act deployment supporting domestic production of heat pumps, building insulation equipment, solar panel components, transformers and batteries. • US EPA Final Rule for Emissions for Oil and Natural Gas Operations; Methane Emissions Reduction Action Plan.
	APS	• Updated NDC aiming to reduce GHG emissions by 50-52% by 2030, from 2005 levels, and national target to reach net zero GHG emissions by 2050. • Commitment to the Global Methane Pledge.
Canada	STEPS	• Energy and emissions reduction-related provisions in the 2020 Healthy Environment and a Healthy Economy Plan; extended Investing in Canada Infrastructure Programme; and Clean Technology Investment Tax Credit. • Hydrogen Strategy and Strategic Innovation Fund. • Regulation Respecting Reduction in the Release of Methane and Certain Volatile Organic Compounds.
	APS	• Updated NDC aiming to reduce GHG emissions by 40 to 45% by 2030, from 2005 levels. Commitment to reach net zero GHG emissions target by 2050. • Commitment to the Global Methane Pledge, and national target to reduce methane emissions from the oil and gas sector by 40-45% by 2025, and further by 75% by 2030 relative to 2012.
Latin America and the Caribbean	STEPS	• Brazil: New Growth Acceleration Programme and Nova Indústria Brazil to boost clean energy infrastructure and industrialisation. Regulations to reduce flaring and extraordinary methane emissions. • Colombia: Energy provisions in the Ten Milestones in 2021 Plan and the National Strategy for Mitigation of Short-Lived Climate Pollutants. Requirements to undertake leak detection and repair, control flaring and reduce methane emissions. • Chile: Energy Efficiency Law (2021), energy intensity reduction by at least 10% by 2030 compared to 2019.
	APS	• 16 pledges out of 33 countries to reach net zero emissions by 2050 or before, including Brazil, Chile, Costa Rica and Colombia. • Updated NDC from Brazil with absolute net emissions limit of 1.2 Gt CO_2-eq in 2030. • Colombia: Main targets of the Just Energy Transition roadmap. • Twenty countries committing to the Global Methane Pledge, including Argentina and Mexico.
Japan	STEPS	• 2023 Green Transformation basic policy, with funded measures promoting renewable energy, offshore wind cost reduction RD&D programmes, hydrogen supply chains and accelerated nuclear policies. • 2023 Basic Hydrogen Strategy to accelerate public and private investment in the hydrogen supply chain. • 2024 Carbon Capture Bill setting the framework for CCUS permits and licences.
	APS	• Act on the Promotion of Global Warming Countermeasures committing to climate neutrality by 2050. • Updated NDC: Reduce GHG emissions by 46% by 2030 from 2013 levels. • Commitment to the Global Methane Pledge.

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Table B.6 ⊳ Cross-cutting policy assumptions for selected regions/countries by scenario (continued)

Region/ country	Scenario	Policies and targets
Korea	STEPS	• 2023 Energy Technology Development Investment. • Korean New Deal provisions on clean energy technologies. • 10th Basic Plan for Long-term Electricity Supply and Demand.
	APS	• Carbon Neutrality and Green Growth Act for Climate Change committing to carbon neutrality by 2050. • Full implementation of the First National Basic Plan for Carbon Neutrality and Green Growth. • Commitment to the Global Methane Pledge; Methane Reduction Plan.
Australia and New Zealand	STEPS	• Australia: Spending and policy measures from the 2020 Climate Solutions Package; Powering Australia Plan; Future Made in Australia; and Long-Term Emissions Reduction Plan. • Updated NDC aims for 43% emissions reduction by 2030 relative to 2005.
	APS	• Australia: Full implementation of the 2022 Climate Change Bill emissions target, including net zero emissions by 2050. Commitment to the Global Methane Pledge. • New Zealand: Net zero emissions target for all GHG except biogenic methane by 2050. Reduction by 50% relative to 2005 levels in the updated NDC. Commitment to the Global Methane Pledge.
European Union	STEPS	• Energy spending provisions in the European Green Deal and national recovery plans elaborated within the framework of the EU Recovery and Resilience Facility. • 2024 EU Regulation on methane emissions reduction in the energy sector.
	APS	• Net zero emissions target by 2050 embedded in the 2021 European Climate Law. • 2023 Renewable Energy Directive to reach a share of energy from renewable sources of at least 42.5% by 2030. • EU member country-level targets for carbon or climate neutrality before 2050: Finland by 2035; Austria by 2040; Germany and Sweden by 2045. • Updated NDC aiming to reduce emissions by at least 55% below 1990 levels by 2030. • Net Zero Industry Act targets to triple key mass-manufactured net zero technologies by 2030. • Partial implementation of the targets set in the REPowerEU Plan, eliminate the import of Russian natural gas supply to the European Union well before 2030. • 23 EU member states committed to the Global Methane Pledge.
Other Europe	STEPS	• United Kingdom: 2023 Energy Act on energy production and security, and regulation of the energy market; Ten Point Plan for a Green Industrial Revolution and provisions of the 2021 North Sea Transition Deal; Methane memorandum. • Norway: 2021 Green Conversion Package. National Methane Action Plan.
	APS	• Climate neutrality targets by 2040 (Iceland), 2050 (Norway, Switzerland and United Kingdom), Türkiye (2053) and 2060 (Ukraine). 14 of 16 countries are signatories of the Global Methane Pledge. • Türkiye: Updated NDC pledge for a peak in emissions by 2038. National Energy Efficiency Action Plan 2030 to reduce energy consumption by 16% and curb emissions by 100 Mt CO_2.

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Table B.6 ▷ **Cross-cutting policy assumptions for selected regions/countries by scenario** (continued)

Region/ country	Scenario	Policies and targets
Eurasia	STEPS	• Kazakhstan: Tax code on combustion of natural gas flaring. Kazakhstan National Methane Emissions Inventory and Reduction Programme. • Uzbekistan: Tax on methane emissions and other environmental pollutants.
	APS	• All NDCs and net zero emissions targets, including Georgia by 2050, Kazakhstan in 2060, the Russian Federation net zero emissions pledge by 2060 with a strong reliance on sinks from land use, land-use change and forestry. • Commitment to the Global Methane Pledge from Azerbaijan, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan.
China	STEPS	• 2024 National Economic and Social Development Plan, with energy consumption per unit of GDP to decline by around 2.5% within the year. • Made in China 2025 target to transition from heavy industry to higher value-added manufacturing, with the goal of raising domestic content of core components and materials to 70% by 2025. • Targets for 20% non-fossil share of the energy mix by 2025 contained in the 14th Five-Year Plan. • Targets to peak CO_2 emissions before 2030 and raise the share of non-fossil energy to 25% in the energy mix by 2030, contained in the updated NDC. • Emissions standard of coal mine methane.
	APS	• Target to lower CO_2 emissions per unit of GDP by over 65% from 2005 levels by 2030 contained in the updated NDC. • Carbon neutrality target by 2060. • 2023 Action Plan on the Control of Methane Emissions.
India	STEPS	• Energy-related elements of the Production Linked Incentives programme. • Enhanced enforcement of energy efficiency policy under the 2022 amendments to the Energy Conservation Act. • National Green Hydrogen Mission.
	APS	• Updated NDC to reduce national emissions intensity by 45% by 2030 from 2005 levels. • Commitment to reach net zero emissions by 2070.
Southeast Asia	STEPS	• Indonesia: 17-19% share of renewable energy in primary energy supply by 2025 and 31% by 2050. • Singapore: Green Plan 2030 and Future Energy Fund. • Viet Nam: Action Plan for Methane Emissions Reduction by 2030.
	APS	• Net zero emissions targets by 2050 (Cambodia, Brunei Darussalam, Lao PDR, Malaysia, Singapore and Viet Nam), 2060 (Indonesia) and 2065 (Thailand). • Just Energy Transition Partnerships in Indonesia and Viet Nam. • Cambodia, Indonesia, Malaysia, Philippines, Singapore and Viet Nam: Commitment to the Global Methane Pledge. • Thailand: Action Plan to Reduce Methane and other Short-lived Climate Pollutants.

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Table B.6 ⊳ **Cross-cutting policy assumptions for selected regions/countries by scenario** (continued)

Region/ country	Scenario	Policies and targets
Africa	STEPS	• South Africa: 2022 Energy Action Plan. New amendments to the 2008 National Energy Act. • Nigeria: National Development Plan 2021-2025. Methane regulations.
	APS	• 18 countries pledged to reach net zero emissions by 2030 (Cote d'Ivoire, Mauritania), 2050 (South Africa, Morocco), 2060 (Nigeria, Ghana) and 2070 (Mauritius). • Uganda: Energy Transition Plan sets an energy sector net zero CO_2 emissions target by 2065. • 38 countries signed the Global Methane Pledge, with Angola and Kenya joining at the COP28. • South Africa: Just Energy Transition Investment Plan.
Middle East	STEPS	• Saudi Arabia: Partial implementation of the Saudi Vision 2030. • Qatar: Executive bylaw for the Environmental Protection Law, including methane regulations and standards. • United Arab Emirates: Conservation of Petroleum Resources Law, including flaring or venting methane restrictions.
	APS	• Net zero emissions targets by 2050 in United Arab Emirates and Oman. Saudi Arabia, Bahrain and Kuwait aiming for 2060. • Oman 2023 updated NDC, from 7% to 21% emission reduction by 2030 compared to business-as-usual. • Iraq Zero Routine Flaring by 2030 initiative. • Nine countries are signatories to the Global Methane Pledge.

Note: STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario; NDC = Nationally Determined Contribution; Gt CO_2-eq = gigatonne of carbon-dioxide equivalent; CCUS = carbon capture, utilisation and storage; GHG = greenhouse gases; GW = gigawatt; Gt = gigatonne; Mt = megatonne; RD&D = research, development and demonstration.

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Table B.7 ▷ Electricity sector policies and measures as modelled by scenario for selected regions/countries

Region/ country	Scenario	Policies and targets
United States	STEPS	• New Environment Protection Agency (EPA) rule on greenhouse gas standards and guidelines for fossil fuel-fired power plants. • Inflation Reduction Act (2022) grants and tax credits for renewables, nuclear power and CCUS. • 100% carbon-free electricity or energy targets by 2050 in up to 24 states plus Puerto Rico and Washington DC. • Updated renewable portfolio standard policies in 2024 (including Michigan and Vermont). • 12 states have set offshore wind targets, with a combined total of over 70 GW by 2040.
	APS	• G7 commitments: Achieve predominantly decarbonised electricity sector by 2035.
Canada	STEPS	• Reach nearly 90% non-emitting renewables generation by 2030. • Phase out conventional coal-fired plants by 2030.
	APS	• G7 commitment: Achieve predominantly decarbonised electricity sector by 2035.
Latin America and the Caribbean	STEPS	• Argentina: National Energy Transition Plan to 2030 aims to have at least 50% electricity from renewable sources, of which 1 GW is distributed solar PV capacity by 2030. • Brazil: At least 23% renewables, excluding hydropower, in the power supply by 2030. • Chile: Phase out unabated coal use by 2040. • 24 of 33 countries have targets to expand installed capacity of renewables.
	APS	• Chile: National Hydrogen Strategy aims to reach 25 GW of electrolysis capacity by 2030. • Colombia: New National Energy Plan, target to reach 100% renewable electricity by 2050. • Costa Rica: Generation Expansion Plan 2022-2040 target for 1 775 MW of solar and wind capacity.
Japan	STEPS	• Achieve electricity generation mix by 2030 in the 6th Strategic Energy Plan. • Restart nuclear power plants aligned with the 6th Strategic Energy Plan and the Green Transformation policy initiative.
	APS	• Accelerated nuclear expansion, including small modular reactors, under discussion in the Green Transformation Implementation Council. • Green Growth Strategy: 30-45 GW of offshore wind capacity in 2040. 6th Strategic Energy Plan, with additional policies to support renewables in power generation. • G7 commitments: Achieve predominantly decarbonised electricity sector by 2035.
Korea	STEPS	• Increase nuclear in electricity generation to 35% and renewables to over 30%, and decrease coal-fired power to less than 15% by 2036 under the 10th Basic Plan for Long-term Electricity Supply and Demand.
	APS	• Power sector emissions reduction target to 45.9% by 2030 from 2018 levels in the 2023 update of the National Basic Plans for Carbon Neutrality and Green Growth.
Australia and New Zealand	STEPS	• Australia: 82% renewable electricity generation by 2030.
European Union	STEPS	• 16 member states have coal phase-out commitments. Ten EU member states are already coal free or never had coal. • Updated development plans and targets for offshore wind, notably in Germany (30 GW by 2030) and the Netherlands (21 GW by 2032). • Updated development plans for nuclear in France, Poland and Czech Republic.
	APS	• G7 commitment: Achieve predominantly decarbonised electricity sector by 2035. • Updates of National Energy and Climate Plans for EU member states.

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Table B.7 ⊳ Electricity sector policies and measures as modelled by scenario for selected regions/countries (continued)

Region/ country	Scenario	Policies and targets
Other Europe	STEPS	• United Kingdom: Energy Security Plan sets targets to expand offshore wind, solar PV and nuclear power. Phase out conventional coal-fired plants by 2024.
	APS	• United Kingdom: commitment to 100% clean electricity by 2035.
China	STEPS	• 14th Five-Year Plan for renewables targets for 3 300 TWh of renewables by 2025, a twofold increase in solar and wind generation, and for over 50% of incremental electricity consumption to be met by renewables. • Pumped hydro storage capacity to exceed 62 GW by 2025 and 120 GW by 2030. • Retrofit some coal-fired power plants to co-fire biomass, green ammonia or with carbon capture to reduce emissions per unit of output by 50% by 2027. • Target for at least 1 200 GW of installed solar and wind capacity by 2030.
	APS	• Overall coal use to decline in the 15th Five-Year Plan period (2025-2030).
India	STEPS	• Updated Nationally Determined Contribution: 50% cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030. • Target to reach 500 GW of non-fossil capacity by 2030. • 2023 National Electricity Plan: share of non-fossil-based capacity to increase to 68.4% by the end of 2031-32.
Southeast Asia	STEPS	• Viet Nam: Power Development Plan 8 aims to boost installed utility-scale solar PV capacity to around 13 GW and wind capacity to around 28 GW by 2030. Coal-fired capacity to peak at 30 GW. • Cambodia: Power Development Plan 2022-2040 targets 3.2 GW of solar capacity and 3 GW of hydropower by 2040.
	APS	• Coal phase out commitments: Malaysia (by 2044), Thailand (by 2050), Indonesia (by 2056, which can be accelerated to 2050 with Just Energy Transition Partnership (JETP) support) and Viet Nam (by 2050 with JETP support). • Indonesia: Based on the National Electricity Plan, PT Perusahaan Listrik Negara (PLN) draft Electricity Supply Business Plan targets about 30 GW of additional renewable energy capacity by 2033. • Malaysia: National Energy Transition Roadmap, aiming to increase the share of renewables to 40% in 2040 and 70% in 2050.
Africa	STEPS	• South Africa: Increased renewables capacity and reduced coal-fired capacity under the 2019 Integrated Resource Plan.
	APS	• Kenya: 100% renewable electricity by 2030. • Senegal: 40.7% renewable share in the energy mix by 2035. • Full implementation of national electrification targets.
Middle East	STEPS	• Saudi Arabia: Saudi Vision 2030 aims to phase out oil use in power and provide 50% of electricity generation from renewables and 50% from natural gas by 2030.

Note: CCUS = carbon capture, utilisation and storage; EPA = US Environmental Protection Agency; STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario. TWh = terawatt-hour; GW = gigawatt; MW = megawatt.

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Table B.8 ⊳ Industry sector policies and measures as modelled by scenario for selected regions/countries

Region/ country	Scenario	Policies and targets
All regions	APS	• UN Resolution to end plastic pollution. Recycling, reuse and ban of single-use plastics are some of the possible approaches to be adopted to reduce plastic pollution.
United States	STEPS	• Inflation Reduction Act (2022); Clean manufacturing tax credits for CCUS; Carbon Utilization Procurement Grants (2023).
	APS	• Department of Energy Industrial Decarbonization Roadmap: 80% emissions reduction compared to 2015 from energy efficiency, CCUS and switching to low-emissions fuels. • Federal Buy Clean Initiative: Public procurement of low-carbon construction materials.
Canada	STEPS	• Clean industry packages and provisions to promote clean industry, as part of Building Canada's Clean Industrial Advantage.
Latin America and the Caribbean	STEPS	• Argentina: ○ Industry 4.0 development plan to promote efficiency and high-tech industries. ○ Argentinian Productivity Plan 2030 to modernise and increase the productivity of traditional manufacturing sectors and National Hydrogen Strategy to accelerate the domestic production of low-emissions hydrogen and critical minerals. • Brazil: Energy efficiency guarantee fund. • Colombia: 25% tax break on energy efficiency investment.
	APS	• Argentina, Brazil and Chile: Product Efficiency Call to Action initiative aims to double the efficiency of new lighting equipment and motors by 2030. • Brazil: National Hydrogen Program USD 30 billion in low-carbon hydrogen projects announced.
Japan	STEPS	• Green Innovation Fund provides USD 20 billion R&D funding for transportation and manufacturing-related industries until 2030.
	APS	• Targets in the Technology Roadmap for Transition Finance in the cement, pulp and paper branches.
Korea	STEPS	• Korean New Deal government investment in industrial energy efficiency by 2025 with USD 3 billion allocated until 2025.
Australia and New Zealand	STEPS	• Australia: National Hydrogen Strategy to develop clean hydrogen. • New Zealand: Ban on new coal boilers in industries as well as phase out of existing ones by 2037.
	APS	• Australia: The safeguard mechanism imposes a 4.9% year-on-year reduction of emissions from large industries, including a total emissions ceiling.
European Union	STEPS	• EU Emissions Trading System, including phasing out of some industry free allowances with the implementation of the Carbon Border Adjustment Mechanism from 2026. • EU Innovation Fund support for renewables, energy-intensive industries, storage and CCUS. • France: Green Industry Bill to create new green industries and accelerate the decarbonisation of existing ones, earmarking USD 3 billion. • Germany: Federal Fund for Industry and Climate Action with USD 3.5 billion.
	APS	• EU Hydrogen Strategy for a Climate Neutral Europe: 42% of hydrogen to come from renewable energy by 2030. • Net Zero Industry Act: Target to reach 40% of near zero emissions material production capacity in capacity additions in the European Union by 2030.

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Table B.8 ▷ Industry sector policies and measures as modelled by scenario for selected regions/countries (continued)

Region/ country	Scenario	Policies and targets
Other Europe	STEPS	• United Kingdom: Industrial Decarbonisation Challenge. Pilot funding for low-emissions industrial clusters and Industrial Energy Transformation Fund funding for energy efficiency. United Kingdom emissions trading system. Net Zero Growth Plan and Industrial Energy Transformation Fund with total grant funding of up to USD 690 million until 2028.
	APS	• United Kingdom: Industrial Decarbonisation Strategy and Net Zero Strategy.
Eurasia	APS	• Regulation 048/2019 of the Eurasian Economic Union on requirements for energy efficiency of energy-consuming devices, including industrial motors.
China	STEPS	• Made in China 2025 targets for industrial energy intensity. Raising domestic content of electronic and transportation industries core components and materials to 70% by 2025. • Reduce energy consumption per tonne of steel by 2% by 2025.
India	STEPS	• Perform, Achieve and Trade Scheme to trade energy saving credits. • Make in India programme to improve the availability of modern and facilitating infrastructure by developing industrial corridors and smart cities and upgrading existing industrial clusters. • Production Linked Incentives programme provides subsidies related to new manufacturing capacity for solar PV and modern batteries. • Pilot project guidelines for using Green Hydrogen in Steel Sector with USD 2.4 billion allocated until 2029-30.
Africa	STEPS	• Egypt: Updated standards for industrial motors in 2023.
	APS	• Nigeria: Energy transition plan (2022) with targets for cement and hydrogen production by 2030 and 2060.
Middle East	STEPS	• Saudi Arabia: IE3 Minimum Energy Performance Standards for Electric (2018).

Note: STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario; CCUS = carbon capture, utilisation and storage; R&D = research and development; UN = United Nations.

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Table B.9 ⊳ Buildings sector policies and measures as modelled by scenario for selected regions/countries

Region/ country	Scenario	Policies and targets
United States	STEPS	• Inflation Reduction Act (2022): Tax rebates for heat pumps and energy efficiency upgrades in residential and commercial buildings. • Updated building codes for new buildings in California, Connecticut, Florida, Illinois, Hawaii, New Jersey, Vermont and Washington (2021 International Energy Conservation Code). • Updated minimum energy performance standards (MEPS) for central air conditioners and heat pumps (2023).
	APS	• Federal Building Performance Standard: Target to achieve net zero emissions in all federal buildings by 2045 with interim targets for electrification and decarbonisation. • Multistate Memorandum of Understanding: nine states set targets for heat pumps to account for almost two-thirds of heating and cooling equipment by 2030.
Canada	STEPS	• Updated National Energy Code of Canada for Buildings (2022). • Oil to Heat Pump Affordability Programme.
	APS	• All new buildings to meet zero carbon-ready standards by 2030.
Latin America and the Caribbean	STEPS	• Brazil: Updated MEPS for air conditioners (2022). • Colombia: Subsidies for households purchasing efficient lighting, refrigeration and cooking equipment established in partnership with the Inter-American Development Bank (2023). • Peru: Updated building energy codes for new buildings (2021). • Common regulation on minimum energy performance standards (MEPS) (2022) for air conditioners in El Salvador, Honduras, Nicaragua, Costa Rica, Guatemala and Panama.
	APS	• Chile: Energy 2050 Strategy: All households to have access to low-emissions sources for heating and cooking by 2040; all new buildings to be net zero energy use by 2050. • All national clean cooking targets are met. Three countries are already in compliance with the SDG 7 goal, which aims to ensure access to affordable, reliable, sustainable and modern energy for all by 2030.
Japan	STEPS	• Subsidies for retrofits and efficient water heaters introduced as part of the Residential Energy Conservation Campaign (2024). • Strengthened MEPS for air conditioners, water heaters, glazing and televisions, introduced as part of the changes to the Top Runner Programme for 2025-27.
	APS	• All new residential and services buildings meet the Zero Energy Home or Zero Energy Building standard by 2030, in line with the objectives of the 6th Basic Energy Plan.
Korea	STEPS	• Subsidies for highly energy efficient appliances distributed via on-bill rebates as part of the Korea Electric Power Corporation Programme. • Korean New Deal: Increased funding to improve the efficiency of schools, public housing, and recreational and healthcare facilities. • Updated energy saving design standards for new buildings (2023).
	APS	• All new public buildings meet zero carbon-ready standards as of 2030 in accordance with the Second Master Plan for Green Building Policy.
Australia and New Zealand	STEPS	• Australia: Updated energy efficiency standards for new homes (2023). Updated MEPS for air conditioners and heat pumps (2023). • New Zealand: Replacement of all coal-fired boilers in schools with electric or renewable biomass alternatives by 2025.

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Table B.9 ⊳ Buildings sector policies and measures as modelled by scenario for selected regions/countries (continued)

Region/ country	Scenario	Policies and targets
European Union	STEPS	• National government incentives and investment in buildings energy efficiency and appliance upgrades, funded via the EU Recovery and Resilience Facility. • 2018 Energy Efficiency Directive: requirements to renovate 3% of the floor area of public buildings owned by the central government annually. • National and sub-national bans and policies to limit the installation of certain fossil fuel boilers in buildings, such as the German Buildings Energy Act (2024) and the Austrian Renewable Heat Act (2024).
	APS	• Revised 2024 Energy Performance of Buildings Directive, with MEPS for existing non-residential buildings; renovation targets for existing residential buildings; prohibition of subsidies for heating systems based on fossil fuels as of 2025, and the installation of such systems in new buildings as of 2030.
Other Europe	STEPS	• Türkiye: Updated building codes for all new buildings and large existing buildings (2023). • United Kingdom: Updated building code for new and existing buildings (2024); Low-Carbon Heat Support and Heat Networks Investment Project; Home Upgrade Grant allocations; and financial incentives to purchase clean household technologies.
	APS	• Norway: Target to reduce energy use in buildings by 10 TWh by 2030 compared to 2015. • United Kingdom: Bans on the installation of oil, LPG and coal boilers introduced for new buildings to be implemented in the second-half of the 2020s.
China	STEPS	• General Code for Building Energy Efficiency and Renewable Energy Utilization (2022). • Updated MEPS for air conditioners and heat pumps (2022). • National financing allocated for replacement of appliances with more efficient alternatives in line with the Action Plan for Promoting the Replacement of Consumer Goods (2024). • Newly established sub-national subsidies and trade-in schemes promoting the replacement of appliances with more energy efficient models in Jiangsu, Shandong, Hubei and Guangdong provinces.
	APS	• Action Plan for Carbon Dioxide Peaking Before 2030: Sectoral Blueprint for Buildings.
India	STEPS	• Strengthened building codes for new commercial buildings and energy labelling for residential buildings in accordance with the revised Energy Conservation Bill (2022). • Updated energy labelling for refrigerators, air conditioners and fans (2021-22). • Subsidy scheme for residential rooftop PV systems (2024).
	APS	• AC @ 24 Campaign incentivising behavioural change to reduce cooling energy demand.
Southeast Asia	STEPS	• Malaysia: Introduced Green Building Index (2023). • Singapore: Updated building codes for new and existing buildings (2021). Subsidies for retrofits provided as part of the GMIS Programme (2022). • Indonesia: Updated MEPS for air conditioners (2021).
Africa	STEPS	• Kenya: Introduction of a building code for new construction (2022). • Updated MEPS for lighting (South Africa, 2024); air conditioners and heat pumps (Egypt, 2022); appliances, air conditioners, refrigerators, water heaters and lighting (Ghana, 2022).
	APS	• All eight countries with national clean cooking targets meet the SDG 7 goals by 2030 (Angola, Kenya, Malawi, Mali, Mozambique, Rwanda, Sudan and Eswatini).
Middle East	STEPS	• Saudi Arabia: Updated MEPS for air conditioners (2021).

Note: STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario; GW = gigawatt; LPG = liquefied petroleum gas; MEPS = minimum energy performance standards; SDG = Sustainable Development Goals.

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Table B.10 ⊳ Transport sector policies and measures as modelled by scenario for selected regions/countries

Region/ country	Scenario	Policies and targets
All regions	STEPS	• International Maritime Organisation (IMO) standards include: Energy Efficiency Design Index for new ships; Energy Efficiency Existing Index for existing ships and the Carbon Intensity Index for operational efficiency for all ships, which aim to reduce emission intensity by up to 11% in 2026 relative to the 2019 baseline.
United States	STEPS	• Inflation Reduction Act (2022): Offers tax credits for electric car purchases and investments in electric vehicle charging infrastructure to 2032. Tax credits for biofuels including sustainable aviation fuel and USD 66 billion investment in rail. • Infrastructure Investment and Jobs Act: Funding for construction of EV charging infrastructure, battery-related projects and alternative fuels infrastructure. • Environment Protection Agency (EPA) GHG emissions standards (2024) which target a nearly 50% reduction in fleet average GHG emissions levels for model year (MY) 2032 vehicles compared to the existing MY 2026 standards for light-duty vehicles and a 44% reduction for medium-duty vehicles. • EPA Phase 3 GHG emissions standards for new heavy-duty vehicles, targeting 30-60% GHG emissions reductions for MY 2032 vehicles compared to MY 2026, depending on vehicle type. • California: Advanced Clean Cars II regulation aims to achieve 100% zero emissions passenger cars and light truck sales by 2035. In addition, Advanced Clean Trucks and Fleets regulations require an increase in sales of zero emissions medium- and heavy- freight trucks. Other states have announced similar actions.
	APS	• Sustainable Aviation Fuel Grand Challenge to scale up the production of at least 3 billion gallons per year by 2030, and sufficient sustainable aviation fuel to meet 100% of domestic aviation demand by 2050. • Reduce domestic aviation emissions by 20% by 2030 compared to business-as-usual.
Canada	STEPS	• Electric Vehicle Availability Standard regulates annual zero-emission light-duty vehicles sales targets beginning in 2026 and reaching 100% in 2035. • CO_2 emissions standards for heavy commercial vehicles to reduce emissions by 5% to 27% in 2027, compared to 2017. • British Columbia: Low Carbon Fuels Act mandates renewable jet fuel share of 1% in 2028, 2% in 2029 and 3% in 2030.
	APS	• Target of 10% sustainable aviation fuel use by 2030. • Canadian National Railway commitment to reach net zero emissions by 2050.
Latin America and the Caribbean	STEPS	• Chile: Law on Energy Efficiency updating fuel economy standards to reduce fuel economy for light-duty vehicles less than 4 litres/100 km by 2030. • Brazil: Reduction of at least 1% of CO_2 emission in aviation sector through sustainable aviation fuel starting from 2027. Mandate to increase biodiesel blending to 15% by 2026. • Mexico: In 2024, revised CO_2 emission standards were published with stricter emission limits on new light-duty vehicles up to model year 2027.
	APS	• Brazil: Biodiesel blending to increase to 20% by 2030. • Mexico: Preliminary Draft Resolution issuing the National Electric Mobility Strategy, with 100% of passenger car, two/three-wheeler and bus sales to be electric and plug-in hybrids by 2040.
Japan	STEPS	• Fuel economy standard for light-duty vehicles to improve fuel efficiency by 32% to 2030 relative to 2016 levels.
	APS	• Green Growth Strategy and 6th Strategic Energy Plan aims for 100% sales of EVs, fuel cell vehicles and hybrids for passenger cars by 2035 and for light commercial vehicles by 2040. • Mandate for 10% sustainable aviation fuel use by 2030 for national airlines.

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Table B.10 ⊳ Transport sector policies and measures as modelled by scenario for selected regions/countries (continued)

Region/ country	Scenario	Policies and targets
Korea	STEPS	• Grants available for the purchase of private and commercial light-duty EVs and subsidies for electric buses. • Subsidies for shifting from road freight to rail.
	APS	• Target of 51% of new light-duty vehicles to be electric, fuel cell or hybrid by 2025 and 83% by 2030. • Rail Infrastructure Plan targets investments in rail sector, infrastructure expansion and electrification rate increase to 78% by 2030.
Australia and New Zealand	STEPS	• Australia: New Vehicle Efficiency Standard Bill (2024) to reduce emissions of new passenger and light commercial vehicles by 2029 to around 58 g CO_2/km and 110 g CO_2/km, measured using the New European Driving Cycle. The CO_2 targets are adjusted as a function of vehicle weight. • New Zealand: Clean Car Standard (2022) to reduce emissions of new passenger and light commercial vehicles by 2027 to around 63.3 g CO_2/km and 87.2 g CO_2/km. The CO_2 targets are adjusted as a function of vehicle weight.
	APS	• Australia: National Electric Vehicle Strategy includes details of state-level targets. • New Zealand: 100% of new cars and van sales to be zero emissions by 2035. Targets zero emissions vehicles to make up 100% of urban bus sales by 2025 and 100% of stock by 2035. Increase zero emissions vehicles to 30% of the light-duty vehicle fleet by 2035.
European Union	STEPS	• 100% CO_2 emissions reduction for both new cars and vans from 2035. • CO_2 emissions standards for new heavy-duty vehicles with reduction targets of 15% by 2025, 45% by 2030, 65% by 2035 and 90% for 2040, relative to 2019 levels. New urban buses to reduce emissions by 90% by 2030 and become zero-emission vehicles by 2035. • Alternative Fuels Infrastructure Regulation to accelerate the roll-out of recharging infrastructure for vehicles and hydrogen refuelling stations. Developing electricity infrastructure for maritime ports and airports. • Inclusion of the maritime sector in the EU Emissions Trading System from January 2024. • ReFuelEU Aviation sets minimum shares of sustainable aviation fuels, starting from 2% in 2025 and reaching 70% by 2050, with sub-obligations for synthetic fuels. • FuelEU Maritime initiative targets the reduction of average GHG intensity of energy used on board ships up to 80% by 2050 relative to 2020 levels.
	APS	• Renewable Energy Directive III to reach a 29% share of renewables in transport by 2030. • France: Plan to invest EUR 100 billion in railway infrastructure by 2040 and for SNCF, the national rail company, to reduce emissions by 30% by 2030, reaching net zero emissions by 2050. • Germany: Deutsche Bahn, the German rail company, target to reach climate neutrality by 2040.
Other Europe	STEPS	• United Kingdom: 80% of new cars and 70% of new vans to be zero emissions vehicles by 2030, increasing to 100% by 2035. • Switzerland: CO_2 emissions reduction regulation in line with the EU CO_2 emissions standards for light-duty vehicles.
	APS	• United Kingdom: 100% zero emissions vehicle sales for heavy-duty vehicles (HDVs) under 26 tonnes from 2035 and for all new HDVs from 2040. Minimum sustainable aviation fuel share of 2% by 2025, 10% by 2030, 15% by 2035, and 22% by 2040. Transport Decarbonisation Plan (2021) targets net zero emissions from rail by 2050, and 2023 target to increase freight rail market by 75% by 2050.
Eurasia	APS	• Russia: At least 72 000 charging stations by 2030, of which 28 000 are fast charging stations.

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Table B.10 ▷ Transport sector policies and measures as modelled by scenario for selected regions/countries (continued)

Region/ country	Scenario	Policies and targets
China	STEPS	• Trade-in subsidies for replacing fossil fuel-powered vehicles with new energy or fuel-efficient vehicles. • Corporate average fuel consumption target for light-duty vehicles of 4.0 litres/100 km in 2025 and 3.2 litres/100 km in 2030. • Extension of tax exemption for new energy vehicles to 2027. • Target for new energy vehicle sales to account for 45% of total vehicle sales by 2027. • Installation of charging infrastructure for more than 20 million EVs by 2025.
	APS	• National Transport Planning Outline 2021-2035: Increase the national rail network to 70 000 km of high-speed lines and 130 000 km of conventional lines by 2035.
India	STEPS	• Subsidies for EVs provided under the Faster Adoption & Manufacturing of Electric Vehicles (FAME) II scheme, followed by the Electric Mobility Promotion Scheme between July and September 2024, and the PM E-DRIVE thereafter. These schemes incentivise and subsidise the uptake of electric two/three-wheelers, buses and freight vehicles. • Partial implementation of 20% bioethanol blending target for gasoline and 5% biodiesel in 2025-2026.
	APS	• National railway target of net zero emissions by 2030. • Indicative sustainable aviation fuel blending target of 1% by 2027, increasing to 5% by 2030.
Southeast Asia	STEPS	• Indonesia: Subsidies to support deployment of battery electric vehicles. • Singapore: Vehicle emissions scheme complying with Euro VI emission standards for all new gasoline and diesel vehicles.
	APS	• Indonesia: Government targets to have 2 million EVs in passenger light-duty vehicle stock and 13 million electric motorcycles in the fleet by 2030. Target to extend the national railway network to 10 524 km by 2030. Increases in biodiesel blends from 35% to 40% mandate by 2025. • Viet Nam: Net zero GHG emissions in the transport sector by 2050, with a goal of 100% of road transport to use electricity and green energy. • Target for 100% zero emissions vehicles in new sales from 2035 in Thailand; passenger ICE vehicles phase out by 2040 in Singapore. • Pakistan: Targets for new vehicle sales: 30% of passenger light-duty vehicle sales to be electric by 2030; 90% of truck sales to be electric vehicles by 2040; 90% of urban bus sales to be electric vehicles by 2040; and 50% of electric two/three-wheeler sales by 2030. • Sustainable aviation fuel target of 1% by 2026 and 3-5% by 2030 in Singapore; 5% by 2025 in Indonesia.
Africa	STEPS	• Four countries have adopted the LDV Euro 3 or superior standard for second-hand vehicle imports, as well an upper age limit of eight years for imports. • Ethiopia: Ban on the import of ICE vehicles.
	APS	• Ghana: 4%, 16% & 32% of cars & buses sold to be EVs in 2025, 2030 and 2050 respectively. • Kenya Railways 2023-2027 Strategic Plan.
Middle East	STEPS	• Saudi Arabia: 2024-2028 Saudi Arabia Corporate Average Fuel Economy standards.

Notes: STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario. IMO = International Maritime Organization; EPA = US Environmental Protection Agency; MoU = Memorandum of Understanding; GHG = greenhouse gases; km = kilometre; ICE = internal combustion engine; EVs = electric vehicles; FCEV = fuel cell electric vehicle; CNG = compressed natural gas; LDV = light-duty vehicle; g CO_2/km = grammes of carbon dioxide per kilometre. Light-duty vehicles include passenger cars and light commercial vehicles (gross weight <3.5 tonnes). Heavy-duty vehicles include medium-freight trucks (gross weight 3.5 to 15 tonnes), heavy-freight trucks (gross weight >15 tonnes) and buses.

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Table B.11 ▷ Industry and intergovernmental-led initiatives and manufacturing targets by scenario

Initiatives	Pledge type	Signatories pledge	Achievement in: STEPS	Achievement in: APS	Achievement in: NZE
Buildings					
Buildings Breakthrough	Emissions reduction	Make near-zero emissions and resilient buildings the norm for new buildings by 2030.	Unmet	Partial	Full
Steel					
First Mover Coalition	Procurement	10% of low-carbon steel by 2030.	Unmet	Full	Full
Net Zero Initiative	Technology deployment	Bring zero-carbon primary steel production technologies to market by 2030.	Unmet	Full	Full
Glasgow Breakthrough	Procurement	Near zero emissions steel to be preferred for every member of the coalition (including European Union and United States).	Unmet	Full	Full
Cement					
Concrete Action for Climate	Emissions reduction	Achieve net zero carbon emissions from operations by 2050.	Unmet	Partial	Full
Rail					
UIC Railway Climate Responsibility Pledge	Emissions reduction	Align CO_2 emissions reduction to achieve carbon neutrality by 2050.	Unmet	Partial	Full
Shipping					
2023 revised IMO GHG Strategy	Emissions reduction	Net zero emissions international shipping around 2050.	Unmet	Full	Full
Aviation					
IATA Net Zero Initiative	Emissions reduction	Net zero emissions from aviation by 2050.	Unmet	Partial	Full
ICAO long-term aspirational goal	Emissions reduction	Net zero emissions from international aviation by 2050.	Unmet	Partial	Full
ICAO initiative (CORSIA)	Emissions reduction	Offset CO_2 emissions of international aviation above 85% of 2019 levels (2024-2035).	Unmet	Full	Full
Zero emissions vehicles					
Global MoU on Zero Emissions Medium-duty and Heavy-Duty Vehicles	Technology deployment	100% of new MHDVs to be zero emissions by 2040.	Unmet	Full	Full
COP26 Declaration	Technology deployment	All sales of new light-duty vehicles to be zero emissions globally by 2040, and by no later than 2035 in leading markets.	Unmet	Full	Full
Car manufacturers corporate targets	Sales targets	EV share to reach 42-58% globally (IEA estimates).	Low-range met	Mid-range met	High-range met

Note: UIC = International Union of Railways; IMO = International Maritime Organization; IATA = International Air Transport Association; ICAO = International Civil Aviation Organization; CORSIA = Carbon Offsetting and Reduction Scheme for International Aviation; MoU = Memorandum of Understanding; EV = electric vehicle; MHDVs = medium-duty and heavy-duty vehicles.

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Definitions

This annex provides general information on terminology used throughout this report including: units and general conversion factors; definitions of fuels, processes and sectors; regional and country groupings; and abbreviations and acronyms.

Units

Area	km^2	square kilometre
	Mha	million hectares
Batteries	Wh/kg	watt hours per kilogramme
Coal	Mtce	million tonnes of coal equivalent (equals 0.7 Mtoe)
Distance	km	kilometre
Emissions	ppm	parts per million (by volume)
	t CO_2	tonnes of carbon dioxide
	Gt CO_2-eq	gigatonnes of carbon-dioxide equivalent (using 100-year global warming potentials for different greenhouse gases)
	kg CO_2-eq	kilogrammes of carbon-dioxide equivalent
	g CO_2/km	grammes of carbon dioxide per kilometre
	g CO_2/kWh	grammes of carbon dioxide per kilowatt-hour
	kg CO_2/kWh	kilogrammes of carbon dioxide per kilowatt-hour
Energy	EJ	exajoule (1 joule x 10^{18})
	PJ	petajoule (1 joule x 10^{15})
	TJ	terajoule (1 joule x 10^{12})
	GJ	gigajoule (1 joule x 10^{9})
	MJ	megajoule (1 joule x 10^{6})
	boe	barrel of oil equivalent
	toe	tonne of oil equivalent
	ktoe	thousand tonnes of oil equivalent
	Mtoe	million tonnes of oil equivalent
	bcme	billion cubic metres of natural gas equivalent
	MBtu	million British thermal units
	kWh	kilowatt-hour
	MWh	megawatt-hour
	GWh	gigawatt-hour
	TWh	terawatt-hour
	Gcal	gigacalorie
Gas	bcm	billion cubic metres
	tcm	trillion cubic metres
Mass	kg	kilogramme
	t	tonne (1 tonne = 1 000 kg)
	kt	kilotonne (1 tonne x 10^{3})
	Mt	million tonne (1 tonne x 10^{6})

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Monetary	USD million	1 US dollar x 10^6
	USD billion	1 US dollar x 10^9
	USD trillion	1 US dollar x 10^{12}
	USD/t CO_2	US dollars per tonne of carbon dioxide
Oil	barrel	one barrel of crude oil
	kb/d	thousand barrels per day
	mb/d	million barrels per day
	mboe/d	million barrels of oil equivalent per day
Power	W	watt (1 joule per second)
	kW	kilowatt (1 watt x 10^3)
	MW	megawatt (1 watt x 10^6)
	GW	gigawatt (1 watt x 10^9)
	TW	terawatt (1 watt x 10^{12})

General conversion factors for energy

		Multiplier to convert to:					
		EJ	**Gcal**	**Mtoe**	**MBtu**	**bcme**	**GWh**
Convert from:	**EJ**	1	2.388 x 10^8	23.88	9.478 x 10^8	27.78	2.778 x 10^5
	Gcal	4.1868 x 10^{-9}	1	10^{-7}	3.968	1.163 x 10^{-7}	1.163 x 10^{-3}
	Mtoe	4.1868 x 10^{-2}	10^7	1	3.968 x 10^7	1.163	11 630
	MBtu	1.0551 x 10^{-9}	0.252	2.52 x 10^{-8}	1	2.932 x 10^{-8}	2.931 x 10^{-4}
	bcme	0.036	8.60 x 10^6	0.86	3.41 x 10^7	1	9 999
	GWh	3.6 x 10^{-6}	860	8.6 x 10^{-5}	3 412	1 x 10^{-4}	1

Note: There is no generally accepted definition of barrel of oil equivalent (boe); typically the conversion factors used vary from 7.15 to 7.40 boe per tonne of oil equivalent. Natural gas is attributed a low heating value of 1 MJ per 44.1 kg. Conversions to and from billion cubic metres of natural gas equivalent (bcme) are given as representative multipliers but may differ from the average values obtained by converting natural gas volumes between IEA balances due to the use of country-specific energy densities. Lower heating values (LHV) are used throughout.

Currency conversions

Exchange rates *(2023 annual average)*	**1 US dollar (USD) equals:**
British Pound	0.80
Chinese Yuan Renminbi	7.08
Euro	0.92
Indian Rupee	82.60
Japanese Yen	140.49
Korean Won	1 305.66

Source: World Bank Data: Official exchange rate (Local Currency Units per USD, period average), https://data.worldbank.org/indicator/PA.NUS.FCRF, accessed September 2024.

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Definitions

Advanced bioenergy: Sustainable fuels produced from waste, residues and non-food crop feedstocks (excluding traditional uses of biomass), which are capable of delivering significant life cycle greenhouse gas emissions savings compared with fossil fuel alternatives and of minimising adverse sustainability impacts. Advanced bioenergy feedstocks either do not directly compete with food and feed crops for agricultural land or are only developed on land previously used to produced food crop feedstocks for biofuels.

Agriculture: Includes all energy used on farms, in forestry and for fishing.

Agriculture, forestry and other land use (AFOLU): A sector included in greenhouse gas accounting frameworks which encompasses managed ecosystems. AFOLU emissions include greenhouse gas emissions from agriculture, land use, land-use change and forestry.

Ammonia (NH_3): A compound of nitrogen and hydrogen (NH_3) that is an industrially produced input to fertiliser manufacturing, typically produced by using fossil fuel inputs to generate the input hydrogen. With properties similar to liquefied petroleum gas (LPG), ammonia can also be used directly as a fuel in direct combustion processes, as well as in fuel cells, and can be cracked to release its hydrogen content. As it can be made from low-emissions hydrogen, ammonia has the potential to be a low-emissions fuel if the production process, including nitrogen separation, is powered by low-emissions energy. Produced in such a way, ammonia is considered a low-emissions hydrogen-based liquid fuel.

Aviation: This transport mode includes both domestic and international flights and their use of aviation fuels. Domestic aviation covers flights that depart and land in the same country; flights for military purposes are included. International aviation includes flights that land in a country other than the departure location.

Back-up generation capacity: Households and businesses connected to a main power grid may also have a source of back-up power generation capacity that, in the event of disruption, can provide electricity. Back-up generators are typically fuelled with diesel or gasoline. Capacity can be as little as a few hundred watts. Such capacity is distinct from mini-grid and off-grid systems that are not connected to a main power grid.

Battery storage: Energy storage technology that uses reversible chemical reactions to absorb, store and release electricity on demand.

Biodiesel: Diesel-equivalent fuel made from the transesterification of vegetable oils and animal fats, hydrogenated vegetable oil (HVO), thermal processes such as gasification and fermentation.

Bioenergy: Energy content in solid, liquid and gaseous products derived from biomass feedstocks and biogas. It includes solid bioenergy, liquid biofuels and biogases. Excludes hydrogen produced from bioenergy, including via electricity from a biomass-fired plant, as well as synthetic fuels made with CO_2 feedstock from a biomass source.

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Biogas: A mixture of methane, CO_2 and small quantities of other gases produced by anaerobic digestion of organic matter in an oxygen-free environment. It includes landfill gas and sewage sludge gas, and it can be upgraded by removing non-methane constituents, principally CO_2.

Biogases: Include both biogas and biomethane.

Biogasoline: Includes all liquid biofuels (advanced and conventional) used to replace gasoline.

Biojet kerosene: Kerosene substitute produced from biomass. It includes conversion routes such as hydro-processed esters and fatty acids (HEFA) and biomass gasification with Fischer-Tropsch. It excludes synthetic kerosene produced from biogenic carbon dioxide.

Biomethane: Biomethane is a near-pure source of methane produced either by "upgrading" biogas (a process that removes any carbon dioxide and other contaminants present in the biogas) or through the gasification of solid biomass followed by methanation. It is also known as renewable natural gas.

Buildings: The buildings sector includes energy used in residential and services buildings. Services buildings include commercial and institutional buildings and other non-specified buildings. Building energy use includes space heating and cooling, water heating, lighting, appliances and cooking equipment.

Bunkers: Include both international marine bunker fuels and international aviation bunker fuels.

Capacity credit: The proportion of the nameplate generating capacity of an electrical generator that can be reliably expected to generate electricity during times of peak demand on the grid to which it is connected. The sum of all capacity credits across an electricity system is useful as an approximation of the firm power that the system can reliably provide at a given time.

Carbon capture, utilisation and storage (CCUS)**:** The process of capturing carbon dioxide emissions from fuel combustion, industrial processes or directly from the atmosphere. Captured CO_2 emissions can be stored in underground geological formations, onshore or offshore, or used as an input or feedstock in manufacturing.

Carbon dioxide (CO_2)**:** A gas consisting of one part carbon and two parts oxygen. It is an important greenhouse (heat-trapping) gas.

Chemical feedstock: Physical energy products used as raw materials to produce chemical products, typically in the petrochemicals sector. Examples are crude oil-based ethane or naphtha to produce ethylene in steam crackers.

Clean cooking systems: Cooking solutions that release less harmful pollutants, are more efficient and environmentally sustainable than traditional cooking options that make use of solid biomass (such as a three-stone fire), coal or kerosene. This refers to improved cook

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stoves, biogas/biodigester systems, electric stoves, liquefied petroleum gas, natural gas or ethanol stoves.

Clean energy: In *power*, clean energy includes: renewable energy sources, nuclear power, fossil fuels fitted with CCUS, hydrogen and ammonia; battery storage; and electricity grids. In *efficiency*, clean energy includes energy efficiency in buildings, industry and transport, excluding domestic navigation. In *end-use applications*, clean energy includes: direct use of renewables; electric vehicles; electrification in buildings, industry and international marine transport; CCUS in industry and direct air capture. In *fuel supply*, clean energy includes low-emissions fuels, direct air capture and measures to reduce the emissions intensity of fossil fuel production.

Coal: Consists of both primary coal, i.e. lignite, coking and steam coal, and derived fuels, e.g. patent fuel, brown-coal briquettes, coke-oven coke, gas coke, gas works gas, coke-oven gas, blast furnace gas and oxygen steel furnace gas. Peat is also included.

Coalbed methane (CBM)**:** Category of unconventional natural gas that refers to methane found in coal seams.

Coal-to-gas (CTG)**:** A process by which mined coal is first turned into synthesis gas or syngas, i.e. a mixture of hydrogen and carbon monoxide, and then into synthetic methane.

Coal-to-liquids (CTL)**:** The transformation of coal into liquid hydrocarbons. This can be achieved through either coal gasification into synthesis gas or syngas, i.e. a mixture of hydrogen and carbon monoxide, combined with Fischer-Tropsch or methanol-to-gasoline synthesis to produce liquid fuels, or through the less developed direct-coal liquefaction technologies in which coal is directly reacted with hydrogen.

Coking coal: A type of coal that can be used for steel making (as a chemical reductant and a source of heat), where it produces coke capable of supporting a blast furnace charge. Coal of this quality is commonly known as metallurgical coal.

Concentrating solar power (CSP)**:** Thermal power generation technology that collects and concentrates sunlight to produce high temperature heat to generate electricity.

Conventional liquid biofuels: Fuels produced from food crop feedstocks. Commonly referred to as first generation biofuels and include sugar cane ethanol, starch-based ethanol, fatty acid methyl ester (FAME) from vegetable oils such as palm, rapeseed or soybean oil, straight vegetable oil (SVO) and hydrotreated vegetable oil (HVO) produced from vegetable oils such as palm, rapeseed or soybean oil.

Conventional natural gas: Refers to natural gas extracted using traditional drilling techniques. It includes both onshore and offshore natural gas (including from the Arctic).

Conventional oil: Refers to oil extracted using traditional drilling methods. It includes onshore and offshore crude oil (including from the Arctic), enhanced oil recovery, and natural gas liquids produced from conventional gas fields.

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Critical minerals: A wide range of minerals and metals that are essential in clean energy technologies and other modern technologies and have supply chains that are vulnerable to disruption. Although the exact definition and criteria differ among countries, critical minerals for clean energy technologies typically include chromium, cobalt, copper, graphite, lithium, manganese, molybdenum, nickel, platinum group metals, zinc, rare earth elements and other commodities.

Decomposition analysis: A statistical method that decomposes an aggregate indicator to quantify the relative contribution of a set of pre-defined factors leading to a change in the aggregate indicator. The *World Energy Outlook* uses an additive index decomposition of the type Logarithmic Mean Divisia Index (LMDI).

Demand-side integration (DSI)**:** Consists of two types of measures: actions that influence load shape such as energy efficiency and electrification; and actions that manage load such as demand-side response measures.

Demand-side response (DSR)**:** Describes actions which can influence the load profile such as shifting the load curve in time without affecting total electricity demand, or load shedding such as interrupting demand for a short duration or adjusting the intensity of demand for a certain amount of time.

Direct air capture (DAC)**:** A type of CCUS technology that captures CO_2 directly from the atmosphere using liquid solvents or solid sorbents. It is generally coupled with permanent storage of the CO_2 in deep geological formations or its use in the production of fuels, chemicals, building materials or other products. When coupled with permanent geological CO_2 storage, DAC is a carbon removal technology, and it is known as direct air capture and storage (DACS).

Dispatchable generation: Electricity from technologies whose power output can be readily controlled up to the nameplate capacity, i.e. increased to maximum rated capacity or decreased to zero, in order to help match supply with demand.

Electric arc furnace: Furnace that heats material by means of an electric arc. It is used for scrap-based steel production but also for ferroalloys, aluminium, phosphorus or calcium carbide.

Electric vehicles (EVs)**:** Electric vehicles comprise of battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs).

Electricity demand: Defined as total gross electricity generation less own use generation, plus net trade (imports less exports), less transmission and distribution losses.

Electricity generation: Defined as the total amount of electricity generated by power only or combined heat and power plants including generation required for own use. This is also referred to as gross generation.

Electrolysis: Process of converting electric energy to chemical energy. Most relevant for the energy sector is water electrolysis, which splits water molecules into hydrogen and oxygen molecules. The resulting hydrogen is called electrolytic hydrogen.

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End-use sectors: Include industry, transport, buildings, agriculture and other non-energy use.

Energy demand: See total energy supply.

Energy-intensive industries: Includes production and manufacturing in the branches of iron and steel, chemicals, non-metallic minerals (including cement), non-ferrous metals (including aluminium), and paper, pulp and printing.

Energy-related and industrial process CO_2 emissions: Carbon dioxide emissions from fuel combustion, industrial processes, and fugitive and flaring CO_2 from fossil fuel extraction. Unless otherwise stated, CO_2 emissions in the *World Energy Outlook* refer to energy-related and industrial process CO_2 emissions.

Energy sector greenhouse gas (GHG) emissions: Energy-related and industrial process CO_2 emissions plus fugitive and vented methane (CH_4) and nitrous dioxide (N_2O) emissions from the energy and industry sectors.

Energy services: A personal or societal gain from the use of energy. Include, *inter alia,* heating, cooling, lighting, entertainment, mobility, nourishment, hygiene and education. Also see useful energy.

Ethanol: An alcohol with broad application in the chemical sector and as a fuel additive. When produced from bioresources it is known as bioethanol, which has applications as biogasoline (a liquid fuel) and as a biochemical. In the *World Energy Outlook (WEO)*, the term exclusively refers to bioethanol.

Fischer-Tropsch synthesis: Catalytic process to produce synthetic fuels, e.g. diesel, kerosene or naphtha, typically from mixtures of carbon monoxide and hydrogen (synthesis gas or syngas). The inputs to Fischer-Tropsch synthesis can be from biomass, coal, natural gas, or hydrogen and CO_2.

Fossil fuels: Consist of coal, oil and natural gas. Total fossil fuel use is equal to unabated fossil fuels plus fossil fuels with CCUS plus non-energy use of fossil fuels.

Gaseous fuels: Fuels in gaseous form including natural gas, biogas, biomethane, hydrogen and synthetic methane.

Gases: See gaseous fuels.

Gas-to-liquids (GTL): A process by which methane reacts with oxygen or steam to produce synthesis gas or syngas, i.e. a mixture of hydrogen and carbon monoxide, followed by Fischer-Tropsch synthesis. This is similar to the process used in coal-to-liquids.

Geothermal: Heat derived from the sub-surface of the earth, usually using a working fluid such as water and/or steam to bring the energy to the surface. Depending on its characteristics, geothermal energy can be used for heating and cooling purposes or be harnessed to generate clean electricity if the temperature is adequate.

Heat (end-use): Can be obtained from the combustion of fossil or renewable fuels, direct geothermal or solar heat systems, exothermic chemical processes and electricity (through

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resistance heating or heat pumps which can extract it from ambient air and liquids). This category refers to the wide range of end-uses, including space and water heating, and cooking in buildings, desalination and process applications in industry. It does not include cooling applications.

Heat (supply)**:** Obtained from the combustion of fuels, nuclear reactors, large-scale heat pumps, geothermal or solar resources. It may be used for heating or cooling, or converted into mechanical energy for transport or electricity generation. Commercial heat sold is reported under total final consumption with the fuel inputs allocated under power generation.

Heavy-duty trucks (HDTs): Include both medium freight trucks (gross weight 3.5 to 15 tonnes) and heavy freight trucks (gross weight >15 tonnes).

Heavy-duty vehicles (HDVs): Include HDTs and buses.

Heavy industries: Iron and steel, chemicals and cement.

Hydrogen: Hydrogen is used in the energy system as an energy carrier, as an industrial raw material, or is combined with other inputs to produce hydrogen-based fuels. Unless otherwise stated, hydrogen in this report refers to low-emissions hydrogen.

Hydrogen-based fuels: Include ammonia and synthetic hydrocarbons (gases and liquids) that derive their energy content from a pure (or nearly pure) hydrogen feedstock. If produced from low-emissions hydrogen, these fuels are low-emissions hydrogen-based fuels.

Hydropower: Refers to the electricity produced in hydropower projects, with the assumption of 100% efficiency. It excludes output from pumped storage and marine (tide and wave) plants.

Improved cook stoves: Intermediate and advanced improved biomass cook stoves (ISO tier >= 3). It excludes basic improved stoves (ISO tier 0-2).

Industry: The sector includes fuel used within the manufacturing and construction industries. Key industry branches include iron and steel, chemicals and petrochemicals, cement, aluminium, and paper, pulp and printing. Use by industries for the transformation of energy into another form or for the production of fuels is excluded and reported separately under other energy sector. There is an exception for fuel transformation in blast furnaces and coke ovens, which are reported within iron and steel. Consumption of fuels for the transport of goods is reported as part of the transport sector, while consumption of fuels by off-road vehicles is reported under the specific sector. For instance, fuels consumed by bulldozers as a part of industrial operations is reported in industry.

International aviation bunkers: Include the deliveries of aviation fuels to aircraft for international aviation. Fuel used by airlines for their road vehicles are excluded. The domestic/international split is determined on the basis of departure and landing locations and not by the nationality of the airline.

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International marine bunkers: Include the quantities delivered to ships of all flags that are engaged in international navigation. The international navigation may take place at sea, on inland lakes and waterways, and in coastal waters. Consumption by ships engaged in domestic navigation is excluded. The domestic/international split is determined on the basis of port of departure and port of arrival, and not by the flag or nationality of the ship. Consumption by fishing vessels and by military forces is excluded and instead included in the residential, services and agriculture category.

Investment: Investment is the capital expenditure in energy supply, infrastructure, end-use and efficiency. Fuel supply investment includes the production, transformation and transport of oil, gas, coal and low-emissions fuels. *Power sector* investment includes new construction and refurbishment of generation, electricity grids (transmission, distribution and public electric vehicle chargers), and battery storage. *Energy efficiency* investment includes efficiency improvements in buildings, industry and transport. *Other end-use* investment includes the purchase of equipment for the direct use of renewables, electric vehicles, electrification in buildings, industry and international marine transport, equipment for the use of low-emissions fuels, and CCUS in industry and direct air capture. Data and projections reflect spending over the lifetime of projects and are presented in real terms in year-2023 US dollars converted at market exchange rates unless otherwise stated. Total investment reported for a year reflects the amount spent in that year.

Levelised cost of electricity (LCOE)**:** An indicator of the expected average production cost for each unit of electricity generated by a technology over its economic lifetime. The LCOE combines into a single metric all the cost elements directly associated with a given power technology, including construction, financing, fuel, maintenance and costs associated with a carbon price. It does not include network integration or other indirect costs. For a more complete indicator, see value-adjusted levelised cost of electricity (VALCOE).

Light-duty vehicles (LDVs)**:** Include passenger cars and light commercial vehicles (gross vehicle weight < 3.5 tonnes).

Light industries: Include non-energy-intensive industries: food and tobacco; machinery; mining and quarrying; transportation equipment; textiles; wood harvesting and processing and construction.

Lignite: A type of coal that is used in the power sector mostly in regions near lignite mines due to its low energy content and typically high moisture levels, which generally make long-distance transport uneconomic. In the *World Energy Outlook,* data on lignite includes peat.

Liquid biofuels: Liquid fuels derived from biomass or waste feedstock, including ethanol, biodiesel and biojet fuels. They can be classified as conventional and advanced biofuels according to the combination of feedstock and technologies used to produce them and their respective maturity. Unless otherwise stated, biofuels are expressed in energy-equivalent volumes of gasoline, diesel and kerosene.

Liquid fuels: Include oil, liquid biofuels, synthetic oil products and hydrogen-based fuels, i.e. ammonia and methanol.

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Low-emissions electricity: Includes output from renewable energy technologies, nuclear power, fossil fuels fitted with CCUS, hydrogen and ammonia.

Low-emissions fuels: Include modern bioenergy, low-emissions hydrogen and low-emissions hydrogen-based fuels.

Low-emissions gases: Include biogas, biomethane, low-emissions hydrogen and low-emissions synthetic methane.

Low-emissions hydrogen: Includes hydrogen which is produced through water electrolysis with electricity generated from a low-emissions source (such as renewables, e.g. solar and wind turbines, and nuclear). Hydrogen produced from biomass or from fossil fuels with carbon capture, utilisation and storage (CCUS) technology is also counted as low-emissions hydrogen. Production from fossil fuels with CCUS is included only if upstream emissions are sufficiently low, if capture – at high rates – is applied to all CO_2 streams associated with the production route, and if all CO_2 is permanently stored to prevent its release into the atmosphere. The same principle applies to low-emissions feedstocks and hydrogen-based fuels made using low-emissions hydrogen and a sustainable carbon source (of biogenic origin or directly captured from the atmosphere).

Low-emissions hydrogen-based fuels: Fuels produced from low-emissions hydrogen. Includes ammonia, methanol and other synthetic hydrocarbons (gases and liquids) made from low-emissions hydrogen when any carbon inputs, e.g. from CO_2, are not from fossil fuels or fossil-derived process emissions.

Low-emissions hydrogen-based liquid fuels: A subset of low-emissions hydrogen-based fuels that includes only ammonia, methanol and synthetic liquid hydrocarbons, such as synthetic kerosene.

Lower heating value: Heat liberated by the complete combustion of a unit of fuel when the water produced is assumed to remain as a vapour and the heat is not recovered.

Marine energy: Mechanical energy harvested from ocean currents, tidal movement or wave motion and exploited for electricity generation.

Middle distillates: Include jet fuel, diesel and heating oil.

Mini-grids: Small electric grid systems, not connected to main electricity networks, linking a number of households and/or other consumers.

Modern energy access: Includes household access to a minimum level of electricity (initially equivalent to 250 kilowatt-hours (kWh) annual demand for a rural household and 500 kWh for an urban household); household access to less harmful and more sustainable cooking and heating fuels, and improved/advanced stoves; access that enables productive economic activity; and access for public services.

Modern gaseous bioenergy: See biogases.

Modern liquid bioenergy: Includes biogasoline, biodiesel, biojet kerosene and other liquid biofuels.

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Modern solid bioenergy: Includes all solid bioenergy products (see solid bioenergy definition) except the traditional use of biomass. It also includes the use of solid bioenergy in intermediate and advanced improved biomass cook stoves (ISO tier >= 3).

Natural gas: A gaseous fossil fuel, consisting mostly of methane. Occurs in deposits, whether liquefied or gaseous. In IEA analysis and statistics, it includes both non-associated gas originating from fields producing hydrocarbons only in gaseous form, and associated gas produced in association with crude oil production, as well as methane recovered from coal mines (colliery gas). Natural gas liquids, manufactured gas (produced from municipal or industrial waste, or sewage) and quantities vented or flared are not included. Natural gas has a specific energy content of 44.09 MJ/kg on a higher heating value basis. Natural gas data in cubic metres are expressed on a gross calorific value basis and are measured at 15 °C and at 760 mm Hg (Standard Conditions). Natural gas data expressed in tonnes of oil equivalent, mainly to allow comparison with other fuels, are on a net calorific basis. The difference between the net and the gross calorific value is the latent heat of vapourisation of the water vapour produced during combustion of the fuel.

Natural gas liquids (NGLs): Liquid or liquefied hydrocarbons produced in the manufacture, purification and stabilisation of natural gas. NGLs are portions of natural gas recovered as liquids in separators, field facilities or gas processing plants. NGLs include, but are not limited to, ethane (when it is removed from the natural gas stream), propane, butane, pentane, natural gasoline and condensates.

Near zero emissions capable material production capacity: Capacity that will achieve substantial emissions reductions from the start – but fall short of near zero emissions material production initially (see following definition) – with plans to continue reducing emissions over time such that they could later achieve near zero emissions production without additional capital investment.

Near zero emissions material production: For steel and cement, production that achieves the near zero GHG emissions intensity thresholds as defined in *Achieving Net Zero Heavy Industry Sectors in G7 Members*[1]. The thresholds depend on the scrap share of metallic input for steel and the clinker-to-cement ratio for cement. For other energy-intensive commodities such as aluminium, fertilisers and plastics, production that achieves reductions in emissions intensity equivalent to the considerations for near zero emissions steel and cement.

Near zero emissions material production capacity: Capacity that when operational will achieve near zero emissions material production from the start.

Network gases: Gaseous fuels transported in a pipeline gas network, either separately or blended together. Include natural gas, biomethane, synthetic methane and hydrogen blended in a gas network.

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[1] International Energy Agency (2022), Achieving Net Zero Heavy Industry Sectors in G7 Members, https://www.iea.org/reports/achieving-net-zero-heavy-industry-sectors-in-g7-members

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Non-energy-intensive industries: See other industry.

Non-energy use: The use of energy products as raw materials for the manufacture of non-energy products, e.g. natural gas used to produce fertiliser, as well as for direct uses that do not involve using the products as a source of energy, or as a transformation input e.g. lubrication, sealing, roading surfacing, preservation or use as a solvent.

Non-renewable waste: Non-biogenic waste, such as plastics in municipal or industrial waste.

Nuclear power: Refers to the electricity produced by a nuclear reactor, assuming an average conversion efficiency of 33%.

Off-grid systems: Mini-grids and stand-alone systems for individual households or groups of consumers not connected to a main grid.

Offshore wind: Refers to electricity produced by wind turbines that are installed in open water, usually in the ocean. Includes fixed offshore wind (fixed to the seabed) and floating offshore wind.

Oil: A liquid fuel. Usually refers to fossil fuel mineral oil. Includes oil from both conventional and unconventional oil production. Petroleum products include refinery gas, ethane, liquid petroleum gas, aviation gasoline, motor gasoline, jet fuel, kerosene, gas/diesel oil, heavy fuel oil, naphtha, white spirits, lubricants, bitumen, paraffin, waxes and petroleum coke.

Other energy sector: Covers the use of energy by transformation industries and the energy losses in converting primary energy into a form that can be used in the final consuming sectors. It includes losses in low-emissions hydrogen and hydrogen-based fuels production, bioenergy processing, gas works, petroleum refineries, coal and gas transformation and liquefaction. It also includes energy own use in coal mines, in oil and gas extraction and in electricity and heat production. Transfers and statistical differences are also included in this category. Fuel transformation in blast furnaces and coke ovens are not accounted for in the other energy sector category.

Other industry: A category of industry branches that includes construction, food processing, machinery, mining, textiles, transport equipment, wood processing and remaining industry. It is sometimes referred to as non-energy-intensive industry.

Passenger car: A road motor vehicle, other than a moped or a motorcycle, intended to transport passengers. It includes vans designed and used primarily to transport passengers. Excluded are light commercial vehicles, motor coaches, urban buses and mini-buses/mini-coaches.

Peat: A solid formed from the partial decomposition of dead vegetation under conditions of high humidity and limited air access (initial stage of coalification). It is available in two forms for use as a fuel, sod peat and milled peat. Peat used for non-energy purposes is not included.

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Plastic collection rate: Proportion of plastics that is collected for recycling relative to the quantity of recyclable waste available.

Plastic waste: Refers to all post-consumer plastic waste with a lifespan of more than one year.

Power generation: Refers to electricity generation and heat production from all sources of electricity, including electricity-only power plants, heat plants, and co-generation (i.e. combined heat and power) plants. Both main activity producer plants and small plants that produce fuel for their own use (auto-producers) are included.

Process emissions: CO_2 emissions produced from industrial processes which chemically or physically transform materials. A notable example is cement production, in which CO_2 is emitted when calcium carbonate is transformed into lime, which in turn is used to produce clinker.

Process heat: The use of thermal energy to produce, treat or alter manufactured goods.

Productive uses: Energy used towards an economic purpose: agriculture, industry, services and non-energy use. Some energy demand from the transport sector, e.g. freight, could be considered as productive, but is treated separately.

Rare earth elements (REEs)**:** A group of seventeen chemical elements in the periodic table, specifically the fifteen lanthanides plus scandium and yttrium. REEs are key components in some clean energy technologies, including wind turbines, electric vehicle motors and electrolysers.

Renewables: Include modern bioenergy, geothermal, hydropower, solar photovoltaics, concentrating solar power, wind, marine (tide and wave) energy, and renewable waste.

Residential: Energy used by households including space heating and cooling, water heating, lighting, appliances, electronic devices and cooking.

Road transport: This refers to all road vehicle types (passenger cars, two/three-wheelers, light commercial vehicles, buses and medium and heavy freight trucks).

Self-sufficiency: Corresponds to indigenous production divided by total energy supply.

Services: A component of the buildings sector. It represents energy used in commercial facilities, e.g. offices, shops, hotels, restaurants and in institutional buildings, e.g. schools, hospitals, public offices. Energy use in services includes space heating and cooling, water heating, lighting, appliances, cooking and desalination.

Shale gas: A type of unconventional natural gas contained within a commonly occurring rock classified as shale. Shale formations are characterised by low permeability, with more limited ability for gas to flow through the rock than is the case within a conventional reservoir. Shale gas is generally produced using hydraulic fracturing. See also tight oil.

Shipping/navigation: This transport mode includes both domestic and international navigation and their use of marine fuels. Domestic navigation covers the transport of goods

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or people on inland waterways and for national sea voyages (starts and ends in the same country without any intermediate foreign port). International navigation includes quantities of fuels delivered to merchant ships (including passenger ships) of any nationality for consumption during international voyages transporting goods or passengers.

Single-use plastics (or disposable plastics)**:** Plastic items used only one time before disposal.

Solar: Includes solar photovoltaics (PV), concentrating solar power (CSP), and solar heating and cooling.

Solar home systems (SHS)**:** Small-scale photovoltaic and battery stand-alone systems with capacity higher or equal to 10 watt peak (Wp), supplying electricity for single households or small businesses. They are most often used off-grid, but also where grid supply is not reliable. They exclude smaller solar systems of capacity lower than 10 Wp (i.e. solar multi light systems and solar lanterns), which are not included within the IEA access accounting methodology.

Solar photovoltaics (PV)**:** Electricity produced from solar photovoltaic cells including utility-scale and small-scale installations.

Solid bioenergy: Includes charcoal, fuelwood, dung, agricultural residues, wood waste and other solid biogenic wastes.

Solid fuels: Include coal, modern solid bioenergy, traditional use of biomass and industrial and municipal wastes.

Stand-alone systems: Small-scale autonomous electricity supply for households or small businesses. They are generally used off-grid, but also where grid supply is not reliable. Stand-alone systems include solar home systems, small wind or hydro generators, diesel or gasoline generators. The difference compared with mini-grids is in scale and that stand-alone systems do not have a distribution network serving multiple costumers.

Steam coal: A type of coal that is mainly used for heat production or steam-raising in power plants and, to a lesser extent, in industry. Typically, steam coal is not of sufficient quality for steel making. Coal of this quality is also commonly known as thermal coal.

Synthetic methane: Methane from sources other than natural gas, including coal-to-gas and low-emissions synthetic methane.

Synthetic oil: Liquid fuels obtained via a process other than the refining of crude oil or bituminous oils. Synthetic oil is produced through Fischer-Tropsch conversion or methanol synthesis. It includes oil products from coal-to-liquids, gas-to-liquids, thermochemical biomass-to-liquids, and non-ammonia low-emissions liquid hydrogen-based fuels.

Tight oil: A type of unconventional oil produced from shale or other very low permeability formations, generally using hydraulic fracturing. Sometimes referred to as light tight oil. Tight oil includes tight crude oil and condensate production except for the United States, which includes tight crude oil only (US tight condensate volumes are included in natural gas liquids).

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Total energy supply (TES): Represents domestic demand only, and is equivalent to electricity and heat generation plus the other energy sector, excluding electricity, heat and hydrogen, plus total final consumption, excluding electricity, heat and hydrogen. TES does not include ambient heat from heat pumps or electricity trade.

Total final consumption (TFC): Is the sum of consumption by the various end-use sectors. TFC is broken down into energy demand in the following sectors: industry (including manufacturing, mining, chemicals production, blast furnaces and coke ovens); transport; buildings (including residential and services); and other (including agriculture and other non-energy use). It excludes international marine and aviation bunkers, except at world level where it is included in the transport sector.

Total final energy consumption (TFEC): Is a variable defined primarily for tracking progress towards target 7.2 of the United Nations Sustainable Development Goals (SDG). It incorporates total final consumption by end-use sectors, but excludes non-energy use. It excludes international marine and aviation bunkers, except at world level. Typically this is used in the context of calculating the renewable energy share in total final energy consumption (indicator SDG 7.2.1), where TFEC is the denominator.

Traditional use of biomass: Refers to the use of solid biomass with basic technologies, such as a three-stone fire or basic improved cook stoves (ISO tier < 3), often with no or poorly operating chimneys. Forms of biomass used include wood, wood waste, charcoal, agricultural residues and other bio-sourced fuels such as animal dung.

Transport: Includes fuels and electricity used in the transport of goods or people within the national territory irrespective of the economic sector within which the activity occurs. This includes: fuel and electricity delivered to vehicles using public roads or for use in rail vehicles; fuel delivered to vessels for domestic navigation; fuel delivered to aircraft for domestic aviation; and energy consumed in the delivery of fuels through pipelines. Energy consumption from marine and aviation bunkers is presented only at the world level and is excluded from the transport sector at a domestic level.

Trucks: Includes all size categories of commercial vehicles: light trucks (gross vehicle weight < 3.5 tonnes); medium freight trucks (gross vehicle weight 3.5-15 tonnes); and heavy freight trucks (gross vehicle weight > 15 tonnes).

Unabated fossil fuel use: Fossil fuels used for energy purposes without carbon capture, utilisation and storage (CCUS). Total fossil fuel use is equal to unabated fossil fuels plus fossil fuels with CCUS plus non-energy use of fossil fuels.

Unconventional natural gas: Includes tight gas, shale gas, coalbed methane, gas hydrates and coal-to-gas products.

Unconventional oil: Includes mining and in-situ extra-heavy oil and bitumen (synthetic crudes made by upgrading bituminous, e.g., oil sands in Canada, or extra heavy crude oils, light tight oil, kerogen oil, coal-to-liquids (CTL) and gas-to-liquids (GTL) products, additives and natural gas liquids from unconventional natural gas fields.

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Useful energy: Energy available to end-users to satisfy their need for energy services. 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. See also energy services.

Value-adjusted levelised cost of electricity (VALCOE): A more complete metric to evaluate the competitiveness of power generation technologies, which includes all direct technology costs (LCOE) combined with the estimated value of three services provided to the system: energy, flexibility and capacity.

Variable renewable energy (VRE): Sources of renewable energy (usually electricity) where the maximum output of an installation at a given time depends on the availability of fluctuating environmental inputs. VRE includes a broad array of technologies such as wind power, solar PV, run-of-river hydro, concentrating solar power (where no thermal storage is included) and marine (tidal and wave).

Zero carbon-ready buildings: A zero carbon-ready building is highly energy efficient and either uses renewable energy directly or an energy supply that can be fully decarbonised, such as electricity or district heat.

Zero emissions vehicles (ZEVs): Vehicles that operate without tailpipe CO_2 emissions (battery electric, plug-in hybrids and fuel cell vehicles).

Regional and country groupings

Advanced economies: OECD regional grouping and Bulgaria, Croatia, Cyprus[1,2], Malta and Romania.

Africa: North Africa and sub-Saharan Africa regional groupings.

Asia Pacific: Southeast Asia regional grouping and Australia, Bangladesh, Democratic People’s Republic of Korea (North Korea), India, Japan, Korea, Mongolia, Nepal, New Zealand, Pakistan, The People’s Republic of China (China), Sri Lanka, Chinese Taipei, and other Asia Pacific countries and territories.[3]

Caspian: Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan.

Central and South America: Argentina, Plurinational State of Bolivia (Bolivia), Bolivarian Republic of Venezuela (Venezuela), Brazil, Chile, Colombia, Costa Rica, Cuba, Curaçao, Dominican Republic, Ecuador, El Salvador, Guatemala, Guyana, Haiti, Honduras, Jamaica, Nicaragua, Panama, Paraguay, Peru, Suriname, Trinidad and Tobago, Uruguay and other Central and South American countries and territories.[4]

China: Includes (the People's Republic of) China and Hong Kong, China.

Developing Asia: Asia Pacific regional grouping excluding Australia, Japan, Korea and New Zealand.

Emerging market and developing economies: All other countries not included in the advanced economies regional grouping.

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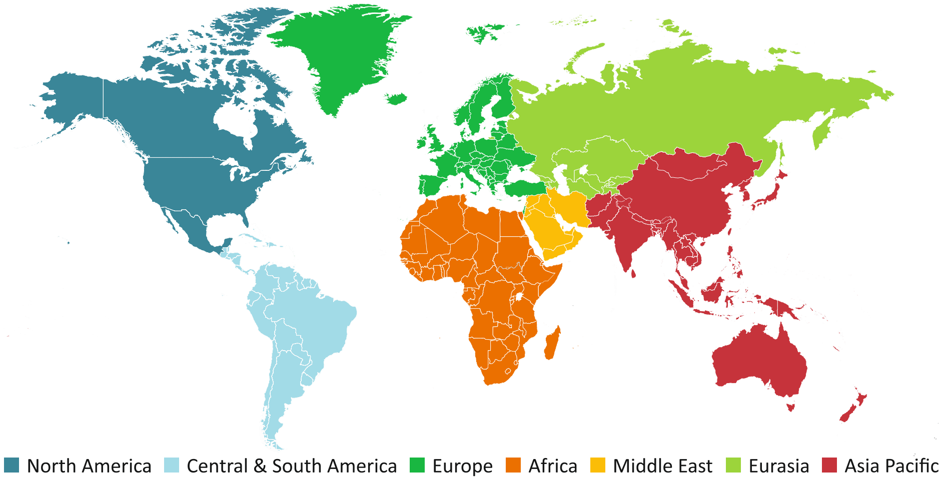
Figure C.1 ⊳ Main country groupings



Note: This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

Eurasia: Caspian regional grouping and the Russian Federation (Russia).

Europe: European Union regional grouping and Albania, Belarus, Bosnia and Herzegovina, Gibraltar, Iceland, Israel[5], Kosovo, Montenegro, North Macedonia, Norway, Republic of Moldova, Serbia, Switzerland, Türkiye, Ukraine and United Kingdom.

European Union: Austria, Belgium, Bulgaria, Croatia, Cyprus[1,2], Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain and Sweden.

IEA (International Energy Agency)**:** Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Korea, Lithuania, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Türkiye, United Kingdom and United States.

Latin America and the Caribbean (LAC)**:** Central and South America regional grouping and Mexico.

Middle East: Bahrain, Islamic Republic of Iran (Iran), Iraq, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syrian Arab Republic (Syria), United Arab Emirates and Yemen.

Non-OECD: All other countries not included in the OECD regional grouping.

Non-OPEC: All other countries not included in the OPEC regional grouping.

North Africa: Algeria, Egypt, Libya, Morocco and Tunisia.

North America: Canada, Mexico and United States.

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OECD (Organisation for Economic Co-operation and Development)**:** Australia, Austria, Belgium, Canada, Chile, Colombia, Costa Rica, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Türkiye, United Kingdom and United States.

OPEC (Organization of the Petroleum Exporting Countries)**:** Algeria, Bolivarian Republic of Venezuela (Venezuela), Equatorial Guinea, Gabon, Iraq, Islamic Republic of Iran (Iran), Kuwait, Libya, Nigeria, Republic of the Congo (Congo), Saudi Arabia and United Arab Emirates.

OPEC+: OPEC grouping plus Azerbaijan, Bahrain, Brunei Darussalam, Kazakhstan, Malaysia, Mexico, Oman, Russian Federation (Russia), South Sudan and Sudan.

Southeast Asia: Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic (Lao PDR), Malaysia, Myanmar, Philippines, Singapore, Thailand and Viet Nam. These countries are all members of the Association of Southeast Asian Nations (ASEAN).

Sub-Saharan Africa: Angola, Benin, Botswana, Cameroon, Côte d'Ivoire, Democratic Republic of the Congo, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Ghana, Kenya, Kingdom of Eswatini, Madagascar, Mauritius, Mozambique, Namibia, Niger, Nigeria, Republic of the Congo (Congo), Rwanda, Senegal, South Africa, South Sudan, Sudan, United Republic of Tanzania (Tanzania), Togo, Uganda, Zambia, Zimbabwe and other African countries and territories.[6]

Country notes

[1] Note by Republic of Türkiye: The information in this document with reference to "Cyprus" relates to the southern part of the island. There is no single authority representing both Turkish and Greek Cypriot people on the island. Türkiye recognises the Turkish Republic of Northern Cyprus (TRNC). Until a lasting and equitable solution is found within the context of the United Nations, Türkiye shall preserve its position concerning the "Cyprus issue".

[2] Note by all the European Union Member States of the OECD and the European Union: The Republic of Cyprus is recognised by all members of the United Nations with the exception of Türkiye. The information in this document relates to the area under the effective control of the Government of the Republic of Cyprus.

[3] Individual data are not available and are estimated in aggregate for: Afghanistan, Bhutan, Cook Islands, Fiji, French Polynesia, Kiribati, Macau (China), Maldives, New Caledonia, Palau, Papua New Guinea, Samoa, Solomon Islands, Timor-Leste, Tonga and Vanuatu.

[4] Individual data are not available and are estimated in aggregate for: Anguilla, Antigua and Barbuda, Aruba, Bahamas, Barbados, Belize, Bermuda, Bonaire, Sint Eustatius and Saba, British Virgin Islands, Cayman Islands, Dominica, Falkland Islands (Malvinas), Grenada, Montserrat, Saint Kitts and Nevis, Saint Lucia, Saint Pierre and Miquelon, Saint Vincent and Grenadines, Saint Maarten (Dutch part), Turks and Caicos Islands.

[5] The statistical data for Israel are supplied by and under the responsibility of the relevant Israeli authorities. The use of such data by the OECD and/or the IEA is without prejudice to the status of the Golan Heights, East Jerusalem and Israeli settlements in the West Bank under the terms of international law.

[6] Individual data are not available and are estimated in aggregate for: Burkina Faso, Burundi, Cabo Verde, Central African Republic, Chad, Comoros, Djibouti, Gambia, Guinea, Guinea-Bissau, Lesotho, Liberia, Malawi, Mali, Mauritania, Sao Tome and Principe, Seychelles, Sierra Leone and Somalia.

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Abbreviations and acronyms

AC	alternating current
AFOLU	agriculture, forestry and other land use
APEC	Asia-Pacific Economic Cooperation
APS	Announced Pledges Scenario
ASEAN	Association of Southeast Asian Nations
BECCS	bioenergy equipped with CCUS
BEV	battery electric vehicles
CAAGR	compound average annual growth rate
CAFE	corporate average fuel economy standards
CBM	coalbed methane
CCGT	combined-cycle gas turbine
CCUS	carbon capture, utilisation and storage
CDR	carbon dioxide removal
CEM	Clean Energy Ministerial
CH_4	methane
CHP	combined heat and power; the term co-generation is sometimes used
CNG	compressed natural gas
CO	carbon monoxide
CO_2	carbon dioxide
CO_2-eq	carbon-dioxide equivalent
COP	Conference of Parties (UNFCCC)
CSP	concentrating solar power
CTG	coal-to-gas
CTL	coal-to-liquids
DAC	direct air capture
DACS	direct air capture and storage
DC	direct current
DER	distributed energy resources
DFI	development finance institutions
DRI	direct reduced iron
DSI	demand-side integration
DSO	distribution system operator
DSR	demand-side response
EHOB	extra-heavy oil and bitumen
EMDE	emerging market and developing economies
EOR	enhanced oil recovery
EPA	Environmental Protection Agency (United States)
ESG	environmental, social and governance
ETS	emissions trading system
EU	European Union
EU ETS	European Union Emissions Trading System
EV	electric vehicle

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FAO	Food and Agriculture Organization of the United Nations
FCEV	fuel cell electric vehicle
FDI	foreign direct investment
FID	final investment decision
FiT	feed-in tariff
FOB	free on board
GEC	Global Energy and Climate (IEA model)
GDP	gross domestic product
GHG	greenhouse gases
GTL	gas-to-liquids
H_2	hydrogen
HDV	heavy-duty vehicle
HEFA	hydrogenated esters and fatty acids
HFO	heavy fuel oil
HVDC	high voltage direct current
IAEA	International Atomic Energy Agency
ICE	internal combustion engine
ICT	information and communication technologies
IEA	International Energy Agency
IGCC	integrated gasification combined-cycle
IIASA	International Institute for Applied Systems Analysis
IMF	International Monetary Fund
IMO	International Maritime Organization
IOC	International oil company
IPCC	Intergovernmental Panel on Climate Change
IPT	independent power transmission
LCOE	levelised cost of electricity
LCV	light commercial vehicle
LDV	light-duty vehicle
LED	light-emitting diode
LNG	liquefied natural gas
LPG	liquefied petroleum gas
LULUCF	land use, land-use change and forestry
MEPS	minimum energy performance standards
MER	market exchange rate
NDC	Nationally Determined Contribution
NEA	Nuclear Energy Agency (an agency within the OECD)
NGLs	natural gas liquids
NGV	natural gas vehicle
NOC	national oil company
NPV	net present value
NO_X	nitrogen oxides
N_2O	nitrous oxide
NZE	Net Zero Emissions by 2050 Scenario

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OECD	Organisation for Economic Co-operation and Development
OPEC	Organization of the Petroleum Exporting Countries
PHEV	plug-in hybrid electric vehicles
PLDV	passenger light-duty vehicle
PM	particulate matter
$PM_{2.5}$	fine particulate matter
PPA	power purchase agreement
PPP	purchasing power parity
PV	photovoltaics
R&D	research and development
RD&D	research, development and demonstration
SAF	sustainable aviation fuel
SDG	Sustainable Development Goals (United Nations)
SHS	solar home systems
SME	small and medium enterprises
SO_2	sulphur dioxide
STEPS	Stated Policies Scenario
T&D	transmission and distribution
TES	total energy supply
TFC	total final consumption
TFEC	total final energy consumption
TPA	tonne per annum
TPED	total primary energy demand
TSO	transmission system operator
UAE	United Arab Emirates
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
USGS	United States Geological Survey
VALCOE	value-adjusted levelised cost of electricity
VRE	variable renewable energy
WACC	weighted average cost of capital
WEO	World Energy Outlook
WHO	World Health Organization
ZEV	zero emissions vehicle
ZCRB	zero carbon-ready building

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Inputs to the Global Energy and Climate Model

General note

This annex includes references of databases and publications used to provide input data to the International Energy Agency (IEA) Global Energy and Climate (GEC) Model. The IEA's own databases of energy and economic statistics provide much of the data used in the GEC Model. These include IEA statistics on energy supply, transformation, demand at detailed levels, carbon dioxide emissions from fuel combustion and energy efficiency indicators that form the bedrock of the *World Energy Outlook* modelling and analyses.

Supplemental data from a wide range of external sources are used to complement IEA data and provide additional detail. This list of databases and publications is comprehensive, but not exhaustive. The abbreviation 'n.d.' is used for undated publications.

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The IEA's flagship *World Energy Outlook*, published every year, is the most authoritative global source of energy analysis and projections. It identifies and explores the biggest trends in energy demand and supply, as well as what they mean for energy security, emissions and economic development.

This year's *Outlook* comes against a backdrop of escalating risks in the Middle East and heightened geopolitical tensions globally, and explores a range of energy security issues that decision makers face as they proceed with clean energy transitions. With rising investment of clean technologies and rapid growth in electricity demand, the *WEO 2024* examines how far the world has come on its journey towards a safer and more sustainable energy system, and what more needs to be done to reach its climate goals.

Reflecting today's uncertainties, our three main scenarios are complemented with sensitivity cases for renewables, electric mobility, liquefied natural gas and how heatwaves, efficiency policies and the rise of artificial intelligence might affect the outlook for electricity.