World Energy Outlook 2025

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This latest edition of the International Energy Agency (IEA) flagship publication, the *World Energy Outlook (WEO)*, comes at a time when energy is increasingly at the centre of political and geopolitical tensions. Of course, the links between energy and politics have always been close, but when we look at the energy world in recent decades, there is no other time when energy security tensions have applied to so many fuels and technologies at once.

Governments are contending with a formidable array of potential threats, vulnerabilities, dependencies and uncertainties spanning areas such as oil, natural gas, electricity, energy infrastructure, critical minerals, technology supply chains, data centres and AI, and more.

Energy security today is truly a matter of economic and national security – and safeguarding it requires the same spirit of cooperation and focus that governments showed when the IEA was created after the 1973 oil shock.

Take, for example, critical minerals, which are a major theme of this *WEO* but also reflect the broader role of the IEA on issues of energy security, where we move quickly to identify and address emerging vulnerabilities.

The IEA was the first to highlight the risks of high concentration of critical mineral supplies, especially in refining and processing. Today, a single country is the leading refiner for 19 out of 20 energy-related strategic minerals. As we pointed out in our landmark report on the subject in 2021, reliance on a small number of suppliers raises the risks of supply disruptions or economic coercion.

Over the past few years, the IEA has invested heavily in building up our global data and analytical capabilities in critical minerals, mirroring the world-leading capacities that we have across other parts of the energy sector, and setting up a Critical Minerals Security Programme. The topic was also a major focus at our Summit on the Future of Energy Security, held in London partnership with the UK government in April 2025.

Today, the risks that we identified in 2021 are no longer a theoretical concern; they have become a hard reality. The implications spread across different energy technologies but also apply to other strategic sectors such as energy, automotive, AI and defence. They affect millions of jobs. As we highlight again in this *Outlook*, urgent action is needed both in the near term to strengthen preparedness against potential disruptions, and over the longer term to diversify supply chains and reduce structural risks. All of this shows how the IEA's analysis transfers across into real-world impact.

There are many other aspects of this *Outlook* that also have real operational implications for energy policymakers. The focus on electricity security; the countries like India, Indonesia and Brazil that are increasingly shaping energy market trends; the sea change in gas markets that is on the horizon with the new wave of liquefied natural gas (LNG), led by the United States.

We also highlight, once again, two critical areas where the world is clearly falling short: universal energy access and climate change. Both of these have been longstanding focus areas for the IEA and the *WEO* for decades. We present a new pathway in this year's *WEO* for enabling everyone around the world to benefit from the advantages of electricity connections and modern cooking stoves – advantages that many of us take for granted. This builds on the momentum created by the landmark Summit on Clean Cooking Africa that the IEA and our partners organised in Paris in May 2024.

And we highlight once again that, far from limiting global warming to 1.5 °C or well below 2 °C, we are currently heading towards outcomes in the range of 2.5-3 °C, with severe implications for lives and livelihoods around the world. There are still pathways that mitigate these risks significantly, while the options to reduce emissions substantially are well understood and, in many cases, cost effective.

I would like to warmly thank the team of IEA colleagues who worked extremely hard on this new *WEO* under the outstanding leadership of my colleagues Laura Cozzi and Tim Gould. More than ever, the world needs clear data and analysis to help navigate a complex and dangerous world. The *WEO* has always fulfilled that vital role and I am very glad and proud that it remains in that role today.

Dr Fatih Birol
Executive Director
International Energy Agency

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More information about the *World Energy Outlook* is available at iea.li/WEO2025.

Annexes

In a volatile world, energy security takes centre stage

Pressing threats and longer term hazards are elevating energy to a core issue of economic and national security. Energy is at the heart of today's geopolitical tensions, with traditional risks to fuel supply now accompanied by restrictions affecting supplies of critical minerals. The electricity sector – so essential to modern economies – is also increasingly vulnerable to cyber, operational and weather-related hazards. Decisions taken by energy policy makers will be crucial to address these risks, but they do so against a complex backdrop:

- **Geopolitical fragility coexists with subdued oil prices**. Ongoing conflicts and instability sit alongside oil market balances showing a large surplus of supply over demand.
- **Countries are prioritising energy security and affordability but are reaching for different levers to achieve them**. Some, including many fuel-importing countries, lean towards renewables and efficiency as solutions. Others focus more on ensuring ample supplies of traditional fuels.
- **There are fractures in the international system and uncertainties over the outlook for trade, but energy trade is more important than ever.** Abundant supplies of oil, solar panels, batteries and, before long, liquefied natural gas (LNG) create strong incentives for producers to seek out international markets.
- **There is less momentum than before behind national and international efforts to reduce emissions, yet climate risks are rising**. 2024 was the hottest year on record and the first in which global temperatures exceeded 1.5 degrees Celsius (°C) above pre-industrial levels.

At the same time, the world remains thirsty for energy. New technologies are entering the system at speed, and renewables set new records for deployment in 2024 for the 23rd consecutive year. Oil, natural gas and coal consumption, and nuclear output, all reached record highs as well. Driven mainly by China, since 2019 demand for coal has grown 50% faster than the next fastest growing fossil fuel, natural gas, a key reason why energy-related emissions have continued to grow.

There is no single storyline about the future of energy, which is why the *World Energy Outlook* presents multiple scenarios, none of which is a forecast. The framework presented in this *Outlook* is based on the latest and most comprehensive data on policies, technologies and markets, together with rigorous modelling. This allows readers to explore the implications of different choices and pathways.

Scenarios

The *World Energy Outlook 2025* (*WEO-2025*) has three main scenarios. Two of these set starting conditions and then examine where they lead – the Current Policies Scenario (CPS) and the Stated Policies Scenario (STEPS). A third, the Net Zero Emissions by 2050 (NZE) Scenario, maps out a pathway to achieve specific energy and climate-related goals.

- The **Current Policies Scenario** considers a snapshot of policies and regulations that are already in place and offers a cautious perspective on the speed at which new energy technologies are deployed and integrated into the energy system.

- The **Stated Policies Scenario** considers the application of a broader range of policies, including those that have been formally put forward but not yet adopted, as well as other official strategy documents that indicate the direction of travel. Barriers to the introduction of new technologies are lower than in the CPS, but the STEPS does not assume that aspirational targets are met.
- The **Net Zero Emissions by 2050 Scenario** takes a different approach, describing a pathway to reduce global energy-related carbon dioxide (CO_2) emissions to net zero by 2050, while recognising that each country will have its own route.

An additional normative scenario, the **Accelerating Clean Cooking and Electricity Services Scenario** (ACCESS), provides a new roadmap to achieve universal access to electricity and clean cooking – crucial development goals that the IEA has actively supported for more than two decades. The *WEO-2025* does not include the Announced Pledges Scenario, which models a future for the energy system in which key national energy and climate targets, such as countries' nationally determined contributions (NDCs), are achieved in full and on time. Our assessment of the new round of NDCs that were due this year, generally covering the period to 2035, will follow once there is a more complete picture of these commitments.

What do the *WEO* scenarios allow us to assert with confidence about the future? Our scenarios cover a wide range of trajectories, highlighting different opportunities and vulnerabilities, but there are common elements. Most fundamentally, as economies expand and populations and incomes grow, each scenario sees the world's need for energy services increase with demand rising for mobility; for heating, cooling, lighting and other household and industrial uses; and increasingly for data and artificial intelligence (AI)-related services. Beyond this, four other commonalities stand out: the changing nature of energy security, with the supply of critical minerals as an acute vulnerability; the arrival of the Age of Electricity; a shift in the centre of gravity of the energy system towards India and other emerging economies beyond China; and a rising role for renewables, accompanied by the comeback of nuclear energy.

Serious threats are hanging over critical minerals supply chains

Traditional hazards affecting the security of oil and gas supply are now accompanied by vulnerabilities in other areas, most visibly in critical minerals supply chains. These new dimensions to energy security have been a consistent focus for the International Energy Agency. They were central to our Summit on the Future of Energy Security in London in 2025 and have been underscored by China's new export controls on rare earth elements and battery components and technologies. The key risk for critical minerals is high levels of market concentration. A single country is the dominant refiner for 19 out of 20 energy-related strategic minerals, with an average market share of around 70%. The minerals in question are vital for power grids, batteries and electric vehicles (EVs), but they also play a crucial role in AI chips, jet engines, defence systems and other strategic industries. As of November 2025, more than half of these strategic minerals are subject to some form of export controls.

Fostering more diverse and resilient supply chains for critical minerals will take a concerted policy effort; market forces alone will not deliver. Since 2020, most of the growth in refined production of key energy minerals came from the leading suppliers. As a result, geographic concentration in refining increased for nearly all key energy minerals, and particularly for nickel and cobalt. Our analysis of announced projects suggests that reversing this process is set to be slow. In the CPS, supply concentration would be likely to remain higher than in the STEPS, as weaker minerals demand translates into lower prices that favour incumbent producers with lower costs. Determined action is required today to enhance preparedness against potential disruptions, and over the longer term to build up new partnerships and projects that diversify supply chains more quickly.

Resilience is key in a world of growing security risks

There is also an urgent need to build greater resilience to rising weather-related risks, cyberattacks and other malicious activity targeting critical infrastructure. A new IEA dataset shows that recent annual operational disruptions to critical energy infrastructure affected energy supplies to more than 200 million households around the world. Droughts constrain output from hydropower and some thermal generators, while storms, floods and wildfires force shutdowns and damage different types of energy facilities, from solar plants to offshore oil and gas facilities. Power lines are particularly vulnerable: transmission and distribution grids were affected in about 85% of incidents. Weather-related risks are set to rise across our scenarios, which all exceed 1.5 °C warming on a regular basis by around 2030, diverging only after 2035.

The Age of Electricity is here

Electricity is at the heart of modern economies and electricity demand grows much faster than overall energy use in all scenarios. It rises by around 40% to 2035 in both the CPS and the STEPS, and by more than 50% in the NZE Scenario. Demand growth comes in varying proportions from appliances and air conditioners, advanced manufacturing and other light industries, electric mobility, data centres and electrified heating. Investors are reacting to this trend: spending on electricity supply and end-use electrification already accounts for half of today's global energy investment. Rising electricity use means that electricity prices are becoming a key reference point for consumers and policy makers. For the moment, electricity accounts for only 21% of total final consumption globally, but it is the key source of energy for sectors accounting for over 40% of the global economy and the main source of energy for most households. This underscores the importance of secure and affordable electricity supply, and the economic and social costs of blackouts such as those seen in 2025 in Chile and the Iberian Peninsula.

A pivotal issue for electricity security in the Age of Electricity is the speed at which new grids, storage and other sources of power system flexibility are put in place. For the moment, some of these elements are lagging. Investments in electricity generation have charged ahead by almost 70% since 2015 to reach USD 1 trillion per year, but annual grid spending has risen at less than half the pace to USD 400 billion. This increases congestion, delays the connection of new sources of electricity generation and demand, and pushes up electricity prices. Curtailment of wind and solar output is on the rise, as are incidences of negative pricing in wholesale markets, but slow permitting is holding back grid projects, as are tight markets for transformers and other components. Risks have been mitigated in part by the rise of battery storage, where annual additions rose to more than 75 gigawatts (GW) in 2024, but batteries cannot provide all the answers – especially where seasonal flexibility needs rise alongside short-term ones.

Rising incomes and temperatures underpin a surge in electricity use for air conditioning. Cooling is a rising source of electricity demand in all scenarios, led by emerging and developing economies, with important potential impacts on peak electricity demand. In the STEPS, for example, income-driven air conditioning use adds around 330 GW to global peak demand by 2035, and higher temperatures add another 170 GW. The efficiency of new air conditioners is a critical factor for managing future strains on power systems. In all markets, there are already much more efficient air conditioners available on the shelves, at no or modest additional cost, than the average models being bought today.

Explosive growth in electricity demand for data centres and AI is concentrated in advanced economies and China. Investment in data centres is expected to reach USD 580 billion in 2025. Those who say that "data is the new oil" will note that this surpasses the USD 540 billion being spent on global oil supply. A tripling of the amount of electricity consumed by data centres by 2035 represents less than 10% of total global electricity demand growth, but it is highly concentrated geographically. More than 85% of new data centre capacity additions over the next ten years are expected in the United States, China and the European Union – and many are located near existing data centre clusters, putting additional strain on congested grids.

New players set the trends as demand for energy services continues to rise

Energy market dynamics are increasingly shaped by a group of emerging economies, led by India and Southeast Asia and joined by countries in the Middle East, Latin America and Africa. Collectively, they take up the baton from China – which accounted for more than half of global oil and gas demand growth and 60% of electricity demand growth since 2010 – although no country comes close to replicating China's energy trajectory on its own. This shift in the centre of gravity of the energy system is reflected in multiple indicators. For example, between 2000 and 2010, advanced economies accounted for half of the growth in the global car fleet; in the decade that followed, China alone did the same. Between today and 2035, half of the growth in the global car fleet comes from emerging and developing economies outside China.

Mapping the new geography of demand onto the distribution of global energy resources reveals that, by 2035, 80% of energy consumption growth occurs in regions with high-quality solar irradiation. This is a sharp contrast with the past decade when medium- to low-solar regions drove half of the growth. This helps explain the swift uptake of solar technologies in our scenarios, as well as the rise in demand for cooling. Many of the new demand centres in Asia have some domestic coal resources and rely on imported oil and gas.

The continued rise of renewable energy

The pace varies, but renewables grow faster than any other major energy source in all scenarios, led by solar photovoltaics (PV). In the CPS, where they face stronger headwinds, renewables still meet the largest share of total energy demand growth, followed by natural gas and oil, even though annual solar PV additions in the power sector stall at around today's levels of 540 GW to 2035. In the STEPS, policy changes mean that the United States has 30% less renewables capacity installed in 2035 than in last year's *Outlook*, but at the global level renewables continue their rapid expansion. A boom in solar deployment is accompanied by robust growth across wind, hydropower, bioenergy, geothermal and other technologies, and by improvements in energy efficiency. China continues to be the largest market for renewables, accounting for 45-60% of global deployment over the next ten years across the scenarios, and remains the largest manufacturer of most renewable technologies.

Ample production capacity of solar panels and batteries, much of it in China, keeps prices competitive, but also raises concerns in some markets. In 2024, there was sufficient manufacturing capacity to have produced more than twice as many solar PV modules as were actually deployed, and almost three-times as many battery cells. China's exports of new energy technologies, including EVs, have grown to account for nearly 5% of its total goods exports, and Chinese companies have been investing in manufacturing facilities abroad in Indonesia, Morocco, Hungary, Brazil and elsewhere. While some countries, notably developing economies, see a major opportunity to access cost-competitive technologies, there are also concerns about China's dominance of these new value chains. A key question is what happens to this surplus capacity in the context of trade barriers, demand-side uncertainties, substantial pressures on technology prices, and falling profit margins for some producers.

Nuclear power is making a comeback

Another common element across scenarios is the revival of fortunes for nuclear energy, with investment rising in both traditional large-scale plants and new designs, including small modular reactors (SMRs). More than 40 countries now include nuclear energy in their strategies and are taking steps to develop new projects. In addition to reactors that are restarting operation, notably in Japan, there are more than 70 GW of new capacity under construction, one of the highest levels in 30 years. Innovation, cost control and greater visibility on future cash flows is essential to diversify a sector that has been characterised by high market concentration, including for construction, uranium production and enrichment services. Technology companies are supporting the emergence of new business models, with agreements and expressions of interest for 30 GW of SMRs, mainly to power data centres. With these developments, after more than two decades of stagnation, global nuclear power capacity is set to increase by at least one-third to 2035.

Diverging pathways for the energy mix

Along with some commonalities, the scenarios diverge in the ways in which energy needs are met, reflected in differing outlooks for oil, natural gas and coal. In the CPS, demand for oil and natural gas continue to grow to 2050, although coal starts to fall back before the end of the current decade. In the STEPS, the peak in coal demand is accompanied by a flattening in oil use around 2030. However, in contrast to last year's *Outlook*, gas demand continues growing into the 2030s, due mainly to changes in US policies and lower gas prices. In the NZE Scenario, much swifter deployment of a range of low-emissions technologies brings consequent declines in demand for all the fossil fuels. Although underlying demand for energy services is similar across the scenarios, the amount of energy required to meet it varies significantly. In the CPS, the world's energy demand rises by 90 exajoules (EJ) to 2035 (a 15% increase from today). In the STEPS, it rises by around 50 EJ, or 8%. In an NZE world, it declines. These variations reflect differences in the energy mix and in the technical efficiency of appliances and equipment. More electrified and renewables-rich pathways also use less energy by avoiding waste heat from fuel combustion.

Twists and turns for oil markets and EVs

Oil markets look well supplied in the near term, thanks to a quintet of producers in the Americas – the United States, Canada, Guyana, Brazil and Argentina – and muted demand growth, but today's downward pressures on prices do not last long in the CPS. Underlying declines in production from existing fields and continued growth in consumption run through today's overhang of oil supply relatively quickly. Some 25 million barrels per day (mb/d) of new oil supply projects are needed to 2035 in this scenario to keep markets in balance, and oil prices rise from today's levels to incentivise the additional upstream projects.

EVs are set to account for more than 25% of new car sales globally in 2025 and battery costs have fallen dramatically, but the journey ahead for EV sales and oil demand could take several routes. In the STEPS, we have revised down EV growth projections in advanced economies compared with last year, notably in the United States. Nonetheless, the share of EVs in new car sales rises above 50% by 2035, and oil demand levels off around 2030 at 102 mb/d before starting a slow decline. In the CPS, the share of EVs in total car sales plateaus after 2035 at around 40%, and petrochemical feedstocks, aviation and trucks underpin growth in oil demand out to 113 mb/d in 2050. The NZE Scenario sees much faster electrification of the vehicle fleet, with much stronger implications for oil use.

LNG looking for accommodation

Final investment decisions for new LNG projects have surged in 2025, adding to the expected wave in natural gas supply in coming years and promising lower international prices. Since Russia's cut to pipeline deliveries to Europe, LNG has become the preferred way of trading gas over long distances, reshaping global gas trade and bolstering energy security. There is now an unprecedented 300 billion cubic metres (bcm) of new annual LNG export capacity scheduled to start operation by 2030, a 50% increase in available global LNG supply. Around half is being built in the United States, and a further 20% in Qatar, followed by Canada and others.

Natural gas demand has been revised up in this year's STEPS, but questions still linger about where all the new LNG will go. Europe and China, the main destination for new LNG supply over the past decade, are set to take some of the new volumes, but the upside potential is limited in the STEPS by continued momentum behind the deployment of renewables, nuclear energy in some countries, and efficiency policies. As a result, lower priced LNG flows to other parts of the world where affordability is a key consideration, notably India and other parts of South and Southeast Asia. The response in these price-sensitive markets is significant but not enough to use all of the available LNG supply in the STEPS, resulting in a 65 bcm overhang in 2030. This could be cleared by further coal-to-gas switching, but the prices needed to do so are difficult for LNG exporters to match. In the CPS, a slower pace of transitions sees more LNG going to China and Europe, fully absorbing the coming wave of LNG supply and keeping prices higher. In the NZE Scenario, a concerted focus on bringing down global emissions constrains the space for natural gas. In all scenarios, a downside risk to the uptake of natural gas and LNG is a failure by the industry to reduce methane leaks.

The storyline for coal will be written in Asia

More than for any other fuel, the dynamics in coal markets are determined by a handful of major emerging and developing economies, with China by far the most significant, followed by India, Indonesia and other countries in Southeast Asia. Around half of global coal demand is used for electricity generation in these economies, and the outlook for coal depends to a great extent on their needs for electricity, whether the current momentum behind renewables is sustained, and whether gas can be priced competitively enough to make inroads. In the STEPS, renewables capacity additions in emerging and developing economies average more than 600 GW per year to 2035. This is enough to put global coal demand into steady decline, a trend that is even more pronounced in the NZE Scenario. The CPS highlights what happens if grid integration challenges are high and solar and wind deployment stagnates. In this scenario, coal demand is higher and falls more slowly.

Access to modern energy remains a core challenge, but there is a way forward

Today, around 730 million people still live without electricity, and nearly 2 billion – one-quarter of the global population – rely on cooking methods that are detrimental to human health. Countries such as India, Indonesia and China have shown how ambitious policies and large-scale programmes can transform the outlook, but less progress has been made elsewhere, notably in large parts of sub-Saharan Africa. As things stand, the world is not on track to close this huge gap in the provision of modern energy. The new IEA ACCESS outlines a country-by-country pathway to universal access, reaching this milestone in 2035 for electricity and 2040 for clean cooking. It draws on lessons about what has worked best and the renewed momentum to tackle this longstanding issue, including the IEA 2024 Summit on Clean Cooking in Africa. More than half of the population without access to electricity or clean cooking lives in countries that recently upgraded policies or launched new initiatives in these areas. In our new scenario, LPG underpins most new clean cooking access, increasing its use to around 3.4 mb/d in residential cooking in 2040. At the same time, an average of 80 million people gain access to electricity each year to 2035, with rapid parallel deployment of grids, mini-grids and stand-alone systems.

Diverging futures for global emissions and climate change

Annual global energy-related CO_2 emissions reached a record 38 gigatonnes (Gt) **in 2024 and in the CPS they remain around this level, meaning that by 2050 they are some 10 Gt lower than when we last modelled this scenario in 2019; in the STEPS, emissions fall back below 30 Gt by mid-century.** These trajectories point towards a temperature increase in the CPS of almost 3 °C in 2100, compared with a 2.5 °C outcome in the STEPS. In the updated NZE Scenario, continued high emissions in recent years and sluggish deployment in some areas mean that emissions reductions to 2030 are slower than in previous editions. Reflecting these trends, overshoot of the 1.5 °C target is now inevitable. Peak warming in the NZE Scenario exceeds 1.5 °C for several decades, returning below 1.5 °C by 2100 thanks to a very rapid transformation of the energy sector and to widespread deployment of CO_2 removal technologies that are currently unproven at large scale.

A pathway that mitigates the most severe risks from climate change remains feasible and there is strong momentum behind key technologies, but – ten years on from the signature of the Paris Agreement – some formal country-level commitments have waned. The United States has withdrawn from the Paris Agreement and the new round of NDCs announced to date in 2025 do little, in aggregate, to move the needle beyond the outcomes already projected in the STEPS. Total energy-related emissions from countries that have already submitted new NDCs, as of November 2025, were around 20 Gt in 2024. Full implementation of their NDCs would see their emissions fall to 15-17 Gt by 2035, a reduction of 11-25% – this is aligned with the outcomes in the STEPS. There are signs that some countries, notably China, are committing to NDCs that can comfortably be exceeded in practice.

Options to reduce emissions substantially are well understood and, in many cases, cost effective. They include actions to boost the uptake of wind, solar, hydropower, geothermal, nuclear power and other low-emissions technologies; to improve energy efficiency; to reduce methane emissions; to increase the electrification of end-uses; and to use sustainable fuels like low-emissions hydrogen or technologies like carbon capture, utilisation and storage in cases where electrification is not practicable. The STEPS gets close to achieving the tripling in renewables capacity by 2030 targeted at COP28, with a rise to 2.6-times 2022 levels. However, the annual rate of efficiency improvement in this scenario, at 2%, is a long way from the 4% target agreed as part of the UAE Consensus. Implementing these actions at scale would require an intensified international push to increase transition-related investment in emerging and developing economies, and much more practical efforts to ensure that these investments deliver tangible near-term social and economic benefits.

Mapping out the key choices

Urgent energy security challenges are front and centre for today's energy policy makers, requiring the same spirit and focus that governments showed when they created the IEA after the 1973 oil shock. Their responses need to consider the synergies and trade-offs that can arise with other policy goals, on affordability, access, competitiveness and climate change. Policy makers are reaching different conclusions about the right balance to strike, the course of action that can best improve the lives of their citizens. Our scenarios do not aim to provide all the answers. But they illustrate the key decision points that lie ahead and, together, provide a framework for evidence-based, data-driven discussion over the way forward.

PART A
CONTEXT AND KEY FINDINGS

Part A of the *World Energy Outlook* gives an overview of some of the central findings from this year's energy projections, frames them within a wider context, and describes the scenarios that underlie them.

Chapter 1 sets out the key implications of different scenarios for demand, for the energy mix and for emissions. It also examines the effects of these scenarios on energy markets and energy security, and explores their implications for energy access and affordability.

Chapter 2 examines trends in energy, economics and geopolitics that are shaping the global energy outlook. It also describes each of the scenarios, sets out the key assumptions that drive them, and explores some of the most important ways in which they differ.

Overview and key findings

Ten questions on the future of energy

SUMMARY

- The Stated Policies Scenario (STEPS) and the Current Policies Scenario (CPS) present two views on how the energy system may evolve, building on different assumptions regarding today's policies and technologies. Both scenarios see continued increases in energy demand to 2050, albeit at different speeds, with emerging market and developing economies driving the increase, led by India and Southeast Asia.
- Differences in the pace at which new technologies are brought into the energy system are reflected in the trajectories for fossil fuels. In the CPS, oil and natural gas demand continue to grow to mid-century, although coal goes into decline before 2030. In the STEPS, coal use peaks earlier than in the CPS and oil demand flattens by the end of the decade, but natural gas demand continues to grow into the 2030s, as a wave of new liquefied natural gas (LNG) exports brings downward pressure on prices.
- The emissions trajectory in the CPS is consistent with warming of almost 3 °C by 2100, whereas lower levels of emissions in the STEPS keep this to around 2.5 °C, slightly higher than the 2024 version of the STEPS. In the Net Zero Emissions by 2050 (NZE) Scenario, warming peaks around 2050 at about 1.65 °C and declines slowly after that, largely due to active measures to remove CO_2 from the atmosphere. The resilience of energy infrastructure in the face of extreme weather and other hazards is becoming more critical.
- Electricity plays a growing role in meeting energy service demand in all scenarios, supplied with rising shares of generation from renewables. Peak electricity demand rises around 40% by 2035 in the STEPS, with similar trends in the other scenarios, largely due to increased demand for cooling. Data centres and AI account for less than 10% of global growth in electricity demand, but this is a larger factor in the United States where a large share of new data centres are located.
- Today, around 730 million people still live without electricity, and nearly 2 billion rely on polluting cooking methods. As things stand, the world is not on track to close this huge gap in the provision of modern energy. Our new analysis draws on lessons from countries that have achieved rapid progress and outlines a new pathway to universal access, reaching this milestone in 2035 for electricity and 2040 for clean cooking.
- The nature of energy security is changing; traditional risks have not gone away but electricity and critical mineral security are rising as key priorities. Grids, storage, dispatchable generation, demand-side flexibility and close attention to the quality of grid operation are pivotal for electricity security. In critical minerals the key challenge is supply concentration, particularly in the refining sectors where a single country has an average market share of 70% in 19 out of 20 strategic energy-related minerals.

Introduction

The last several years have been a period of extreme volatility and uncertainty, with the worst pandemic since the 1920s, the worst energy crisis since the 1970s, rapid technological change in and beyond the energy sector, increasingly visible effects of climate change, and increasingly complex geopolitics. Governments are responding in different ways to these challenges, but many are prioritising affordability, competitiveness and energy security. These are all goals which present both synergies and trade-offs with energy transitions.

The scenarios included in the *World Energy Outlook* (*WEO*) provide a framework for evaluating the choices that energy decision makers face and the potential consequences of those choices for the global energy system. Change in such a complex system is driven by multiple factors:

- *Macroeconomic and financial conditions* like interest rates, inflation and the rate and structure of gross domestic product (GDP) growth affect energy demand, investment decisions and the relative attractiveness of different technologies.
- *Energy policies* shape the incentives faced by investors, energy companies and consumers. Policies profoundly influence outcomes, although they do not determine them. They can be overachieved, underachieved, repealed or strengthened. The extent to which they are successful depends on many things, including their legal form, their level of specificity, the incentives on offer, and the way they are implemented.
- *Investor strategies and capital market incentives* influence investment across the energy sector. For example, the availability of capital to support the early development of the shale sector in the United States was instrumental in shaping the supply trajectory, and the way the capital market has more recently encouraged greater capital discipline has had a similarly powerful effect.
- *Innovation and technology progress* occur in response to policies but also independently. Technologies can always surprise: artificial intelligence (AI) as a major driver of electricity demand was not on the radar several years ago. Innovations can spill over from one sector to another, as with semiconductor and solar photovoltaics (PV) manufacturing, or shale production and advanced geothermal.
- *Non-energy policies, trade and geopolitical trends* have important consequences for the energy sector. The energy shocks of the 1970s turbo-charged efforts to improve energy efficiency, led to the first national research and development programmes in technologies like solar PV, and accelerated the deployment of commercial nuclear power. In more recent times, sanctions, tariffs and stockholding strategies have all also influenced energy markets.
- *Consumer preferences, biases and cultural trends* influence the kinds of energy-consuming equipment consumers buy and the ways in which they use them. Consumers are not pure cost-optimisers.

Capturing all this complexity is a daunting task for any forward-looking *Outlook*, but these factors all feature in the design and modelling of our scenarios. None of these scenarios are forecasts: instead, they provide a way to explore the drivers and implications of different pathways. As such, we hope they provide a valuable guide for policy makers, investors and companies as they navigate an uncertain future.

This chapter explores the key findings of the *WEO-2025* by considering ten key questions about the future:

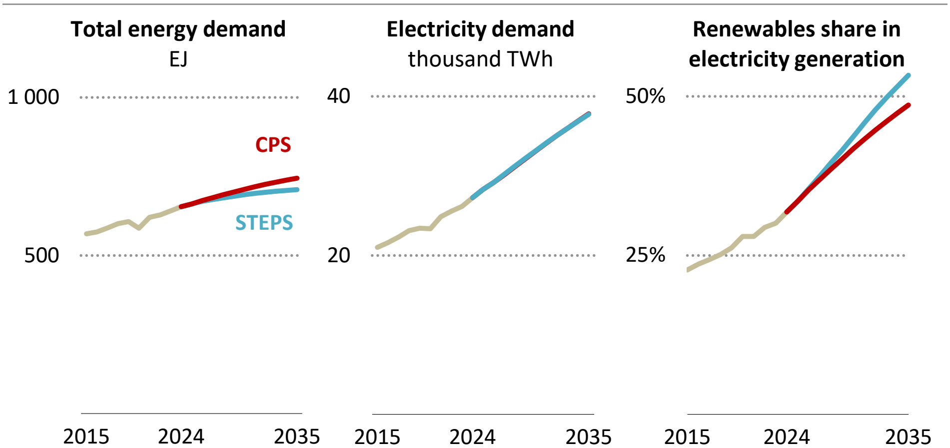
1. Two of the IEA scenarios, the Current Policies Scenario and the Stated Policies Scenario, are exploratory in that they work forwards from slightly different starting assumptions; what do these scenarios tell us about the direction that the energy world is heading?
2. What are the implications of all the IEA scenarios for energy-related emissions and the rise in global average temperatures, and what does this imply for the discussions at COP30 in Belém, Brazil?
3. Examining recent energy history can help to understand some distinctive aspects of the future: how are the drivers of global energy demand in the coming decades different from those in the past?
4. Electricity prices are a sensitive topic for consumers and policy makers alike: what does the prospective Age of Electricity mean for energy affordability?
5. Artificial intelligence will have implications for all parts of our economies and societies: how much difference will AI and our thirst for data make to the future of energy?
6. After some difficult years during the pandemic and the global energy crisis, there is a growing effort to regain momentum on energy access: what more needs to be done to provide universal, affordable access to electricity and clean cooking?
7. Export controls on rare earth elements in 2025 have highlighted the importance of these new dimensions to energy security: how are critical minerals and other emerging issues changing the energy security landscape?
8. Investors and project developers, led by the United States, have continued to approve multiple new export projects for liquefied natural gas (LNG) in 2025: where will all this LNG go?
9. As things stand, there is ample underutilised manufacturing capacity for many clean energy technologies, especially solar PV and batteries, and much of this is in China: will the world use it?
10. Answers to many of the biggest questions about the future will depend on investment: what do our energy investment projections tell us about potential gaps and risks?

1.1 Which way is the energy world heading?

1.1.1 Electricity and emerging market and developing economies drive energy expansion

The Stated Policies Scenario (STEPS) and the Current Policies Scenario (CPS) represent two distinct views on how the energy system may evolve, building on different assumptions regarding today's policies and technologies (Box 1.1). However, in some respects they reveal similar outcomes. Both scenarios see continued increases in energy demand as a larger and richer global population demands more energy services. In the STEPS, total energy demand increases by around 55 exajoules (EJ) to 2035, an 8% increase over today's level. In the CPS, it grows faster, rising by 90 EJ by the same year, or 14% (Figure 1.1). Energy service demand is broadly the same across the two scenarios: the rise in energy demand differs between them because of differences in the efficiency of technologies and fuels. Around 60% of the difference is due to increased use of fossil fuels in electricity generation and transport in the CPS, which leads to higher energy loss as waste heat. Stronger efficiency policies in the STEPS also limit energy demand growth relative to the CPS.

Figure 1.1 ⊳ Total energy demand, electricity demand, and renewables in electricity generation by scenario, 2015-2035



Electricity demand outpaces total energy demand growth by a wide margin; renewables account for an increasing share of surging electricity demand

Note: EJ = exajoule; TWh = terawatt-hour. CPS = Current Policies Scenario; STEPS = Stated Policies Scenario.

In both scenarios, emerging market and developing economies drive nearly all the increase in global energy demand. Energy demand in advanced economies remains below its 2007 peak through to 2035 in both scenarios. Energy demand in emerging market and developing economies rises by around 15% to 2035 in the STEPS and by 20% in the CPS. In the last decade, the People's Republic of China (hereinafter China) accounted for more than half of the demand growth outside advanced economies. However, as China's economy matures, both scenarios see a slowdown in its demand growth. India, Southeast Asia and other developing economies become the main drivers of the increase in global energy demand.

Electricity plays an increasingly important role in the functioning of modern economies, powering advanced manufacturing, high value-added services, the digital economy and AI. In the last decade, electricity demand increased two-times faster than overall energy demand. Both the CPS and the STEPS project electricity demand reaching essentially the same level in 2035, around 37 800 terawatt-hours (TWh). This represents an increase of 40% from today's level and an acceleration of the pace of growth compared to the past decade. The drivers behind this increase vary by scenario: the electrification of new end-uses such as transport and space heating proceeds more slowly in the CPS than in the STEPS, but this effect is offset by slower increases in energy efficiency in the CPS in high growth areas such as space cooling and data centres.

A decade ago, renewables accounted for around one-fifth of electricity generation worldwide. That has now risen to about one-third, reflecting cost reductions in renewable energy technologies and policy support in many markets. The share of renewables in electricity generation increases in both scenarios. However, the speed of the increase in the CPS is slower than in the STEPS as grid integration challenges mount and policy support is not extended after stipulated end-dates. The STEPS, on the other hand, sees the share of renewables in total electricity generation continue to accelerate, and it reaches nearly 55% by 2035. Despite the growth of renewables in both scenarios, neither manages to lower energy-related emissions sufficiently to avoid severe risks from a changing climate (section 1.2).

Box 1.1 ▷ Two views on the outlook for the global energy system

Multiple factors influence the evolution of the energy sector: macroeconomic trends; energy and other policies; technologies and markets; and consumer preferences. Policies are a critical differentiating factor in our two exploratory scenarios: the Current Policies Scenario (CPS) and the Stated Policies Scenario (STEPS). Yet, policies are generally only a partial guide to the direction of travel. They are sometimes imprecise, can have unintended consequences, and are subject to change. They can be met, exceeded or underachieved; they can also be repealed or strengthened.

Neither scenario targets any particular outcome, and both are grounded in a detailed analysis of the latest policies, market trends and technology developments. The differences in outcomes between them can be traced to slightly different starting assumptions, which affect how they project the energy system evolving.

- The **Current Policies Scenario** builds on a narrow reading of today's policies, taking only those that are adopted in legislation and regulation. It offers a generally cautious perspective on the speed at which new energy technologies are deployed and integrated into the energy system. It tends to project slower growth in the adoption of new technologies in the energy system than seen in recent years, or than projected in the STEPS. Consequently, the CPS projects a somewhat bigger continuing role for traditional fuels.
- The **Stated Policies Scenario** builds on a broader reading of the policy landscape, taking account of those that have been formally tabled but not yet adopted as well as of other official strategy documents that indicate the desired direction of travel. It does not, however, assume that aspirational targets are met. It offers a more dynamic perspective on energy technology and market trends, and it projects a slightly more rapid introduction of new energy technologies than the CPS.

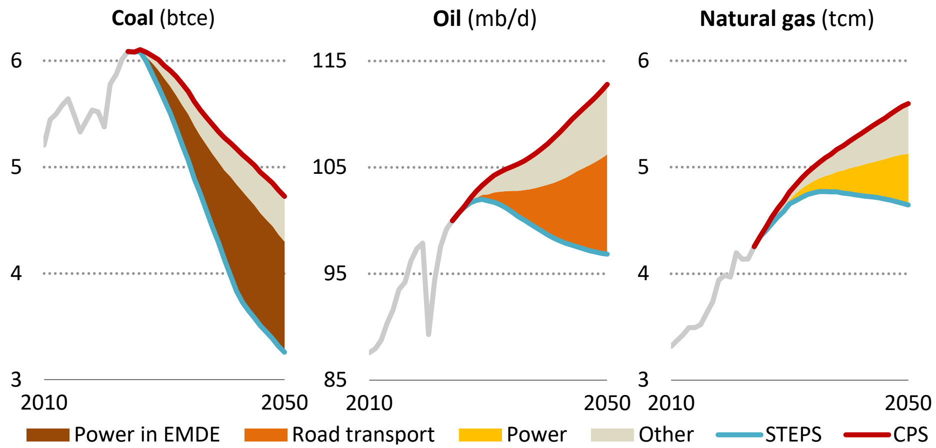
1.1.2 Do we still see demand peaks for coal, oil and natural gas?

Demand for the three fossil fuels follows contrasting trajectories in the STEPS and the CPS. In each case, one major factor helps to explain the difference (Figure 1.2).

Most global coal demand, 55%, comes from electricity generation in emerging market and developing economies, largely China. The outlook for global coal demand accordingly depends to a great extent on whether the current momentum on renewables is sustained. In the STEPS, renewables capacity additions average 620 gigawatts (GW) per year to 2035 in emerging market and developing economies, compared with 515 GW in 2024. This is sufficient to put global coal demand into a decline this decade. In the CPS, less policy support and higher assumed grid integration challenges result in slower renewables growth than in the STEPS. As a result, coal demand is higher, peaks later and declines more slowly in the CPS. In both cases, however, global coal demand starts to fall before the end of this decade.

Road transport accounts for around 45% of global oil demand. The future level of oil demand is shaped to a considerable extent by improvements in the efficiency of internal combustion engine (ICE) vehicles and the uptake of electric vehicles (EVs). In the STEPS, the share of EVs in total global car sales doubles to 2030 and rises above 50% by 2035. This puts road transport oil demand on a declining trajectory and leads to a peak in total oil demand around 2030. In the CPS, the EV sales share broadly plateaus after 2035, and ICE vehicle fuel economy continues to improve broadly in line with historical trends (though in some advanced economies it does so a little more slowly than in the past). In 2035, total oil demand is 5 million barrels per day (mb/d) higher in the CPS than in the STEPS, with 40% of this difference due to the slowdown in EV sales. In the CPS, the flatlining of the EV sales share after 2035 contributes to continued growth in oil demand into the 2030s and beyond.

Figure 1.2 ▷ Demand for coal, oil and gas by major driver and scenario, 2010-2050



Coal and oil demand peak by 2030 in the STEPS; growth is higher in the CPS due to slower uptake of technologies such as renewables and EVs

Note: btce = billion tonnes of coal equivalent; mb/d = million barrels per day; tcm = trillion cubic metres. EMDE = emerging market and developing economies; CPS = Current Policies Scenario; STEPS = Stated Policies Scenario.

Natural gas use in electricity generation is one important determinant of the difference between the two scenarios. In the STEPS, renewables moderate the growth of natural gas-fired power in major consuming regions, and lead to absolute declines in natural gas use in electricity generation in Europe and advanced economies in Asia. The net result is that global natural gas use for electricity generation increases by slightly less than 10% to 2035. In the CPS, renewables and other alternative sources of generation gain ground more slowly, and the use of natural gas for electricity rises by slightly more than 15%. The different trends in the two scenarios result in natural gas demand reaching a plateau around the middle of the 2030s in the STEPS, but continuing to increase in the CPS. The plateau in gas demand in the STEPS occurs later and at a higher level in this year's STEPS compared with last year.

1.1.3 How do market balances play out in the different scenarios?

The *World Energy Outlook* in 2024 (*WEO-2024)* noted that the turbulence caused by the 2022 energy crisis appeared to be receding and that market balances were set to ease in major fuel, commodity and energy technology markets. How market balances play out differs in the scenarios. In the CPS, higher demand mops up any excess oil and LNG supply more quickly, leading in turn to significant pressures on supply investment and higher international fuel prices in the longer term. In the STEPS, the peak in oil demand and plateau in natural gas demand help to mitigate these pressures and damp down price rises.

The bulk of oil and gas investment is needed in these scenarios not to meet increases in demand but to offset declines in production from existing fields. In the CPS, some 25 mb/d of new oil projects need to be approved to keep markets balanced to 2035, compared with around 20 mb/d in the STEPS, and natural gas supply from new fields reaches 1 500 billion cubic metres (bcm) in 2035, compared with 1 200 bcm in the STEPS. Tighter market balances and stronger demand for supply mean that markets pull in higher cost producers, and this in turn pushes up prices. In the CPS, oil prices are around 10% higher than in the STEPS in 2035, and natural gas prices in major importing regions are around 30-40% higher. Moreover, while upstream oil and gas investment needs in the STEPS out to 2035 are broadly in line with the average level of spending in recent years, around USD 100 billion more than that average is needed every year in the CPS.

Market balances for copper and lithium are stretched in both the STEPS and the CPS (section 1.7). Manufacturing capacity for low-emissions technologies such as solar PV, batteries and EVs is substantially in excess of demand in both scenarios, implying fierce competition and downward pressure on prices (section 1.9). In both scenarios, key steps of the value chain for both critical minerals and clean energy technologies continue to be dominated by a small number of countries.

There is no global market for electricity, but similar underlying drivers shape individual markets. Both scenarios see a similar task ahead in terms of meeting rising peak demand and increasing needs for electricity sector flexibility. Peak electricity demand increases around 40% by 2035 in the STEPS, and by slightly more than this in the CPS, with much of the growth coming from the increasing use of appliances such as air conditioners. The projected growth in both overall and peak electricity demand underlines how complex a task it is to boost electricity resilience and security, and at the same time how important it is to succeed in doing so.

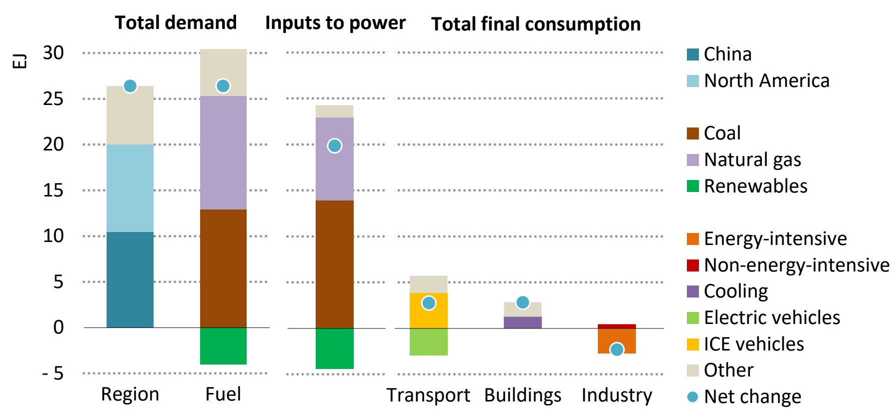
Box 1.2 ⊳ How does the 2025 STEPS differ from the 2024 version?

The Stated Policies Scenario is updated annually to account for changes in policies, market dynamics and technological advancements. It is instructive to look at how the projections have evolved. Changes in assumptions since the *World Energy Outlook-2024* (*WEO-2024*) have had a material impact on the outlook for energy in this 2025 edition (Figure 1.3). Some of the largest changes since the *WEO-2024* include:

- **Evolving policy and market backdrop:** The last year has seen major new policies emerge in 48 countries, most notably in the United States. For example, the 2025 iteration of the STEPS projects 30% less renewables capacity installed in the United States in 2035 than the 2024 STEPS version, and 60% fewer EVs on the road in 2035. However, EV projections have been revised up in several other regions: for example, the 2025 STEPS sees around 20% more EVs on the road in emerging market and developing economies outside China in 2035 compared with the 2024 STEPS, reflecting recent strong sales growth.

- **Higher electricity generation growth**: The 2025 STEPS projects over 44 000 TWh of electricity generation worldwide in 2035, which is around 4% more than in the 2024 STEPS version. The outlook for electricity demand to serve data centres in the United States and elsewhere are higher than in the *WEO-2024,* and higher demand for air conditioning in the Middle East and North Africa also makes a large contribution to the overall increase in electricity demand in the 2025 STEPS. Emerging grid integration challenges in China and other major markets also help to explain the differences in the generation mix between the two editions of STEPS. Most of the upward revision in generation is coal-fired power in China.
- **Increased natural gas consumption:** The 2025 STEPS projects 350 bcm more natural gas consumption in 2035 compared with the 2024 STEPS version. Three-quarters of this is for electricity generation, mainly in the United States, Japan and the Middle East, and reflects higher electricity demand and slower progress in adding renewables to the generation mix than projected in the *WEO-2024*. There is also faster growth in the use of gas for transport, notably for compressed natural gas vehicles in China and LNG for shipping, and for industry in emerging market and developing economies.

Figure 1.3 ▷ Differences in global energy demand in 2035 in the STEPS 2025 relative to the STEPS in the *World* Energy *Outlook 2024*



Differences in power account for most of the change in the STEPS in this Outlook, with shifting policies and slower efficiency gains also driving additional energy demand

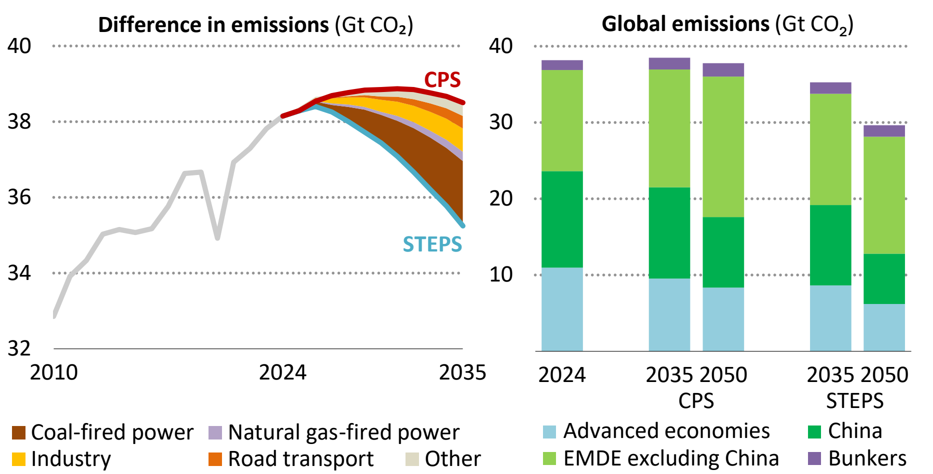
Note: ICE = internal combustion engine.

1.2 What are the implications of the IEA scenarios for the global climate and for COP30?

1.2.1 Outlook for emissions in the exploratory scenarios

Notably, 2024 was the hottest year on record, and the first in which the temperature rise from pre-industrial levels exceeded 1.5 degrees Celsius (°C).[1] The last decade was also the hottest on record (WMO, 2025). As countries submit new national climate targets in accordance with the Paris Agreement, it is important to understand where we are headed and what pathways remain to meet the temperature goals of the Paris Agreement.

Figure 1.4 ▷ Energy-related CO_2 emissions by region and scenario



Emissions from coal-fired power generation in emerging market and developing economies account for most of the difference between the two scenarios to 2035

Note: Mt CO_2 = million tonnes of carbon dioxide. CPS = Current Policies Scenario; STEPS = Stated Policies Scenario; EMDE = emerging market and developing economies.

Both our exploratory scenarios based on today's conditions result in high emissions and high temperatures, although they differ in degree. In the CPS, energy-related emissions remain close to the 2024 level through to 2050 (Figure 1.4). Emissions from coal combustion decline marginally across the outlook, but this is offset by increases in emissions from oil and natural gas. Decreases in advanced economies and China are offset by increases in other emerging market and developing economies. In the STEPS, global energy-related carbon dioxide (CO_2) emissions peak in the next few years, decline modestly to 35.2 gigatonnes (Gt) in 2035, and

[1] This does not mean that the goal of limiting warming to 1.5 °C is missed, as this goal refers to average temperatures across several decades.

continue to fall slowly to 2050. Emissions fall in advanced economies from 11 Gt to 8.6 Gt by 2035, and in China from 12.7 Gt to 10.5 Gt. Emissions in other emerging market and developing economies continue to rise to 2035.

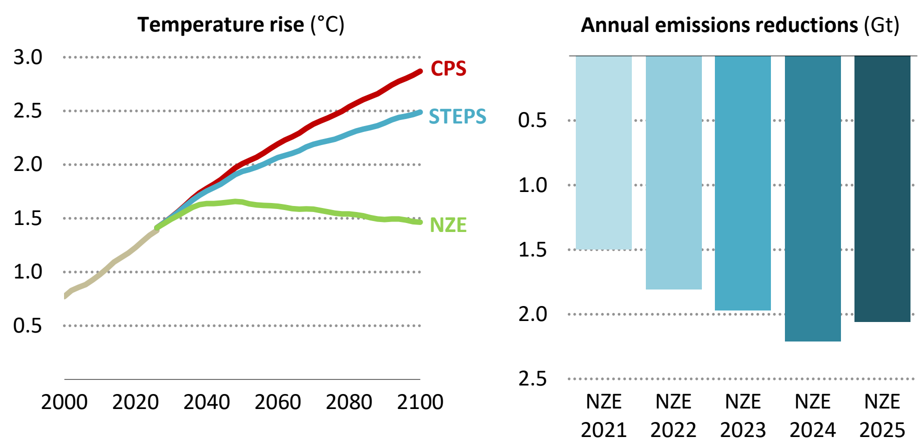
Higher emissions in the CPS from coal-fired electricity, particularly in China, are the main reason for the difference in emissions between the STEPS and the CPS. They account for 1.7 Gt of the gap between them in 2035. Slower increases in efficiency and electrification in industry in the CPS account for a further 0.6 Gt of the difference, and lower EV sales and slower increases in the efficiency of ICE vehicles for another 0.3 Gt.

1.2.2 Temperature outcomes in the scenarios

The long-term global average rise in temperatures above pre-industrial levels was around 1.4 °C in 2024 and since 1980 has been increasing by around 0.2 °C per decade. All scenarios exceed warming of 1.5 °C by around 2030, but differences in climate outcomes between the *WEO* scenarios begin to emerge after 2035.

In the CPS, warming exceeds 2 °C around 2050, reaches 2.9 °C in 2100, and is set to keep rising from there (Figure 1.5).

Figure 1.5 ▷ Global average temperature rise, and annual emissions reductions from peak to 2035 in past NZE Scenario editions



The average temperature rise reaches 2.9 °C in 2100 in the CPS, 2.5 °C in the STEPS, and in the NZE Scenario it peaks at around 1.65 °C in 2050 and falls below 1.5 °C in 2100

Notes: Gt = gigatonnes. CPS = Current Policies Scenario; STEPS = Stated Policies Scenario; NZE = Net Zero Emissions by 2050 Scenario; NZE 20xx = NZE Scenario in the *World Energy Outlook* of the specified year. The figure shows median long-term average global temperature anomaly relative to 1850-1900 and matches the Intergovernmental Panel on Climate Change Sixth Assessment Report definition of warming of 0.85 °C between 1995-2014.

Sources: IEA analysis based on MAGICC 7.5.3 and IPCC (2022).

In the STEPS, lower levels of emissions produce outcomes that diverge somewhat from those in the CPS. Warming exceeds 2 °C by around 2060 and reaches around 2.5 °C by 2100. The 2025 version of STEPS shows an increase in warming compared to its previous iterations.

In the Net Zero Emissions by 2050 Scenario (NZE Scenario), warming peaks around 2050 at about 1.65 °C and declines slowly after that. This decline is due to active measures to remove CO_2 from the atmosphere, reducing emissions of non-CO_2 greenhouse gases, and the natural cooling of the earth system after net zero CO_2 emissions are reached. By 2100, warming drops back to below 1.5 °C.

Inherent uncertainties in how the earth system responds to future emissions and warming mean that higher temperature outcomes cannot be ruled out, highlighting the importance of limiting the risks of extreme outcomes. There is a 5% chance of warming above 4 °C in the CPS in 2100, for example. Whatever its level may be, future warming from current levels is inevitable in all our scenarios and carries with it risks, including the risk that crucial tipping points will be reached. Those risks become extreme at the upper end of the levels of warming possible in the STEPS and the CPS scenarios.

1.2.3 A limited overshoot pathway to 1.5 °C has slipped out of reach, but avoiding the worst climate outcomes is still possible

The IEA has presented its NZE Scenario every year since 2021. It translates the global goal of limiting warming to 1.5 °C into a global pathway for the energy sector. Each country will determine its own pathway: the aim of the NZE Scenario is not to prescribe the same path for all, but rather to show what a global pathway looks like.

In each successive edition of the NZE Scenario, the near-term emissions reductions required to prevent warming substantially exceeding 1.5 °C has become more challenging. Actual emissions have risen year after year, and continued investment in high-emitting infrastructure has constrained the path ahead. To meet the near-term emissions benchmarks necessary to avoid substantially exceeding the 1.5 °C target, each successive edition of the NZE Scenario has featured more rapid near-term emissions reductions, stretching feasibility to its limits.

This year, the short-term emissions trajectory in the NZE Scenario has been revised upward following in-depth sector-by-sector analysis of technology deployment. Compared with previous versions of the NZE Scenario, energy efficiency gains take place at a slower speed, the pace of electrification of some end-uses is less rapid, and the deployments of hydrogen and carbon capture, utilisation and storage in the near term proceed more slowly.

As a result of higher near-term emissions, the NZE Scenario now results in a higher and longer overshoot of the 1.5 °C goal. It is now all but certain that 1.5 °C of warming will be exceeded within a decade or less, and that pathways that limit this overshoot of 1.5 °C to low levels have now slipped out of reach. The NZE Scenario reflects the emerging reality that any realistic pathway to stabilising warming below 1.5 °C in the long term will entail a high overshoot of the 1.5 °C target in the coming years. Technologies to remove CO_2 from the atmosphere are expensive and unproven at scale, and everything must therefore be done to limit reliance on them by reducing emissions as far and fast as possible. However, if warming is to be brought below 1.5 °C, immediate and rapid emissions reductions must be combined with strategies to remove CO_2 from the atmosphere at scale in the decades to come.

In the NZE Scenario, global emissions fall by over half by 2035 from their 2024 level and reach net zero by 2050. Annual CO_2 removal using the technologies available reach 2.1 gigatonnes of carbon dioxide (Gt CO_2) in 2050 and 3.8 Gt CO_2 in 2100. In 2100, this would mean removing the equivalent of the current combined annual energy-related CO_2 emissions of India and Indonesia from the atmosphere.

1.2.4 What can be done to get on track?

The world is clearly not on track to meet internationally agreed climate goals and is facing a challenging set of economic and geopolitical conditions. However, there is significant momentum behind many clean energy technologies, and the options to reduce emissions substantially in the near term are well understood and, in many cases, cost effective. Although the current round of Nationally Determined Contributions (NDCs) has seen reasonably high levels of participation, the scope for progress and the scale of domestic policy ambitions do not seem to have been captured in the updated NDCs in aggregate (Box 1.3).

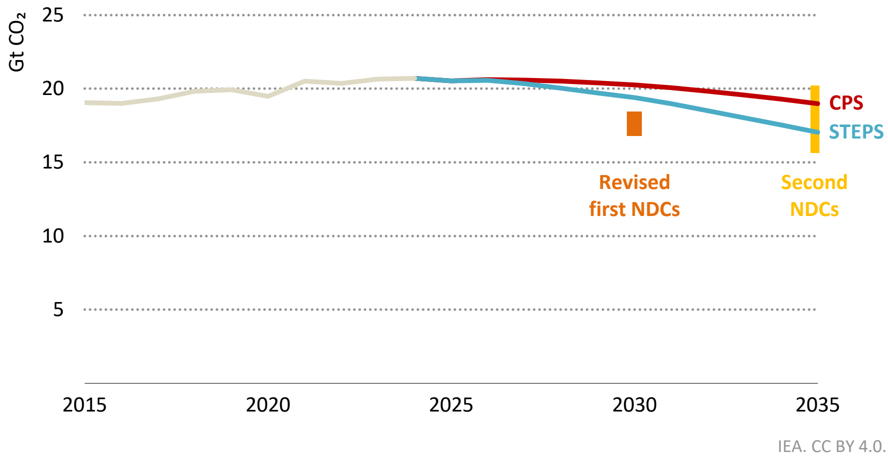
Box 1.3 ⊳ What are the implications of the NDCs that have been put forward?

The Paris Agreement calls on countries to revise their Nationally Determined Contributions (NDCs) every five years, and stipulates that each revision should represent an increase in ambition. As of early November, countries representing around 55% of global energy-related emissions had submitted their new NDCs. In January 2025, the United States announced its withdrawal from the Paris Agreement. The full impact of updated NDCs will be reflected in future analysis; a high-level assessment is shown here.

Total energy-related CO_2 emissions from countries with new NDCs were around 20 Gt in 2024 (Figure 1.6). Full implementation of NDCs would see their emissions fall to 15-17 Gt by 2035, a reduction of 10-25% below current levels. This is in line with the STEPS and would mean emissions falling faster than envisaged in the CPS. In aggregate, however, the NDCs do not imply additional ambition beyond what is currently seen in the policies and market trends captured in the STEPS.

This aggregate picture masks significant differences between countries. Some countries have submitted NDCs that appear less ambitious than they could be in light of current policy and market trends. For example, China's NDC goal of reaching 3 350-3 600 GW of installed wind and solar capacity by 2035 implies an annual rate of capacity additions of 160-180 GW per year. This compares to around 400 GW of additions in 2024, and the goal is achieved before 2030 in the CPS and the STEPS. Other countries have put forward NDCs that imply a faster rate of emissions reductions than captured in the STEPS, indicating that they will need to introduce new policies to deliver on their NDC pledges.

Figure 1.6 ▷ Energy-related emissions trajectories from NDC submissions relative to the Current Policies and Stated Policies scenarios



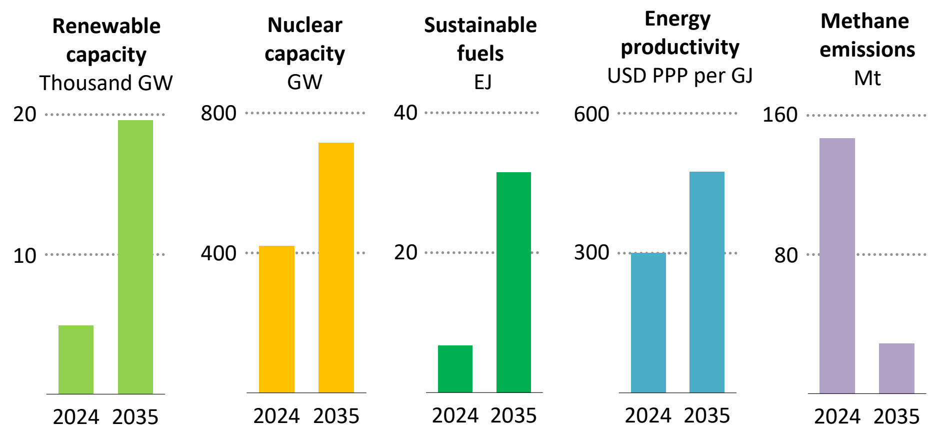
Targets for 2035 in announced second-round NDCs show broadly the same level of ambition as first-round NDCs, and are in line with the trajectory in the STEPS

Notes: Gt CO_2 = billion tonnes of carbon dioxide; NDCs = Nationally Determined Contributions. CPS = Current Policies Scenario; STEPS = Stated Policies Scenario. The estimates aggregate selected countries with 2035 indicative targets announced at the United Nations Climate Summit on 24 September 2025 and the Nationally Determined Contributions submitted to the United Nations Framework Convention on Climate Change (UNFCCC) secretariat as of mid-October 2025.

Several key actions are necessary to put the world on an energy system pathway more closely aligned with internationally agreed climate goals. They include actions to boost the uptake of renewables and other low-emissions technologies, to improve energy efficiency, to reduce methane emissions, to increase the electrification of end-uses, and to use sustainable fuels where electrification is not practicable (Figure 1.7).

Renewables are already expanding strongly; new capacity of over 680 GW was added in 2024. In the STEPS, the global installed capacity of renewables increases from around 4 900 GW in 2024 to around 13 700 GW in 2035, an increase of 2.8-times. This is around 70% of the capacity increase required in the NZE Scenario by 2035, which sees the installed capacity of renewables reach 19 600 GW in 2035. Nuclear and low-emissions fuels also have a part to play, as do actions to improve grid flexibility and resilience in order to facilitate the integration of renewables. Installed nuclear capacity expands by 70% by 2035 in the NZE Scenario.

Figure 1.7 ▷ Key indicators of energy transitions in the NZE Scenario, 2024-2035



Scaling up low-emissions electricity generation, improving energy efficiency and reducing emissions of methane are critical actions to get back on track

Notes: GW = gigawatt; EJ = exajoule; PPP = purchasing power parity; GJ = gigajoule; Mt = million tonnes. Sustainable fuels include liquid biofuels, biogases, low-emissions hydrogen and hydrogen-based fuels, including hydrogen produced and consumed onsite.

There are various ways to improve the energy efficiency of the global economy. They include: switching to more efficient fuels such as electricity; increasing the efficiency of factories, houses and appliances; and delivering universal access to modern forms of energy. In the STEPS, efficiency increases by around 2% per year to 2035, meaning that the global economy produces more than one-quarter more output per unit of energy used than today. In the CPS, this rate of increase is slower. In the NZE Scenario, the rate of improvement doubles to 4% a year by 2030, and it stays at that level to 2035.

The energy sector is responsible for methane emissions of around 4.4 gigatonnes of carbon-dioxide equivalent (Gt CO_2-eq). Major reductions in methane emissions can be achieved with well-known measures at low cost. In the NZE Scenario, methane emissions are reduced by 80% from their 2024 level by 2035. The reductions in the STEPS and the CPS are around 20% and 5% respectively.

Electricity currently accounts for around one-fifth of global energy consumption. Increasing the share of electricity in end-uses has a central part to play to reduce emissions from the end-use sectors. In the STEPS, electricity increases to around one-quarter of global energy consumption by 2035. Increased deployment of EVs, heat pumps and other electrical technologies push this share to around one-third by 2035 in the NZE Scenario. However, electricity alone cannot fully eliminate emissions from energy consumption. Sustainable fuels such as biofuels and hydrogen and hydrogen-based fuels are also required. In the NZE Scenario, their use increases by more than four-times by 2035.

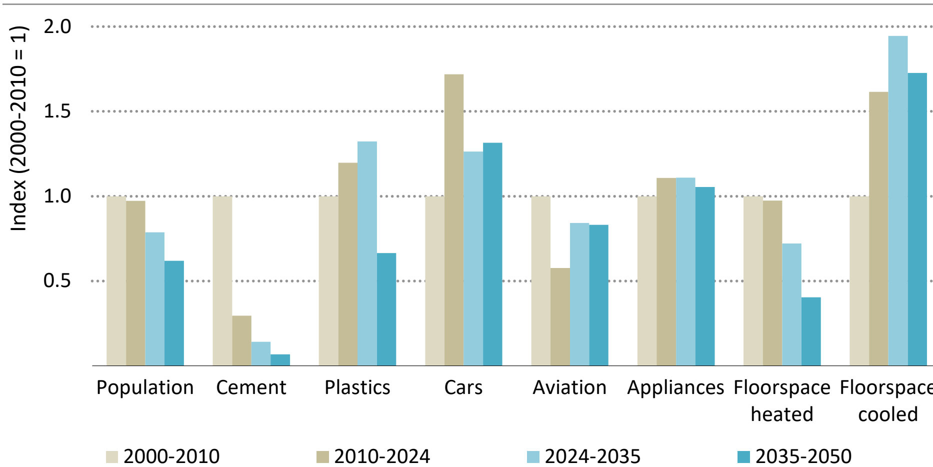
1.3 How are the drivers of future global energy demand different from those in the past?

Between 2000 and 2010, global energy consumption rose at an average annual rate of 2.4%. Then the pace slowed, with growth in consumption falling to an average of 1.3% per year from 2010 to 2024. In the CPS, total final consumption continues to grow at the current rate up to 2035. In contrast, the STEPS sees a slowdown, with annual growth of 1%, while faster electrification and other efficiency gains in the NZE Scenario allow for an annual decline in energy consumption of around 1% up to 2035.

1.3.1 Drivers of energy growth of the past are not the ones of tomorrow

The factors driving global energy demand are shifting. Demographic factors, once a major influence, are waning as population growth slows and even reverses in many advanced economies, the Russian Federation (hereinafter Russia) and China (Figure 1.8). The global population is set to continue to grow, but the average annual increase of 80 million since 2000 is projected to slow to 65 million per year up to 2035 and then to 50 million to 2050. Two-thirds of the world's population already lives in countries with fertility rates that are below the replacement rate (UN DESA, 2025).

Figure 1.8 ▷ Annual growth of selected demand drivers by time period, 2000-2050



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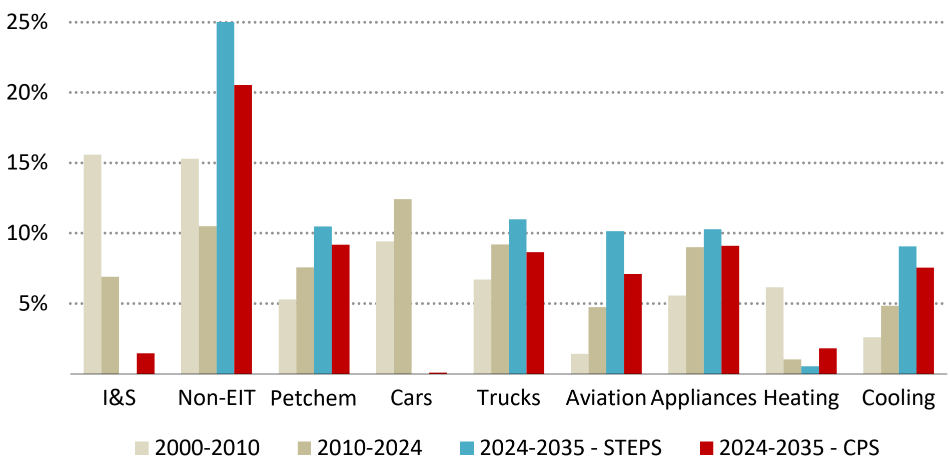
Growth in conventional energy demand drivers is set to slow significantly in the coming years, though cooling needs accelerates

Industrial production – a pillar of energy demand growth – is also evolving. From 2000 to 2010, cement, and iron and steel production contributed 5% and 16% respectively to total consumption growth. Their contributions fell to 2% and 7% between 2010 and 2024, and are set to decline further through to 2050 as growth in these sub-sectors slows. Meanwhile, other industries such as plastics and manufacturing are rapidly expanding.

In the transport sector, the locus of demand is also shifting. During the 2000s, advanced economies accounted for around half of the increase in the global stock of cars. In the following decade, China alone accounted for half. Between now and 2035, rising ownership rates lead to emerging market and developing economies other than China accounting for half of the increase in the stock of cars as advanced economies see car ownership reach a plateau.

Energy demand patterns are also changing in the buildings sector. Space cooling is increasingly a leading driver of demand as rising temperatures stimulate more use of air conditioning, especially in emerging market and developing economies where average incomes are steadily increasing (Figure 1.9). While appliances remain significant, the overall balance of energy consumption in buildings is clearly tilting towards emerging market and developing economies and end-uses, reflecting broader shifts in economic activity and climate trends.

Figure 1.9 ▹ Sectoral share in total final consumption net growth in the STEPS and CPS, 2000-2035



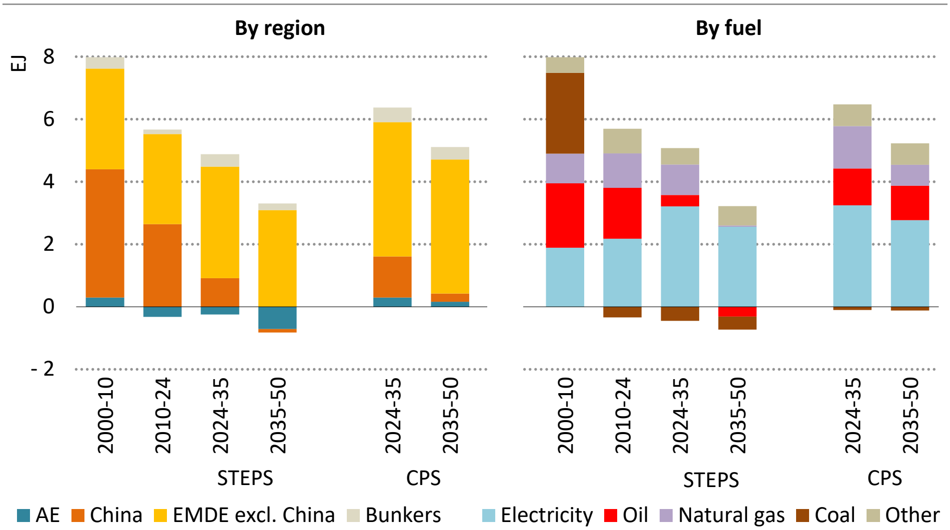
Growth in energy consumption is shifting from traditional industries and cars to non-energy-intensive industries and cooling

Note: I&S = iron and steel; non-EIT = non-energy-intensive industries; Petchem = high value chemicals. CPS = Current Policies Scenario; STEPS = Stated Policies Scenario.

1.3.2 Engines of demand growth are shifting across fuels and regions

Energy consumption growth was largely driven by advanced economies from the start of the Industrial Revolution through to the end of the 20th century. Since 2000, China has been the main engine of global energy consumption growth as its industrial output and household consumption expanded at dizzying speed (Figure 1.10). For example, China accounted for more than half of oil and natural gas consumption growth from 2010 to 2024, and 60% of electricity demand growth. Now China is moving towards a less infrastructure and energy-intensive growth model. This shift is reflected in a peak in production in some energy-intensive industries, e.g. cement and steel, and the transition to more electricity-intensive sectors, such as clean technology manufacturing, along with more stringent efficiency measures and increasing uptake of EVs. It is putting China on a different energy path, in which electricity demand continues to rise rapidly but growth in fossil fuel consumption is much less pronounced. In both the CPS and the STEPS, emerging market and developing economies other than China take over as the primary drivers of energy consumption growth and see energy consumption increase across all sectors. India and Indonesia stand out, with annual increases in energy consumption of between 3% and 3.6% to 2035.

Figure 1.10 ▷ Total final consumption annual increase by region, fuel and scenario, 2000-2050



IEA. CC BY 4.0.

Engine of growth shifts from China to other emerging market and developing economies, with electricity meeting most of the growth; fossil fuels play a larger role in the CPS

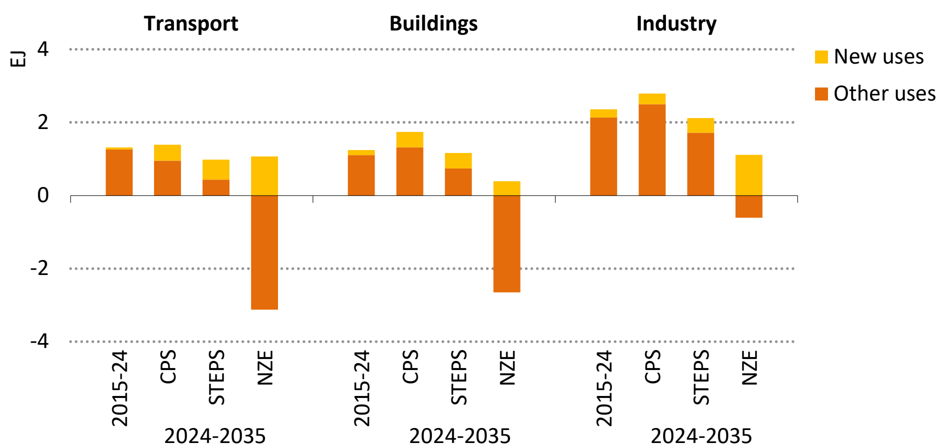
Notes: EJ = exajoule. CPS = Current Policies Scenario; STEPS = Stated Policies Scenario. AE = advanced economies; EMDE excl. China = emerging market and developing economies excluding China. Other includes district heating, solar thermal and geothermal, bioenergy and waste.

Historically, most of the increase in energy consumption was met by fossil fuels. Coal, oil and natural gas supported an expanding base of cars and heating needs, notably in China, plus more industrial activity. The CPS and the STEPS see the same levels of economic growth and broadly similar energy services demand throughout the projection period, but the scenarios differ in how the energy services demand is met. Differences in the stringency of efficiency policies, in fuel mixes and in electrification underpin the variances in the outlook for total energy consumption. In the CPS, total energy consumption increases by 1.3% per year to 2035, and by 1% in the STEPS. Electricity has always been essential to a wide range of activities, but the development of clean technologies in the STEPS boosts its attractiveness, and it meets more than two-thirds of consumption growth in the next decade. In the CPS, the pace of clean technologies deployment is slower, which means that a higher proportion of energy consumption comes from fossil fuels. In the NZE Scenario, global final consumption drops by 4 EJ a year on average over the next decade, with 75% of the decline in advanced economies. While electricity consumption grows by a similar amount as in other scenarios, in the NZE Scenario the consumption of fossil fuels drops by 8 EJ annually, led by oil.

1.3.3 Clean technologies and emerging sectors redefine growth

A range of clean energy technologies made rapid progress over the last decade, and particularly in recent years. Since 2020, global EV sales have surged, heat pump sales rose by more than 25%, and the technology readiness level of several industrial technologies, most notably industrial heat pumps, has advanced. In some regions, new desalination capacity shifted from thermal-based systems to fully electric ones. In parallel, structural changes in economies and the emergence of new demand drivers, such as AI and clean technology manufacturing, are pushing up energy consumption in specific industrial sub-sectors.

Figure 1.11 ▷ Total final consumption growth by sector, end-use type and scenario, 2015-2035



End-uses that were marginal in the last decade account only for a small part of the growth in the CPS, an increasing share of it in the STEPS, and nearly all of it in the NZE Scenario

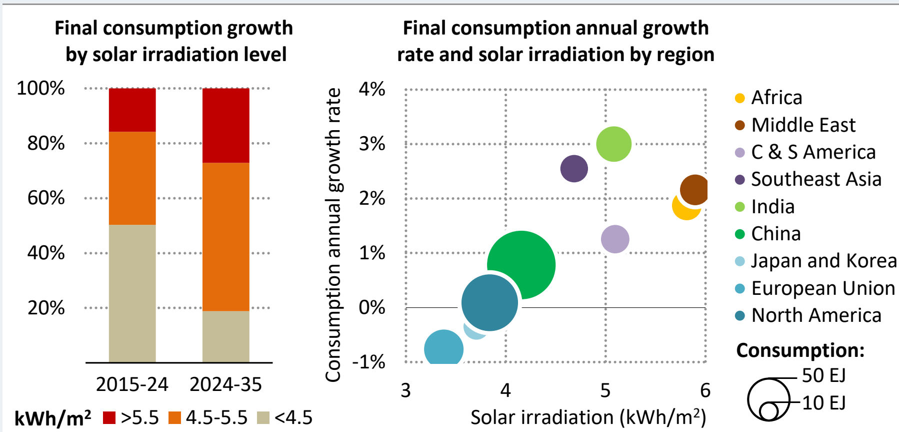
Notes: EJ = exajoule. CPS = Current Policies Scenario; STEPS = Stated Policies Scenario; NZE = Net Zero Emissions by 2050 Scenario. In transport, new uses include hydrogen and EVs; in buildings it includes heat pumps, data centres and electric desalination; in industry it includes heat pumps, hydrogen and clean technology manufacturing.

In the STEPS, such emerging uses and clean technologies account for around half of consumption increases in transport and one-third in buildings (Figure 1.11). Their share is lower in industry: existing technologies meet most of the energy consumption increase as financial and infrastructure barriers continue to hinder the deployment of industrial heat pumps and electrolytic hydrogen at scale. In the CPS, deployment of some of the new technologies is considerably slower, notably EVs and heat pumps. In contrast, the NZE Scenario places end-uses on a decarbonisation path where new clean energy technologies become the sole drivers of consumption growth within each sector.

Box 1.4 ▹ Demand grows where the sun shines over the next decade

Many emerging market and developing economies outside China have excellent solar potential. They include India and a number of countries in Africa, the Middle East, Southeast Asia, and Central and South America. While regions with medium to low solar conditions accounted for half of energy consumption growth over the past decade, their share is projected to more than halve in the coming decade in the STEPS. By 2035, 80% of energy consumption growth occurs in regions with average irradiation above 4.5 kilowatt-hours per square metre (kWh/m^2) per day, and 35% of total consumption growth takes the form of demand for electricity (Figure 1.12).

Figure 1.12 ▹ Total final consumption growth in the STEPS relative to solar irradiation worldwide, 2015-2035, and by region, 2024-2035



Regions with the fastest consumption growth to 2035 have the most favourable solar conditions, highlighting both a demand challenge and a supply opportunity

Notes: kWh/m^2 = kilowatt-hours per square metre; C & S America = Central and South America; STEPS = Stated Policies Scenario. Irradiation is measured per day and averaged over the region. Bubble size reflects total final consumption of a region in 2024.

Favourable solar conditions present both a demand challenge and a supply opportunity. In many regions, strong solar irradiation coincides with high daytime temperatures, driving up demand for air conditioning. In parts of the Middle East, India and Africa, cooling is not just a matter of comfort but a necessity for health and life. In these regions, cooling is a major contributor to electricity demand growth, accounting on average for 20% of the total between now and 2035 (IEA, 2025a). At the same time, these conditions provide an opportunity to harness abundant solar resources that should translate into higher average capacity factors for solar PV than currently registered, and potentially lower average generation costs. In the STEPS, solar PV meets over half of the additional electricity demand projected by 2035 in the Middle East, India and Africa.

1.4 What does the Age of Electricity mean for affordability?

Electricity bills are rising up the political agenda in many parts of the world as households and businesses grapple with higher costs. In the emerging Age of Electricity – where reliable electricity is increasingly central to modern daily life – the price of electricity is becoming a defining indicator of energy affordability. This shift underscores a growing tension: while electrification offers long-term efficiency gains and emissions reductions, it also increases the sensitivity of movements in electricity prices, which are shaped by a complex mix of fuel costs, infrastructure investment, market design and policy choices.

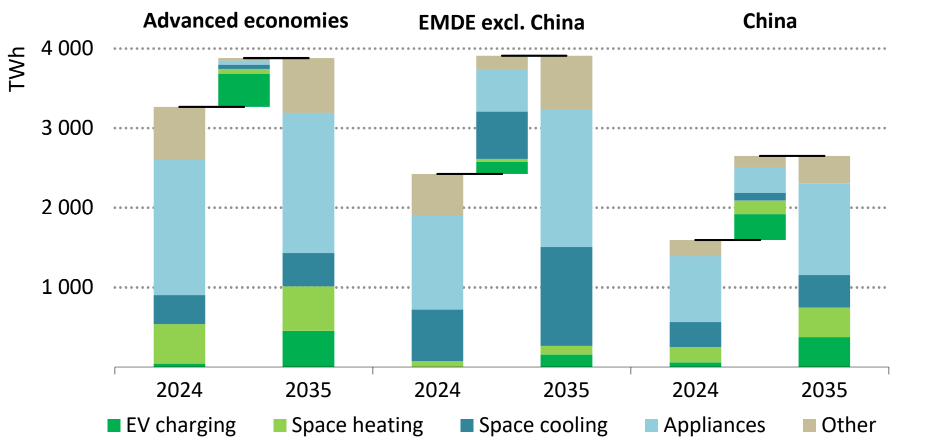
1.4.1 Household electricity demand

The Age of Electricity is reshaping household energy consumption patterns worldwide. As electrification expands across sectors, electricity is becoming a more prominent component of total household energy demand. Globally, average household electricity consumption is projected to rise 25% by 2035 and 60% by 2050 in the STEPS, though regional trends vary (Figure 1.13). This reflects not only the continued use of air conditioners and appliances, such as dishwashers and washing machines, but also the increasing adoption of EVs and electric heating systems. In most cases, these new uses of electricity displace natural gas and oil. Electrification proceeds more slowly in the CPS, while more rapid deployment of EVs and heat pumps in the NZE Scenario push it forward faster than in the STEPS or the CPS.

In advanced economies, household electricity demand is projected to reverse a decade-long trend of stagnation. In the STEPS, it increases about 15% by 2035 and close to 35% by 2050. While increases in energy efficiency moderate consumption for appliances, the electrification of transport is a major driver of expanding electricity use in regions with supportive policy frameworks and increasing EV sales shares. This shift underscores the need for grid readiness and demand flexibility solutions like smart charging to manage peak demand and to improve affordability.

In emerging market and developing economies excluding China, household electricity demand is poised to accelerate significantly, rising 30% by 2035 and 90% by 2050. The primary reason is the increasing use of air conditioning as higher incomes and temperatures boost demand for space cooling. In China, home charging of the rapidly expanding number of EVs is also contributing to higher household electricity consumption. As electrification deepens, ensuring reliable and affordable access to electricity will be critical – not only to meet more demand, but also to support broader development and sustainability goals.

Figure 1.13 ▹ Total household electricity consumption by end-use in selected regions in the STEPS, 2024-2035



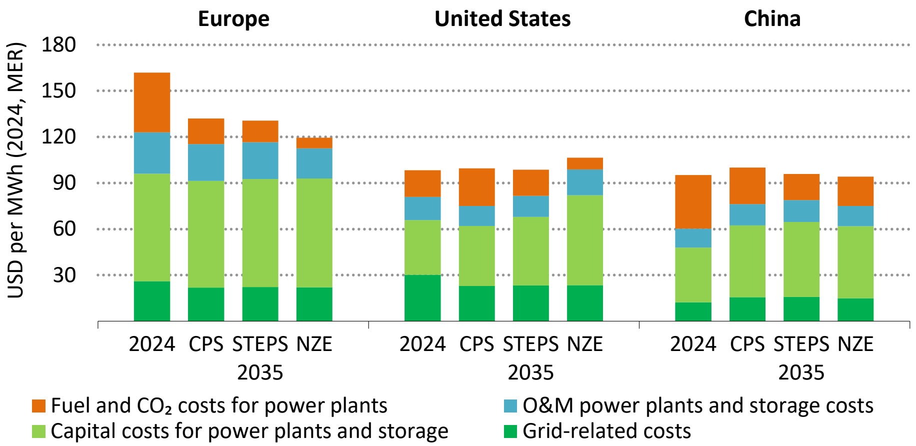
EVs, space heating, cooling and appliances drive growth in household electricity consumption

Notes: TWh = terawatt-hour. EMDE excl. China = emerging market and developing economies excluding China. EV charging considers the total charging needs of all electric passenger light-duty vehicles irrespective of whether they are charged at home, at work or at public chargers. Other includes water heating, cooking and lighting.

1.4.2 Pressures on electricity prices

Rapid growth in electricity demand brings with it a need for substantial investment across the power sector. Grid infrastructure, in particular, is seeing a marked increase in capital spending to connect new loads, integrate new sources of electricity and enhance resilience. While rising investment does not necessarily translate into higher average system costs – especially if demand rises in parallel – the financing conditions and timing of the investment are critical. Power generation capacity is also expanding, with renewables leading the way. New coal- and gas-fired capacity is coming online alongside renewables to meet demand growth and strengthen system security, but these fossil fuel plants are likely to be called upon to operate less frequently as time goes by. Battery storage is expanding rapidly to support the integration of variable renewables, and contributing to a more capital-intensive cost structure for electricity overall (Figure 1.14).

Figure 1.14 ▷ Average electricity system cost by component and scenario in Europe, the United States and China, 2024-2035



The transformation of electricity systems entails a shift in cost structure, from fuel and operational expenses towards upfront investments in clean technologies and infrastructure

Notes: MWh = megawatt-hour; MER = market exchange rate; O&M = operation and maintenance. CPS = Current Policies Scenario; STEPS = Stated Policies Scenario; NZE = Net Zero Emissions by 2050 Scenario. Grid-related costs include capital recovery costs for electricity transmission and distribution systems and grid operation and maintenance costs.

Infrastructure is not the only factor exerting upward pressure on electricity prices. Carbon pricing, as embodied in mechanisms such as the emissions trading systems in the European Union and China, is raising costs for fossil fuel-based generation, although carbon taxes or carbon allowance auction revenues can be recycled to consumers. Tight supply chains are also having a visible impact across the energy sector, increasing the cost of equipment, labour and materials. Market design has a significant influence: if natural gas or oil-fired units continue to set prices most of the time even as their energy share falls, infra-marginal rents for other generators may rise. While the price differentials that exist in this kind of market can incentivise the provision of additional flexibility, for example through the deployment of batteries or demand response, they risk straining affordability if driven by fuel price shocks or market power. Solutions include accelerating grid and interconnection projects, improving market oversight, and offering long-term contracts or targeted support to protect consumers, while keeping price signals intact.

At the same time, several forces help to moderate electricity prices. In many regions, natural gas prices are projected to decline over the coming decade as large volumes of LNG come on stream. Diversification of energy sources and a lower level of reliance on fossil fuels are reducing exposure to volatile fuel markets. As electricity demand rises, the fixed costs of new infrastructure can be spread across a larger volume of consumption, potentially reducing the cost per megawatt-hour. In some cases, this dynamic may even lead to lower electricity prices in real terms despite rising investment levels, highlighting the importance of well-designed policies and market frameworks that enable efficient investment recovery while protecting consumers.

The factors influencing electricity price stability are also shifting. Reduced dependence on fossil fuels can provide insulation from market price shocks, as highlighted in Chapter 5. Increased reliance on weather-dependent renewables introduces a different kind of variability. However, analysis of seasonal patterns over the past 30 years shows that, while weather-related effects vary by region and can be significant, their impacts on electricity costs and prices are generally much smaller than the volatility related to fossil fuel price fluctuations. In many regions, short-term and seasonal flexibility needs are projected to rise substantially by 2050, but systems are increasingly able to manage these shifts through demand response, battery storage, interconnection and sector coupling (IEA, 2024). These findings suggest that while rising deployment of weather-dependent renewables bring new challenges, well-designed systems with enough flexibility can mitigate volatility and maintain price stability even where renewables become dominant.

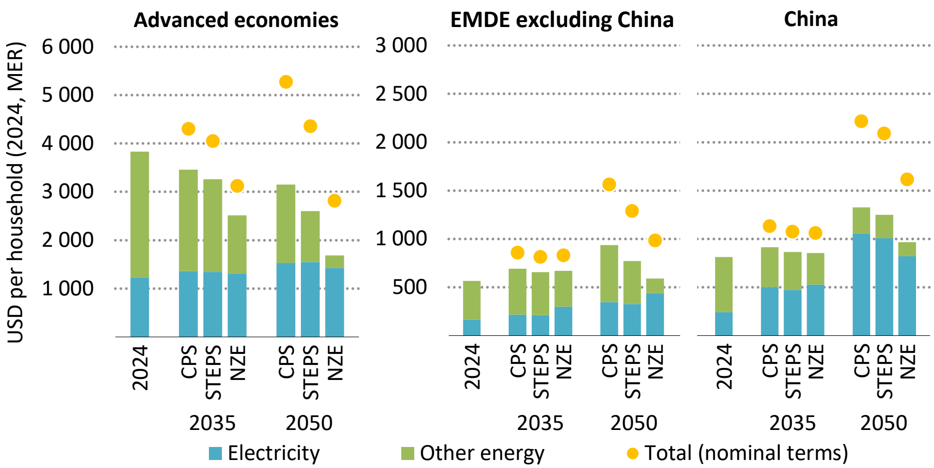
Climate change poses additional risks to electricity prices. Higher temperatures can reduce the availability of thermal and hydropower assets and impair the performance of grid infrastructure. At the same time, they may lead to higher demand, notably from cooling. This underlines the importance of grid investment: delays could pose risks to the stability of electricity prices, given that grid congestion can lead to higher wholesale market and retail electricity prices through the curtailment of renewables, the use of less efficient or more costly generators and reduced market competition.

1.4.3 Household electricity bills

Household electricity bills are projected to rise across most regions as electrification deepens and demand increases, though the scale varies. While increases are modest in advanced economies, they are more pronounced in emerging market and developing economies, where access and appliance ownership expand; they are especially large in China, where end-uses electrify rapidly. The impact on total household energy bills depends to a large extent on the scenario. In the STEPS, and even more so in the CPS, higher electricity outlays are only partly offset in some regions by gradual declines in spending on natural gas and oil for heating and transport (Figure 1.15). As a result, while total energy bills fall in advanced economies, they rise modestly in emerging market and developing economies, including China. In the NZE Scenario, faster efficiency gains and a more rapid shift away from fossil fuels – through heat pumps and EVs – more than compensate for higher electricity spending, even when the effects of phasing out inefficient fossil fuel subsidies are taken into account. Although this scenario requires higher upfront spending on new equipment and efficiency improvements, it leads to a clear decline in total household energy bills in advanced economies and to bills that are broadly in line with today's in real terms in China and other emerging market and developing economies.

It is important to note that energy prices and both electricity and total energy bills may still rise over time in nominal terms because of general price inflation, even though they remain stable or fall when expressed in real, inflation-adjusted terms, as in this *Outlook*.

Figure 1.15 ▷ Electricity and total household energy bills by region and scenario, 2024, 2035 and 2050



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Spending on electricity increases in most markets, though this can help reduce other energy bills, leading to declines in advanced economies and smaller increases elsewhere

Notes: MER = market exchange rate; EMDE = emerging market and developing economies. CPS = Current Policies Scenario; STEPS = Stated Policies Scenario; NZE = Net Zero Emissions by 2050 Scenario. Total energy expenditures in nominal terms assume a constant 2% yearly inflation rate.

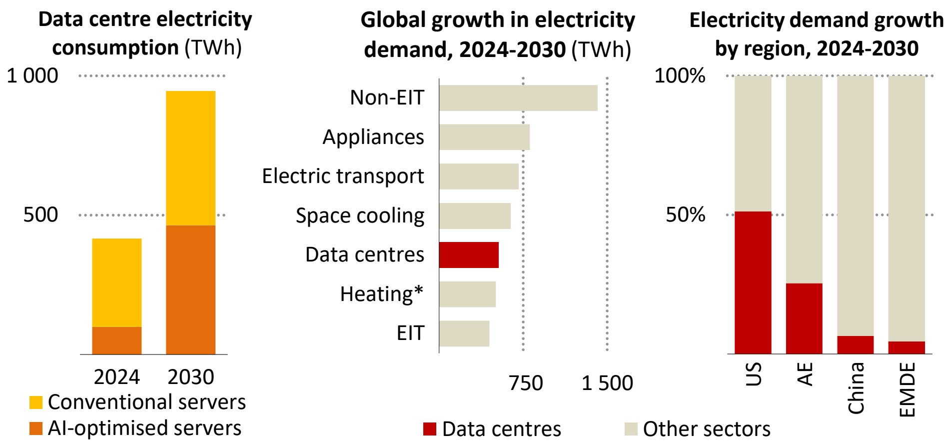
1.5 How much difference will AI make to the future of energy?

1.5.1 Electricity demand outlook from data centres

In recent years, technology companies worldwide have been investing heavily in new data centre capacity to train and deploy increasingly large and widely used AI models. In 2025, around USD 580 billion is estimated to be invested in data centres (IEA, 2025b). This is more than total global investment in oil supply, which is projected to be around USD 540 billion in 2025. This point of comparison provides a telling marker of the changing nature of modern, highly digitalised economies.

Driven by surging data centre expansion, electricity consumption by AI-optimised servers increases fivefold by 2030. This contributes to a doubling of total electricity consumption by data centres by 2030 (Figure 1.16). Despite this rapid growth, data centres account for less than 10% of global electricity demand growth between 2024 and 2030. Other sources, including industry, EVs and air conditioners, account for more of the growth in electricity demand.

Figure 1.16 ▷ Electricity consumption in data centres by server type, and global and regional electricity demand in the STEPS, 2024-2030



Even as electricity consumption from AI-optimised servers surges, data centres remain just one of the many sources of electricity demand growth in most economies

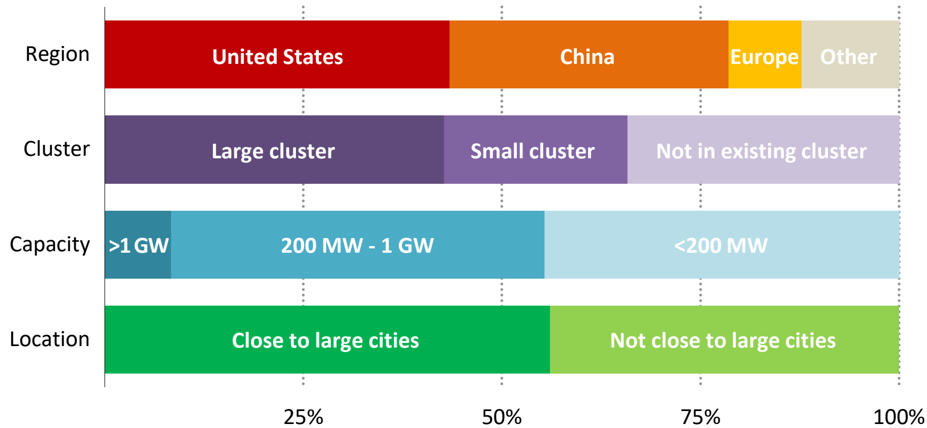
*Space and water heating in buildings.

Note: TWh = terawatt-hour; AI = artificial intelligence; EIT = energy-intensive industry; US = United States; AE = advanced economies; EMDE = emerging market and developing economies.

Data centres are geographically concentrated, with the United States, China and Europe accounting for 82% of global capacity. Over the next few years, over 85% of data centre capacity additions are set to take place in these three regions. In China and the European Union, data centres account for 6-10% of the growth in electricity demand to 2030. This is much lower than the comparable figure in the United States – the world's largest market for data centres – where data centres account around half of the growth in electricity demand in this period.

Aggregate values do not reveal the full picture. A geospatial analysis of the data centre project pipeline reveals that over half of data centres under construction or announced are being developed in or close to cities with a population of at least 1 million people, where grids already cater to large loads; that 55% of the data centres in the pipeline are larger than 200 megawatts (MW) in capacity, and would each consume as much electricity each year as around 200 000 households when they fully come online; and that nearly two-thirds of these upcoming data centres are in regions that are existing data centre clusters (Figure 1.17).

Figure 1.17 ▷ Characteristics of data centre capacity in the pipeline



The majority of data centres in the pipeline are larger than 200 MW, are in clusters in and around large cities, and are located in the United States, China and Europe

Notes: GW = gigawatt; MW = megawatt. Data centre clusters here refer to collections of facilities grouped according to the DBSCAN clustering algorithm using a neighbourhood radius of 100 km. Large clusters have at least 500 MW of maximum designed capacity and small clusters have between 100 MW and 500 MW of maximum designed capacity. Large cities refer to locations within 100 km of the centroid of cities with a population of at least 1 million people.

Source: IEA analysis based on data from (OMDIA, 2025) and (IDC, 2024).

This rapid build out of data centres – especially in clusters and around urban areas – comes with challenges. Grid congestion and connection queues are increasing in many regions, and connection queues for new data centres are often already long. While queue times are one to three years in the United States on average, it can take up to seven years to get connected in northern Virginia. In the United Kingdom and parts of Europe, the average time in the queue has been reported to be as high as seven or ten years. In Dublin, a data centre hub, new data centre connection requests have been paused until 2028. In addition, supply chains for key components like transformers, cables, gas turbines and critical minerals are already under pressure. For example, the backlog for the delivery of transformers has been lengthening, impacting the rollout of infrastructure catering to data centre construction. IEA analysis estimates that because of these factors, around 20% of the projected data centre additions by 2030 could be at risk of delay.

1.5.2 Electricity supply to meet data centre loads

The rapid rollout of data centres also has implications for supply. Most data centres are connected to the grid, and the electricity mix they consume reflects the electricity mix of the region in which they are located. At the global level, renewables remain the leading source of additional electricity for data centres in the STEPS, contributing around 45% of the growth through to 2035, nearly 400 TWh. In the CPS, renewables also provide the largest share of incremental supply, although at around 40% it is slightly lower than in the STEPS.

Natural gas also plays a key role to meet electricity demand growth from data centres, particularly in certain markets such as the United States and the Middle East. Global natural gas-fired generation for data centres increases by 220 TWh to 2035 in the STEPS, and by 285 TWh in the CPS. However, the surge in orders for new gas turbines over the past two years has strained supply chains, increasing both wait times and delivery costs.

Nuclear power is experiencing renewed policy support in many markets, and the technology sector is showing increasing interest in powering data centres with nuclear. In recent months, technology companies and utilities have announced deals to extend the lifetime of existing nuclear plants, and the first power purchase agreement has been signed with a demonstration small modular reactor to power a data centre. In the STEPS, nuclear power provides 190 TWh of additional electricity for data centres by 2035.

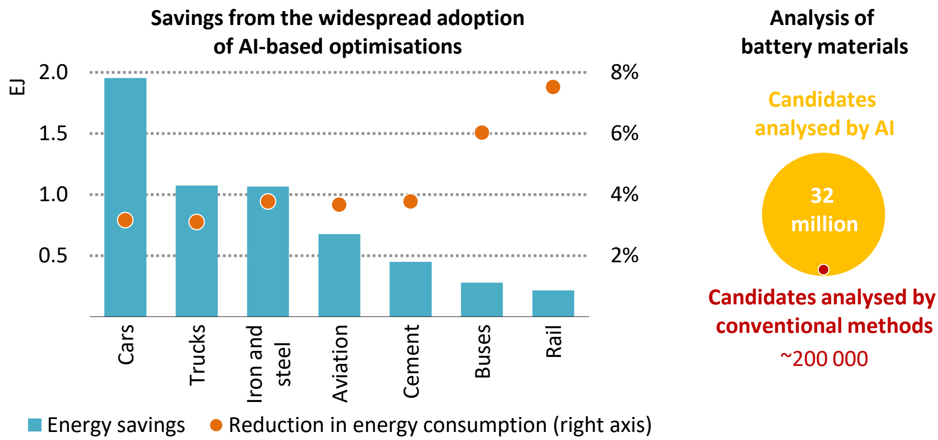
1.5.3 AI for energy

The role of AI in the energy sector goes well beyond being a driver of energy demand. AI is also important to the energy sector because of its potential to enhance the efficiency, security and cost effectiveness of energy operations (IEA, 2025b). AI is already being deployed in the oil and gas industry, in electricity generation and supply, and in energy-consuming sectors, but its potential goes well beyond its present uses. IEA analysis indicates that widespread uptake of AI-related solutions for the energy sector has the potential to boost efficiency by 3-10% across the transport and industry sectors globally by 2035 (Figure 1.18). This equates to total energy savings of 13.5 EJ, which is slightly larger than the total energy demand of Indonesia today. Widespread adoption of AI-led optimisation could facilitate the achievement of energy efficiency targets and unlock emissions reductions across key sectors.

None of this is a given. Limited access to high-quality data sets, insufficient digital infrastructure, regulatory concerns around privacy and the need to manage cybersecurity risks are all barriers to making full use of AI. There is also a risk of rebound effects, for example if increasingly automated private transport contributes to a modal shift away from public transport.

AI also offers potential to accelerate innovation in energy technologies. Many innovation challenges are characterised by the kinds of problems that AI is good at solving: multicriteria searches through extremely large and complex data sets to find optimal designs for materials, chemistries or catalysts, for example. However, the value of such searches depends critically on the data that is searched being sufficiently extensive, robust and information-rich to generate useful predictions. Once an AI model proposes candidates for further analysis, they need to be lab tested, integrated into working prototypes, and demonstrated at commercial scale. To make a real-world impact, products then need to be scaled into industrial supply chains and deployed. All of this takes time. Furthermore, some technologies may still involve a cost or efficiency penalty that hinders their adoption even after extensive AI-driven improvements. AI is therefore a useful tool, not a magic wand.

Figure 1.18 ▷ Global energy savings potential from AI in selected end-uses in 2035, and historical analysis of battery materials by AI



Widespread adoption of known AI applications has the potential to save 13.5 EJ in 2035, which is larger than the total energy consumption in Indonesia today

Notes: EJ = exajoule. Materials research related to batteries considers historical global research and development for screening potential candidates. Conventional methods include both physical experiments and detailed mechanistic computer simulations.

1.5.4 Known unknowns: a longer term view of AI implications on the outlook

While the *World Energy Outlook* takes a relatively long-term look at energy trajectories, its analysis on AI focuses on the near term. AI is a disruptive technology with huge promise, uncertainty and hype. Its broader economic and social impacts are not yet fully visible. There are in addition several "known unknowns" that could affect the course of its development and its implications for the energy outlook. These include:

- ***GDP growth and rebound effects***: The impact of AI on productivity and GDP growth is highly uncertain. Quantitative estimates range from modest to transformative. Higher GDP growth could lead to higher energy demand. There are potential GDP downsides as well, if the huge investment and valuation underpinning the current AI boom turn out to be misplaced in the near term.

- ***Efficiency trends in hardware and software***: Huge progress is being made to improve the efficiency of AI-optimised chips, and breakthroughs in computing paradigms are possible. There is similar potential for improvements in the efficiency of AI models. Recent analysis from Google highlights these trends, reporting a 33-fold reduction in the per-prompt energy consumption of its Gemini model median prompt in just 12 months (Elsworth et al., 2025).

- ***AI uptake*:** The scale of uptake of AI remains uncertain. The type of AI use also matters. Video and image generation are much more energy intensive than text generation. Agentic AI workloads, where AI models perform extended online tasks, are also highly energy intensive.
- ***Innovation in the energy system*:** Perhaps the most substantial mid-term impact of the use of AI in the energy sector could come from accelerated innovation in energy technologies. Sudden solutions to highly complex engineering and scientific challenges should not be banked on. Over time, however, incremental accelerations to energy innovation could have substantial, but uncertain, cumulative effects.

As and when these impacts become apparent, their implications will need to be factored into the outlook. The IEA will continue to monitor the energy sector and broader AI impacts closely.

1.6 What more needs to be done to provide universal, affordable access to electricity and clean cooking?

Achieving universal access to electricity and clean cooking is an integral part of strategies for economic and human development. Remarkable progress has been made over the past two decades: since 2000, 1.6 billion people have gained access to electricity, and 2.2 billion have moved away from traditional, inefficient cooking methods that harm both health and the environment. Yet the challenge remains vast. Today, around 730 million people still live without electricity, and nearly 2 billion – one-quarter of the global population – continue to rely on polluting cooking methods.

Developing countries in Asia and Latin America and the Caribbean have led progress over the past decades. Both regions have now achieved electrification rates of 98% and have registered major gains in clean cooking. Since 2010, almost 1.5 billion people in these regions have gained access to modern stoves and fuels, halving the total number of people without clean cooking in just fifteen years. Countries such as India, Indonesia and China have shown how ambitious policies and large-scale programmes can transform access, but less progress has been made in other countries. In sub-Saharan Africa, electrification and clean cooking initiatives have not kept pace with rapid population growth: the region remains home to 80% of the world's population that lack access to electricity, and the number of people lacking clean cooking solutions continues to rise.

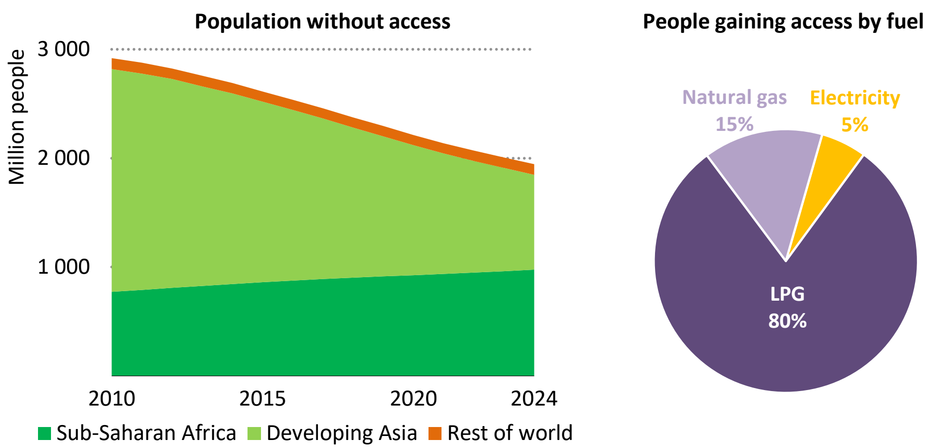
Global progress has slowed in recent years. The Covid-19 pandemic, together with the impacts of the global energy crisis, strained public budgets and made affordability an even bigger challenge. Countries with large remaining access gaps face particularly steep barriers, including high financing costs, heavy debt burdens and shrinking development budgets. In 2022, for the first time in decades, the number of people without access to electricity increased worldwide. That trend has since reversed, but progress remains slower than before the pandemic across all regions. While declining costs for solar PV and batteries, innovative business models, new policy initiatives and fresh investment momentum for both electricity and clean cooking access have brought encouraging signs, current trajectories fall short of the pace required to deliver universal access over the next decade and even by mid-century.

Successful examples from around the world show that ambitious access programmes can close large gaps in a relatively short time. The priority now is to build on these best practices by accelerating and scaling proven, affordable solutions, policy frameworks and programmes while tackling the barriers that continue to hold back progress in the regions most in need. Building on the analysis in Chapter 6, this section explores current trends and what more needs to be done to achieve universal access to modern energy services. It introduces a new scenario, the Accelerating Clean Cooking and Electricity Services Scenario (ACCESS), which projects how access rates would increase if countries were able to replicate the best rates of progress witnessed in other countries.

1.6.1 Clean cooking access

The pace of progress to expand access has slowed in recent years. In 2019, almost 120 million people globally gained access to clean cooking, while in 2023, 100 million people did so (Figure 1.19). In Asia, the countries that drove improvements over the past decades are seeing progress slow as they approach universal access. Part of this deceleration is offset by faster progress in Pakistan, Cambodia and Myanmar, which each recorded all-time highs in households gaining access in 2023. In Latin America and the Caribbean, recent progress has been limited and largely concentrated in the Central American countries.

Figure 1.19 ▷ Population without clean cooking access by region, 2010-2024, and people gaining access by fuel, 2019-2024



LPG drives access gains, while Africa's population without access continues to expand

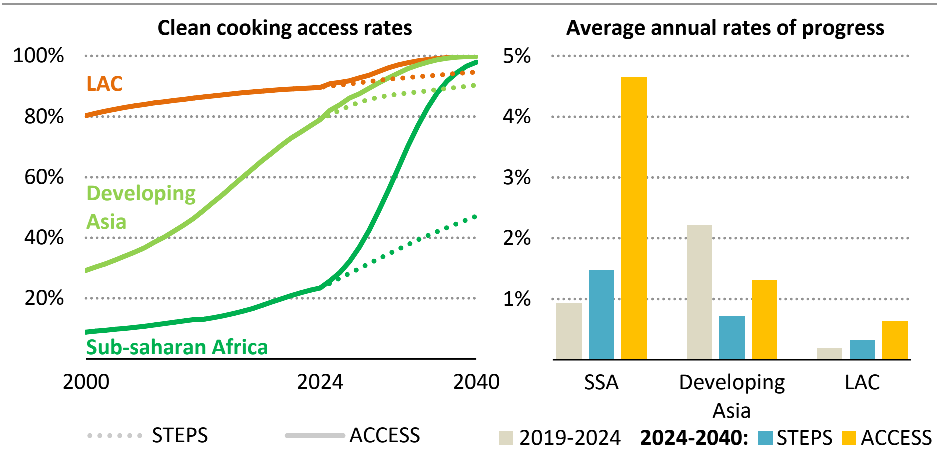
Note: LPG = liquified petroleum gas.

While the number of people without access to clean cooking has been increasing in sub-Saharan Africa, the underlying conditions for extending access have been gradually improving. Private sector businesses and financiers are participating more actively to facilitate access, and innovative technologies and business models are providing new and more cost-effective ways to broaden access. Clean cooking has also attracted recent political attention, with mentions in recent G7 and G20 communiqués and the launch of the 2024 Clean Cooking Declaration.

In a rising number of countries, national strategies, targeted subsidies, tax and tariff reforms, and results-based financing are broadening access and lowering household costs. IEA tracking shows that more than half of the population without access live in countries that demonstrated progress on policies related to clean cooking in 2024. Most progress is concentrated in sub-Saharan Africa, where seven-in-ten people without access live in countries that have recently introduced policies designed to increase access to clean cooking.

Policy action is the main differentiator between the scenarios. In the STEPS, policy commitments are translated into accelerated progress, with the number of people without access decreasing to below 1.7 billion by 2030. The decrease is driven by continued progress in Asia and successful efforts to halt the rise in the number of people without access in sub-Saharan Africa, which peaks in 2028. In the CPS, by contrast, constrained public budgets, higher borrowing costs and slower implementation limit the extent to which outcomes improve. The pace of access gains slows, particularly in rural and peri-urban areas, leaving around 200 million more people without access to clean cooking in 2030 than in the STEPS.

Figure 1.20 ▷ Clean cooking access by region, 2000-2040, and average annual rates of progress in ACCESS and STEPS, 2024-2040



The Latin America and the Caribbean region reaches universal access first, closely followed by developing Asia, while sub-Saharan Africa takes longest to achieve the goal

Note: LAC = Latin America and the Caribbean; STEPS = Stated Policies Scenario; ACCESS = Accelerating Clean Cooking and Electricity Services Scenario.

The ACCESS shows what is possible by replicating the fastest historical rates of progress observed in comparable contexts. In the ACCESS, an average of around 130 million people gain the ability to use modern fuels for cooking each year up to 2040, putting the world on course for universal access to clean cooking around 2040 (Figure 1.20). The bulk of the acceleration occurs in sub-Saharan Africa, where success depends on a concentrated scale-up of national, multilateral and private finance. Average annual investment needs for clean cooking are around USD 4 billion to 2040, with funding shifting from developing Asia, 80% of investment today, to sub-Saharan Africa, two-thirds of investment between 2035 and 2040. The make-up of financing evolves, with debt finance up from 35% today to nearly 60%. While the private sector provides the majority of capital, this is anchored in the ACCESS by public and concessional capital, particularly in less mature markets and lower income communities.

In the ACCESS, demand for modern cooking fuels increases 1.5-times from current level by 2040 in emerging market and developing economies. While this is a substantial shift – roughly equivalent to current total energy use in France – it accounts for a relatively small share of global energy demand growth. Liquefied petroleum gas (LPG) underpins 63% of new access, increasing its use in cooking to around 3.4 mb/d by 2040; electric cooking provides access to 18% of the population and adds about 120 TWh; bioethanol supports access for 4% and use rises to roughly 6.5 billion litres; and the use of biogas and modern solid biomass also expands. In sub-Saharan Africa, the transition to modern cooking fuels has a particularly pronounced impact, reshaping regional energy consumption patterns.

1.6.2 Electricity access

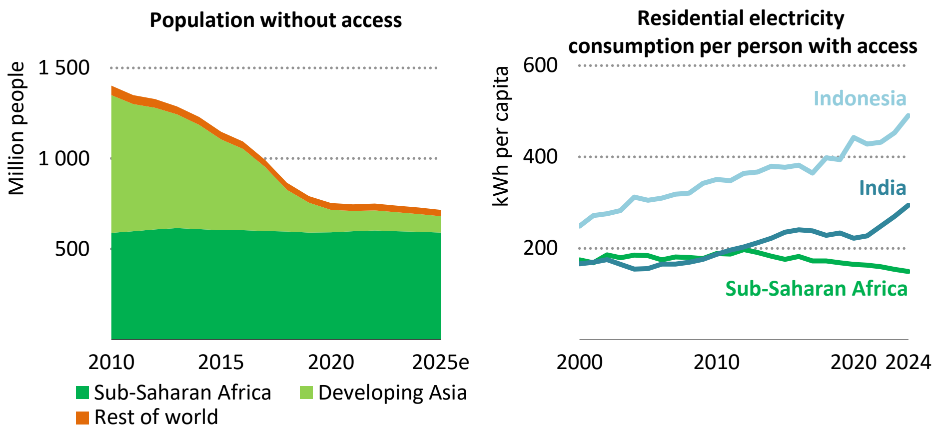
Progress on electricity access has been remarkable in recent decades. Since 2000, the number of people without electricity has fallen by almost a billion, and 40 countries have reached near-universal access (Figure 1.21). After setbacks related to the Covid-19 pandemic and the global energy crisis, the global trend is once again downward, but the pace of progress remains well below that achieved before the pandemic. In 2024, the number of people without access fell by 11 million, which is less than the average 65 million annual reductions seen between 2010 and 2019.

Developing countries in Asia and Latin America and the Caribbean, which have driven most of the gains over the past two decades, are nearing universal access. As their contribution to global progress diminishes, attention is increasingly shifting to Africa, where 80% of the population still without access lives. In sub-Saharan Africa, the pace of electrification has also slowed. High levels of debt in the aftermath of the Covid-19 pandemic and the global energy crisis, combined with cuts in international aid, continue to weigh heavily on progress. In 2024, 27 countries made less progress on electrification than on average during the 2015–2019 period.

New electrification policies and investment plans contribute to an improving outlook. Based on the IEA detailed tracking of energy access policies, around 60% of people without access live in countries that introduced new electricity access measures in 2024 and early 2025.

These include tax and consumer incentives, electrification programmes, national strategies and other targeted actions. Such domestic initiatives are being reinforced by international efforts, including those made under South Africa's G20 Presidency and Mission 300, and may be further strengthened by the focus on electricity and clean cooking access at the COP30 meeting that will take place in Brazil in November 2025.

Figure 1.21 ▷ Population without electricity access, 2010-2025e, and average residential electricity consumption per capita with access, 2000-2024



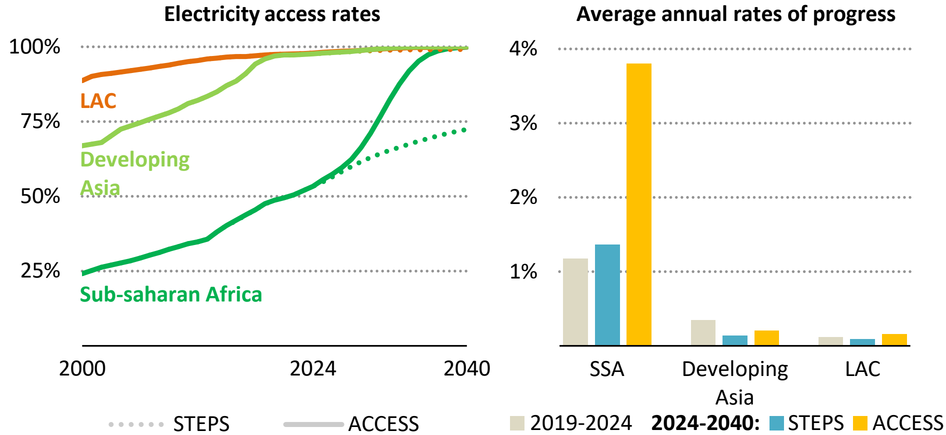
Developing Asia is approaching universal electricity access and electricity use is rising, while progress in sub-Saharan Africa is stagnating and household consumption is falling

Note: 2025e = estimated values for 2025.

On the basis of current trends, around 710 million people are projected to remain without access to electricity in 2030, and 650 million in 2050. Recent policy momentum improves the outlook somewhat: in the STEPS, the number of people without electricity falls by an additional 70 million in 2030 and 140 million in 2050 compared with the CPS. However, the progress made in the STEPS remains insufficient to achieve universal access by 2030 or even by mid-century.

By replicating the fastest electrification progress achieved, universal access to electricity could be reached within just a decade. The ACCESS sees an average of 80 million people gain access to electricity each year to 2035, with rapid parallel deployment of grids, mini-grids and stand-alone systems (Figure 1.22). By 2040, the additional electricity demand from households gaining access in the ACCESS scenario reaches 270 TWh – roughly equivalent to electricity consumption in Italy today. The impact is particularly pronounced in sub-Saharan Africa, where new access accounts for around 45% of additional electricity demand to 2040, compared with 15% in developing Asia and 6% in other regions.

Figure 1.22 ▷ Electricity access rates in the STEPS and ACCESS to 2040, and average rates of progress by scenario, 2024-2040



Developing Asia and Latin America and the Caribbean approach universal access in the STEPS, while sub-Saharan Africa still faces a large gap

Note: LAC = Latin America and the Caribbean; STEPS = Stated Policies Scenario; ACCESS = Accelerating Clean Cooking and Electricity Services Scenario.

The ACCESS outlook depends on around USD 250 billion of investment by 2035 to fund capital expenditure, including the cost of installing grid or mini-grid lines and equipment costs for decentralised solutions. This translates to around USD 23 billion of spending per year, which represents a sizeable portion of expected power sector investment outlays in the coming years, and would mean a sevenfold increase in the level of financing commitments directed to electricity access today. Mobilising more private finance is essential to expand electricity access at this pace, with several new financing solutions showing promise: these include off-balance sheet financing for stand-alone systems, and the use of local currency guarantees and green bonds for mini-grids. For smaller scale projects and harder-to-reach communities, private finance will rely on concessional and public finance to de-risk projects and ensure power is affordable for consumers.

1.7 How are critical minerals and other emerging issues changing the energy security landscape?

In recent years, the global geopolitical landscape has been marked by more fragility and rising tensions. Following Russia's invasion of Ukraine and instability in the Middle East, concerns about the security and affordability of energy supply have deepened, prompting countries to prioritise security considerations in policy and investment decisions. Many countries are turning to more diversified or home-grown energy sources to reduce exposure to geopolitical risk. At the same time, energy and material exports are increasingly being used as instruments of foreign policy. Alongside the expansion of global trade, there has been a notable rise in the use of trade measures as geopolitical tools, including restrictions on materials and access to technologies.

Traditionally, energy security focused on ensuring the adequacy of supply, but diversity, flexibility and resilience are emerging as the new watchwords in today's fragile environment. The focus of electricity policy is shifting from securing investment in generation capacity to mobilising investment in system flexibility that can balance increasingly volatile demand and supply. Rising risks of disruption from geopolitical tensions and extreme weather have pushed the resilience and diversity of supply sources higher up the policy agenda. At the same time, the scope of energy security has broadened as new risk factors come into play.

1.7.1 Critical minerals and energy technology supply chains

The coming Age of Electricity is creating new dependencies that broaden the scope and complexity of the energy security landscape. Critical minerals, which underpin a wide range of energy and industrial technologies, are a prime example of these new hazards. These minerals are vital for power grids, batteries and EVs, but they also play a crucial role in AI chips, jet engines, defence systems and other strategic industries. This makes them central not only to energy security but also to broader economic resilience. These minerals are not directly used to run cars or heat homes, so supply shortages do not have the same immediate impacts as those for fuels like oil and natural gas. Yet disruptions to their supply can still cripple key manufacturing industries, with far-reaching consequences for economies and jobs.

Diversification is central to energy security, yet the production, refining and processing of critical minerals is becoming increasingly concentrated in a few countries, heightening vulnerability to shocks and disruptions. Between 2020 and 2024, most of the growth in refined production of key energy minerals came from the leading suppliers. As a result, geographic concentration in refining increased for nearly all key energy minerals, and particularly for nickel and cobalt. The average market share of the top-three refining nations of key energy minerals rose from around 82% in 2020 to 86% in 2024.

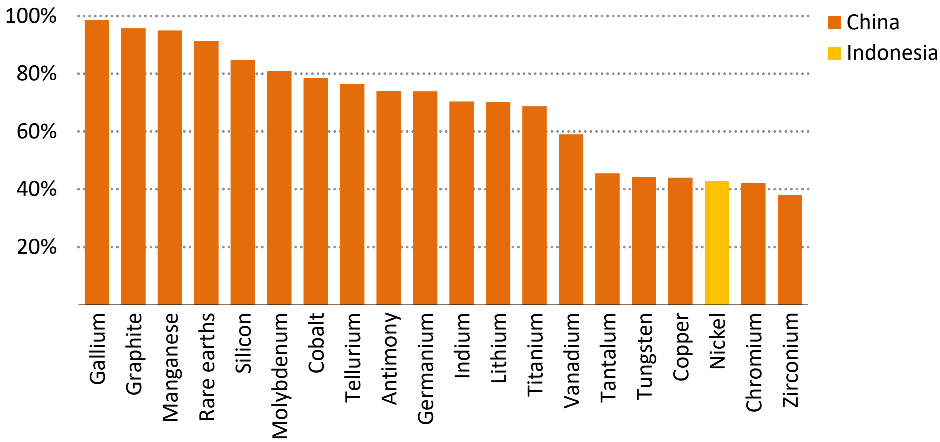
Our detailed analysis of announced projects suggests that progress towards more diversified refining supply chains is set to be slow. By 2035, the average share of the top-three refined material suppliers is projected to decline only slightly to 82%, effectively returning to the concentration levels seen in 2020. In the CPS, supply concentration is likely to remain higher than in the STEPS: it projects weaker demand, which translates into lower prices that favour incumbent producers sitting at the lower end of the cost curve. In the NZE Scenario, supply concentration challenges are compounded by volume risks as demand increases at a much faster pace.

Supply concentration is similarly stark across energy technology supply chains. In solar PV, China holds over 80% of global manufacturing capacity at every stage of the supply chain. In wind power, it accounts for nearly 80% of nacelle production and over 70% of blade manufacturing. China's dominance is even stronger in batteries, where it commands at least 85% of capacity across the value chain and over 95% in the case of anodes.

This high market concentration creates a risk of major supply shortfalls if production from the largest supplier is disrupted by extreme weather, technical failures or trade restrictions. For battery metals and rare earths, when the supply and demand of the largest producer are excluded, supplies outside the leading producer meet on average only half of the remaining demand in 2035.

Expanding the scope of analysis to a wider set of 20 energy-related strategic minerals reveals further vulnerabilities, stemming from high supply concentration, price volatility and by-product dependence (IEA, 2025c). A key point from this analysis is that China is the dominant refiner for 19 of the 20 minerals analysed, holding an average market share of around 70% (Figure 1.23).

Figure 1.23 ▷ Top refiner share of selected energy-related strategic minerals by country



China is the leading producer for nearly all of the 20 energy-related strategic minerals analysed, with an average market share of around 70%

Note: Values refer primarily to 2024, or to the latest year for which data are available in certain cases.
Source: IEA (2025c).

With a recent proliferation of export controls on key materials and technologies, these supply risks are no longer just a theoretical concern. As of October 2025, more than half of these 20 strategic minerals are subject to some form of export controls. A notable development came in April 2025, when the Chinese government introduced export controls on seven heavy rare earth elements, along with their related compounds, metals and magnets. As export volumes fell sharply, many automotive manufacturers in the United States, Europe, and elsewhere struggled to secure rare earth magnets, and some were forced to cut utilisation rates or even temporarily shut down factories. In October 2025, these export controls were tightened to include parts, components and assemblies produced using Chinese materials or technologies. While the market sizes for these strategic minerals are relatively small compared with bulk materials, disruptions in their supply can nevertheless have outsized economic impacts. For example, a 10% disruption in rare earth magnet exports could affect the production of 6.2 million conventional cars, or almost 1 million industrial motors, or 230 000 civilian aircraft, or the construction of over 650 hyper-scale AI data centres. Determined action is required in the near term to enhance preparedness against potential disruptions, and over the longer term to diversify supply chains.

1.7.2 Electricity security

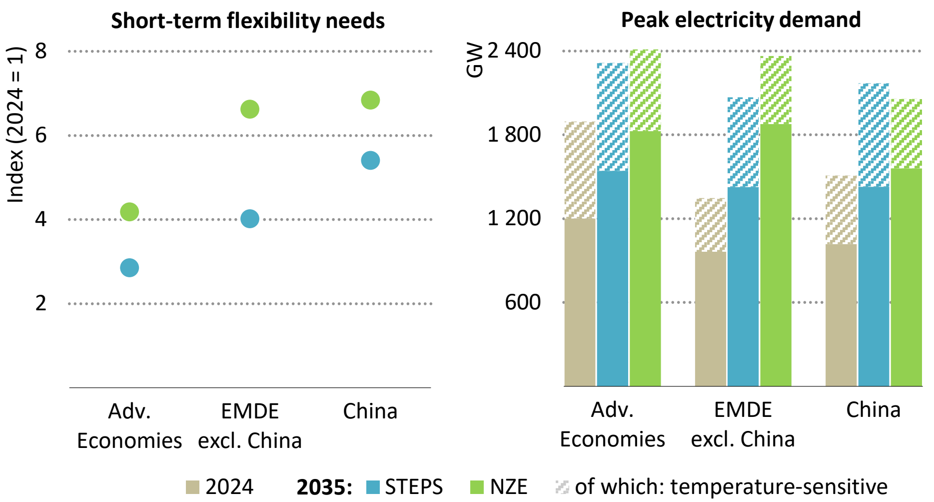
As the share of electricity in the global energy mix rises across all IEA scenarios, the need to ensure the resilience and security of power systems is moving to the top of the energy policy agenda. Its growing importance as a major energy carrier means that the economic cost of power outages and system failures is rising sharply. Recent blackouts in Chile and the Iberian Peninsula illustrate how quickly supply interruptions can cascade through increasingly interconnected systems, affecting millions of households and businesses (see Chapter 8).

Ensuring electricity security begins with maintaining adequate supply to meet rising and increasingly variable demand. Electrification, climate change and shifting consumption patterns are reshaping electricity demand profiles. In the STEPS, global peak electricity demand increases by about 40% between 2024 and 2035. The CPS sees similar growth in peak demand, with lower levels of electrification counterbalanced by slower efficiency improvements. In the NZE Scenario, peak demand increases even faster as electrification accelerates across sectors, particularly in industry and transport. However, improvements in cooling efficiency and the widespread adoption of heat pumps for space heating reduces the temperature sensitivity of electricity demand, enhancing its resilience to weather extremes.

On the supply side, the rapid deployment of variable renewables introduces new operational challenges. Systems dominated by renewables must be able to meet demand when low wind and solar output coincides with periods of high demand. Periods of high renewables generation can also pose stability challenges as low system inertia increases the risk of frequency deviations.

Flexibility, defined as the ability to balance the variability of demand and supply, has become a critical element of electricity security. Short-term flexibility requirements, currently around 10% of average demand in many systems, rise two- to seven-times by 2035 in the STEPS, outpacing electricity demand growth. The NZE Scenario projects a significantly higher need for short-term flexibility requirements, which rise two- to ten-times by 2035 to ensure system reliability amid the swift expansion of variable renewables and changing patterns of electricity demand (Figure 1.24). While dispatchable plants such natural gas, coal, hydropower or nuclear plants remain essential, their role increasingly shifts from bulk generation towards ensuring secure capacity and flexibility. Batteries and demand response are set to become major contributors to system reliability, supplying most of the needed short-term flexibility by 2035. In 2024, global battery storage additions reached 77 GW thanks to strong policy support and declining technology costs. Total installed battery capacity reaches nearly 1 700 GW by 2035 in the STEPS, around 1 400 GW in the CPS, and close to 2 900 GW in the NZE Scenario.

Figure 1.24 ▷ Short-term flexibility needs and peak electricity demand by scenario, 2024-2035



Both short-term flexibility needs and peak demand rise through to 2035; higher efficiency makes demand more resilient to extreme weather in the NZE Scenario

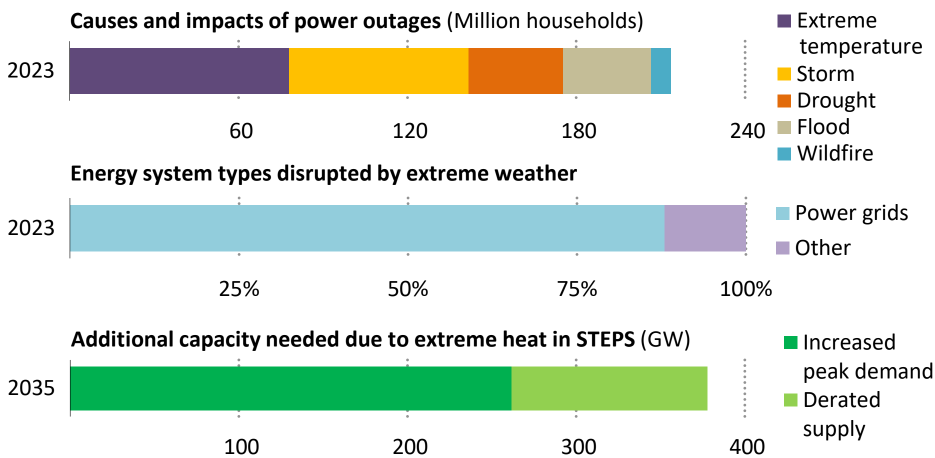
Notes: GW = gigawatt. STEPS = Stated Policies Scenario; NZE = Net Zero Emissions by 2050 Scenario; Adv. Economies = advanced economies; EMDE excl. China = emerging market and developing economies excluding China. Peak demand does not include the activation of demand response.

There are other important facets of electricity security as well. In many regions, seasonal flexibility needs grow faster than overall electricity demand by 2035 in the STEPS, and even more in the NZE Scenario, as a result of the increasing requirement to manage prolonged periods of low renewables output or temperature-driven demand changes. Ageing transmission and distribution networks pose increasing reliability risks, calling for targeted modernisation and digitalisation. Traditional market designs focused on ensuring sufficient generation capacity need to value flexibility, ancillary services and resilience, and market frameworks need to include incentives that reward demand response, smart infrastructure, and innovative technologies that facilitate efficient and secure management of controllable loads.

1.7.3 Infrastructure resilience

The resilience of energy infrastructure in the face of natural hazards is becoming increasingly important. These hazards include geophysical risks such as earthquakes and tsunamis as well as extreme weather and related events such as storms, floods, droughts, heatwaves and wildfires. Extreme weather events are becoming more consequential, undermining the reliability of energy systems through outages and increasing delivery costs to consumers through losses, damages and higher insurance premiums. A new IEA dataset shows that extreme weather events caused nearly 300 disruptions of critical energy infrastructure in 2023. Power lines proved most vulnerable, with damages to transmission and distribution grids accounting for about 85% of these incidents (Figure 1.25). Other notable impacts include: drought-related water scarcity that constrain hydropower output; wildfires that force utilities to de-energise power lines; and hailstorms that damage solar PV facilities. Rising electrification and digitalisation of economic activity means that power outages carry much more significant economic costs.

Figure 1.25 ▷ Impacts of extreme weather events in 2023, and additional power capacity needed from extreme heat in the STEPS, 2035



Extreme weather caused power outages in more than 200 million households in 2023, additional capacity will be needed to compensate for extreme weather impacts

Notes: GW = gigawatt; STEPS = Stated Policies Scenario. The year 2023 provides a snapshot of the impacts of extreme weather events on energy infrastructure. It does not necessarily represent an average weather year, as weather is variable. Outage numbers are likely underestimated due to variability of reporting by region. Events are recorded as a single type, which consolidates compound effects such as storms leading to floods. "Extreme heat" is the difference between the median and the top-three peak demand values across 30 years of weather data (see Chapter 5, section 5.2.4).

Recent trends show that some extreme weather events are becoming more frequent and intense. Extreme heat is a case in point. Rising temperatures drive electricity demand higher as the use of air conditioners increases, and this particularly affects peak demand. In the STEPS, income-driven growth in the use of air conditioning raises peak demand by over 330 GW by 2035 compared to today, and increasing use driven by long-term temperature rise adds another 170 GW. In very hot years, extreme peak temperatures could push demand up by an additional 260 GW. These cumulative increases would raise peak demand by over 15% by 2035 over today's level. The impacts are even more significant in the CPS, where less efficient air conditioning units and higher extreme temperatures amplify peak demand pressures.

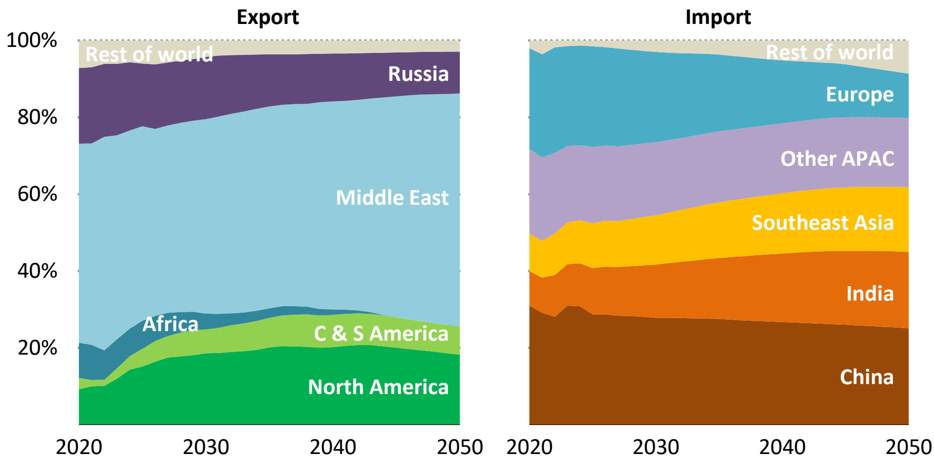
These pressures can be compounded by the effects of extreme weather on power infrastructure, for example when droughts reduce hydropower output or when there are long periods of low wind power output. High temperatures can also lower generation capacity at thermal plants due to constraints on the discharge of water used for cooling, equipment stress and physical decreases in production efficiency. When such capacity reductions coincide with surging demand from extreme heat, we estimate that the combined effect could add an additional 6% to projected peak demand by 2035 in both the CPS and the STEPS. This is equivalent to around one-half to one-third of typical reserve margins, highlighting the importance of considering extreme high temperatures during capacity adequacy planning.

1.7.4 Oil and gas supply chains

The importance of addressing emerging vulnerabilities does not imply any lessening of the need for vigilance when it comes to traditional oil and gas security. Concerns about tightness in fossil fuel markets are beginning to ease, but shifting geopolitical dynamics and persistent risks to oil and gas supply chains could quickly erode existing buffers and alter market balances. For example, accelerating decline rates in existing oil and gas fields pose major supply risks if adequate investment is not maintained. IEA analysis of around 15 000 fields worldwide shows that natural decline rates are becoming steeper (IEA, 2025d). If all capital investment in current oil and gas production were to cease immediately, global oil supply would fall by around 5.5 mb/d each year and natural gas output by 270 bcm. In 2010, these figures were 3.9 mb/d and 180 bcm respectively. Nearly 90% of upstream investment today is directed to offsetting declines rather than expanding capacity.

Both the CPS and the STEPS see rising import dependence in major consuming regions, particularly Asia and Europe. Emerging market and developing economies in Asia, including China, are the destination for around 60% of the oil and gas exported worldwide in 2035 in both scenarios. Asia's share of global oil imports increases in the STEPS from just over 70% today to 80% by 2050 (Figure 1.26). The Middle East remains the dominant oil exporter, sending out three-times more oil than the next-largest exporter in 2035. Oil and gas trade flows become increasingly dominated by exports from the Middle East to Asia. This increases the sector's vulnerability to disruptions at key maritime chokepoints, including the Strait of Hormuz, the Strait of Malacca, the Suez Canal and Red Sea, and the Panama Canal, and at major ports in key exporting and importing regions. Oil and gas exports are also vulnerable to weather-related disruption. By 2035, nearly 30% of LNG passes through the US Gulf Coast, an area historically exposed to hurricane-related disruptions.

Figure 1.26 ⊳ Oil export and import share by region in the STEPS, 2020-2050



Oil trade flows are becoming increasingly concentrated between the Middle East and Asia, heightening exposure to disruptions at major maritime chokepoints and key ports

Note: C & S America = Central and South America; Other APAC = Other Asia Pacific.

1.8 Where will all the LNG go?

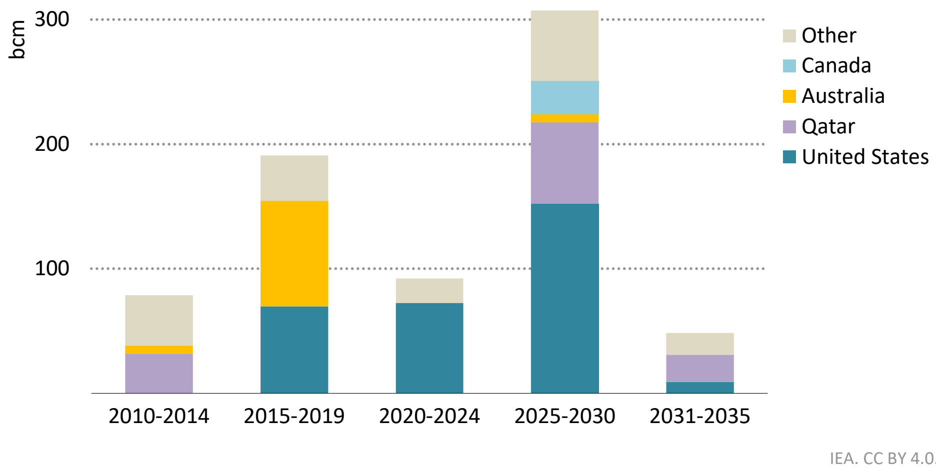
Since 2015, consumption of LNG has increased twice as fast as that of natural gas, and LNG overtook large-scale pipelines in 2023 as the predominant way of trading gas over long distances. The rise of LNG has reshaped global gas trade, opening new markets, upending established trade patterns, reconfiguring geopolitics and bolstering energy security for those countries able to afford it.

LNG supply has tended to expand in cycles. After a relatively muted period of export capacity growth between 2020 and 2024, the period from 2025 to 2030 is set to see an unprecedented 300 bcm of new LNG export capacity come online (Figure 1.27),[2] which will lead to a 50% increase in available global LNG supply. Based on projects currently under construction, more than half of the capacity is being built in the United States, and a further 25% in Qatar. Unlike previous waves of capacity growth, around three-quarters of the new

[2] This translates into a 265 bcm increase in available LNG capacity, which takes into account maintenance work, unplanned outages and issues at upstream facilities, as well as 10 bcm of existing capacity that is set to shut by 2030. LNG demand in 2024 was 560 bcm.

supply is flexible, either as uncontracted gas that can be sold on the spot market or under a long-term contract with flexible destination clauses. The key questions, therefore, are in which markets, at what price and under what conditions this rising tide of LNG supply can be absorbed.

Figure 1.27 ▷ LNG capacity under development by supplying country, 2010-2035



United States has driven global liquefaction capacity growth for the past decade and it is set to expand its capacity by a further 160 bcm to 2035

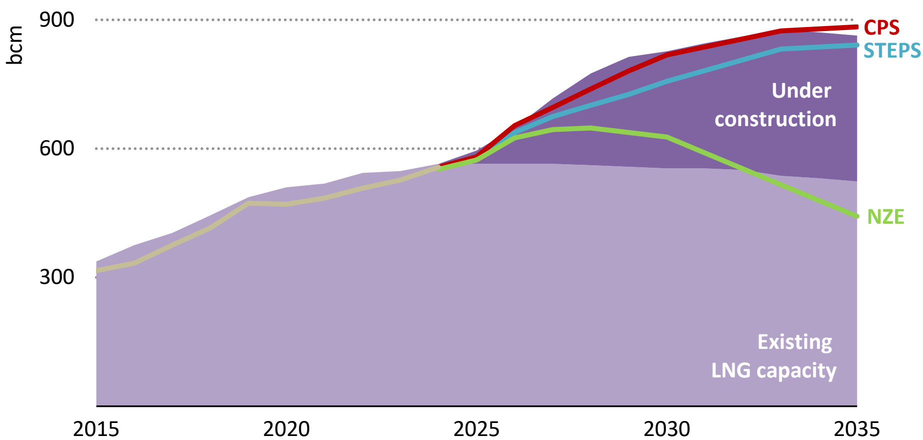
Note: bcm = billion cubic metres.

1.8.1 Global LNG outlook to 2035

In the CPS, global LNG demand increases by 260 bcm between 2024 and 2030 (Figure 1.28), absorbing the increase in available LNG capacity over this period. Gas prices reflect this demand pull, and are close to the long-run marginal cost of delivering LNG, which includes the full capital costs associated with developing liquefaction, shipping and regasification. Large, well-established importers such as China, Europe and Japan absorb around half of the increase in LNG supply to 2030. There are also large increases in LNG demand in emerging market and developing economies in Asia, but high gas prices limit the degree of uptake of natural gas in the CPS in lower income and more price-sensitive countries. By 2035, around 20 bcm per year of LNG export capacity is required above what is currently existing and under development.

In the STEPS, LNG demand increases by 200 bcm between 2024 and 2030. This is smaller than the change in available LNG export capacity, and puts downward pressure on LNG prices, bringing them close to short-run marginal costs. Stronger renewables growth, increased electrification, and more rapid efficiency gains in the STEPS lead to more LNG being crowded out of the market in China and Europe than in the CPS. This frees up relatively low-cost LNG for price-sensitive consumers in other markets, notably in India and other parts of South and Southeast Asia, but – given their stated policy settings and continued efforts to electrify and deploy renewables – the increase in demand from these consumers is not sufficient to absorb all of the remaining wave of new LNG supply. This results in an overhang of available LNG capacity of around 65 bcm in 2030. The surplus is gradually worked off by 2035.

Figure 1.28 ▷ Existing and under construction available LNG export capacity and LNG trade by scenario to 2035



IEA. CC BY 4.0.

The large upcoming wave of additional LNG export capacity is fully absorbed in the CPS but results in well-supplied global gas markets in the STEPS through to 2035

Note: CPS = Current Policies Scenario; STEPS = Stated Policies Scenario; NZE = Net Zero Emissions by 2050 Scenario.

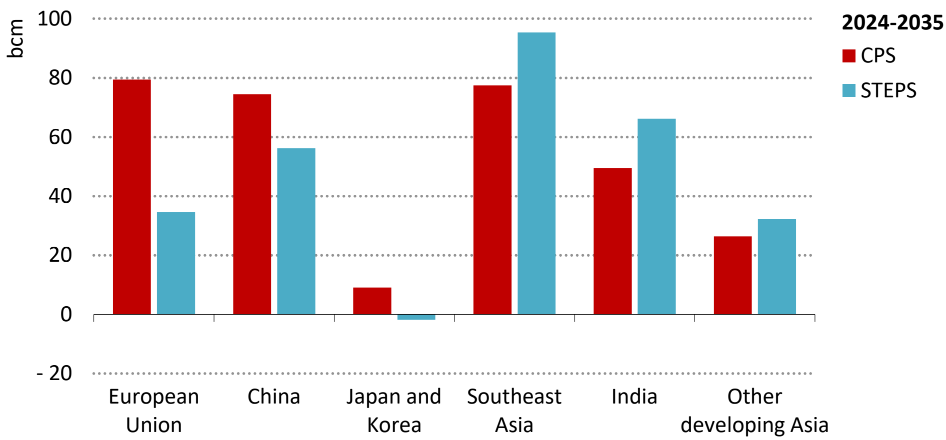
In the NZE Scenario, the sharp decrease in global natural gas demand means that many of the LNG projects currently under construction are no longer necessary. If they were to go ahead, aggregate capacity utilisation would fall to 75% in 2030 and 50% in 2035, and several plants that found themselves unable to compete in a supply glut would be likely to end up closing or being repurposed to trade hydrogen-based fuels such as ammonia or methanol.

1.8.2 Advanced economies

The European Union vastly increased its LNG imports after dramatic cuts to Russian pipeline deliveries in the wake of Russia's invasion of Ukraine in 2022. Acutely aware of dependence on imported fossil fuels as a strategic vulnerability, the European Union has made clear that its efforts to reach net zero emissions are driven by security concerns as well as concerns about climate change.

Natural gas demand in the European Union peaked in 2010, and it fell by 20% between 2021 and 2024. Demand is set to fall further, but LNG imports expand in both the CPS and the STEPS to 2035 as domestic production dwindles, and pipeline imports continue to decline. In the CPS, where the transition to low-emissions energy sources is slower than in the STEPS, gas demand falls by 35 bcm between 2024 and 2035, and LNG imports increase by 80 bcm. In the STEPS, demand falls by 75 bcm to 2035 as the European Union continues to electrify light industry and heating, and the increase in LNG imports is 35 bcm. Gas will nevertheless remain essential to EU energy security in both the CPS and the STEPS in the years ahead, providing power system stability and significant seasonal storage capabilities (Figure 1.29).

Figure 1.29 ▷ Change in LNG demand in the European Union and Asia by scenario, 2024-2035



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Strong demand from established importers raises prices in the CPS, moderating growth elsewhere; in the STEPS, ample supply and low prices boost LNG in developing Asia

Japan and Korea are nearly fully dependent on imported LNG to meet domestic gas demand. In Japan, the prospects for additional LNG use depend to a large extent on nuclear restarts: every 1 GW of capacity brought back online would reduce LNG demand by around 1-1.5 bcm. In the CPS, LNG imports in Japan in 2035 reach around 100 bcm, 7% higher than 2024 levels; in the STEPS, there is a slight reduction in LNG imports. In Korea, LNG imports in the CPS are flat to 2035; in the STEPS, expanding use of renewables slightly lowers gas use in the power sector and offsets modest industrial gas demand growth, and LNG falls slightly to 2035.

1.8.3 Emerging market and developing economies in Asia

Since 2015, around 35% of global LNG supply growth has been absorbed by China, even though natural gas accounts for a relatively small share of its overall energy mix. This reflects significant gas infrastructure expansion, an opening of the domestic market, and broad-based growth in demand.

China is a wild card for global LNG. Its LNG imports are set to be lower in 2025 than in recent years due to stronger domestic production, increased imports of pipeline gas from Russia, and muted gas demand growth. The deepening energy relationship between China and Russia, including the prospect of a second Power of Siberia pipeline, raises questions about China's long-term appetite for additional LNG volumes. A key engine of gas demand growth in China in recent years has been light industry, which is projected to continue to electrify in the STEPS. Gas has also been used to meet rising power demand, but its share of the generation mix has remained around 3% since 2019, while the solar share has risen from 3% in 2019 to 8% in 2024. In the STEPS, LNG demand in China increases from 110 bcm in 2024 to 165 bcm in 2035. LNG demand in the CPS in 2035 is higher at 180 bcm, due to slower electrification and renewables growth.

Fast-growing emerging market and developing countries in Asia offer another major opportunity for future LNG demand growth. This diverse group of countries includes: established importers like Singapore; major current LNG producers such as Indonesia and Malaysia; and relative newcomers to the business of importing LNG such as Viet Nam and the Philippines. In India, LNG has been growing in recent years, driven by opportunistic buyers and strong potential growth in demand, especially in industry. In countries with mature domestic gas production, such as Thailand, Indonesia, Malaysia, Pakistan and Bangladesh, LNG is a logical replacement for declining domestic gas. In many of these countries, natural gas is viewed as a cleaner and more convenient alternative to coal and heavy fuel oil, and there are policies targeting improved air quality or programmes to expand gas infrastructure (Box 1.5).

The critical variable affecting the scale of demand growth is price. In the STEPS, weighted average gas import prices in emerging market and developing countries in Asia are around USD 7.5 per million British thermal units (MBtu) in the 2030-2035 period, around 40% lower than today. This underpins significant LNG demand growth, especially in energy-hungry price-sensitive markets: in Southeast Asia LNG imports quadruple by 2035, and in India they triple. However, this growth depends on overcoming infrastructure constraints: in Southeast Asia, several regasification projects remain in the planning stages; in India, downstream infrastructure is insufficient to fully utilise some of its LNG terminals.

Even at prices near to the short-run marginal cost of supply, LNG remains a premium fuel in a number of markets in Asia. Abundant supply may offer these countries significant optionality for security of supply reasons, and may help them to manage periods of system stress, but the economics of LNG make it difficult to penetrate these markets as a baseload fuel in the long run.

1.8.4 Implications for exporters

The period of LNG surplus in the STEPS makes it difficult for some exporters to fully recover their long-run marginal cost of supply, creating risks that project sponsors write off the value of the assets. The United States, as the most flexible supplier, sees the highest level of exposure to reduced rates of utilisation. This risk is borne primarily by those with equity or trading positions in LNG supply in the United States, such as portfolio players, rather than by LNG liquefaction terminal owners, who primarily sell export capacity at terminals, whether it is used or not. Suppliers selling LNG cargoes on a long-term take-or-pay basis could also pass much of the volume and price risk to off-takers.

However, the potential for LNG surpluses is not just a risk in the United States. The lower rates of LNG capacity utilisation in the STEPS become visible in exporters around the world as volume flexibility in existing contracts is fully exercised, legacy contracts are not renewed, and older plants with relatively high operating costs undergo prolonged maintenance or refurbishment.

Box 1.5 ▷ Can coal-to-gas switching absorb the wave of new LNG?

A central argument made by those that maintain the coming wave of LNG supply can be fully absorbed is that cheap gas could displace coal, especially in emerging market and developing economies in Asia. The potential is indeed significant: global LNG supply today is equivalent to just eight weeks of coal use in China and India alone.

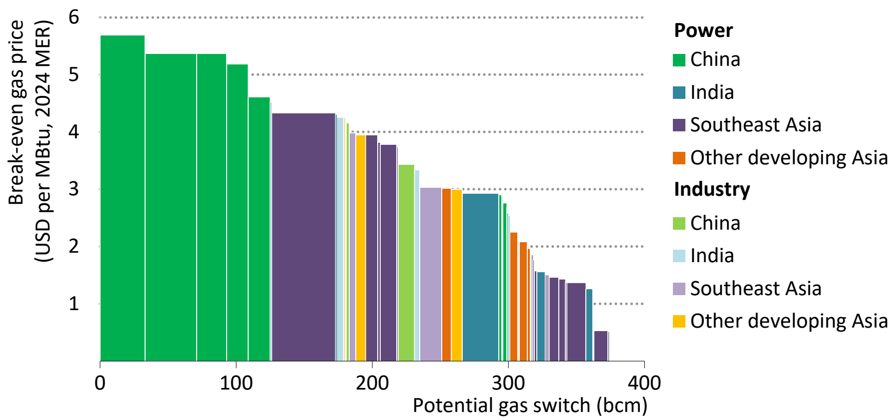
Since 2010, around 30% of the 380 bcm of natural gas demand growth in emerging market and developing economies in Asia has come from coal-to-gas switching, and virtually all of this happened in China. In the STEPS, softer near-term market balances encourage additional switching of around 40 bcm between 2024 and 2030, primarily in China as well as other coal-rich price-sensitive markets in Asia.

There is significant additional scope for coal-to-gas switching in 2030, although several factors limit this potential from being fully realised. For example, the role of coal in power generation is often shielded from market competition, with coal-fired plants operating in regulated markets or under long-term contracts guaranteeing minimum output (IEA, 2022). In addition, many industrial facilities and coal plants rely on cheap domestic coal; in practice the scope for switching using LNG is limited to plants using imported coal. There are also infrastructure and locational constraints, such as the capacity of electricity or gas grids to support near-term switching.

Taking these factors into account, we estimate nearly 400 bcm of coal-to-gas switching potential in the power and industry sectors is technically feasible beyond what occurs in the STEPS (Figure 1.30). This is the short-term switching potential, i.e. electricity generation or industrial output that can switch from coal-fired units to gas-fired units based on facilities and infrastructure that exist in 2030.

If delivered LNG prices were to fall to USD 5/MBtu, this would unlock an additional 100 bcm of short term coal-to gas switching, mainly in China's power sector. Further switching could occur if prices were to remain at this level for an extended period as this may encourage long-term decisions to replace existing or planned coal units with gas units instead, for example in power, steel or chemicals. However, the long-run marginal cost of global LNG supply is well above USD 5/MBtu and so it is unlikely that prices could remain around this level for a prolonged period.

Figure 1.30 ⊳ Additional coal-to-gas switching potential in emerging market and developing economies in Asia in 2030



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Nearly 400 bcm of coal-to-gas switching potential exists in emerging market and developing economies in Asia, but would require gas prices to fall to very low levels

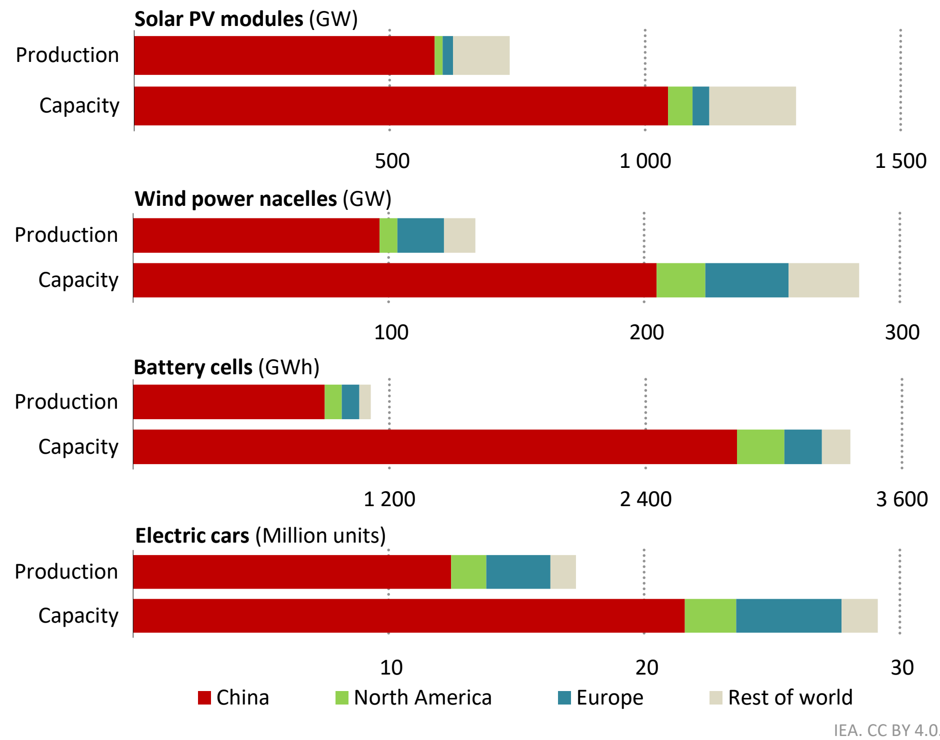
Note: MBtu = million British thermal units; MER = market exchange rate; bcm = billion cubic metres.

1.9 There is ample manufacturing capacity for many clean energy technologies, especially solar PV and batteries: will we use it?

Recent years have seen substantial investment in clean energy technology manufacturing. This has led to significant surplus capacity in the manufacturing of some key technologies (Figure 1.31). Global manufacturing capacity for PV modules was two-times higher than actual production in 2024, with a significant share of this production going into inventories; and three-times higher for battery cells. One of the key questions facing this *Outlook* is what happens to this surplus capacity in the context of increasing trade tensions, substantial pressure on technology prices, and falling profit margins for some technology producers. These themes and others impacting the future of clean energy technology manufacturing and trade will be explored in more detail in the forthcoming edition of *Energy Technology Perspectives*.

Much of this surplus capacity is in China. Since the largest outlet for its manufacturing capacity is its own huge domestic market, what happens in that market has a critical bearing on whether this capacity will be used. In recent years, the rapid growth of renewables deployment, EV sales and battery storage installations in China has been partly driven by aggressive pricing and competition as its producers seek market share. Curtailment rates of wind and solar have ticked up recently, and China raised its wind and solar PV curtailment thresholds in 2024. On the other hand, EV sales continue to increase and are spreading to segments beyond passenger cars, such as medium and heavy-duty trucks.

Figure 1.31 ▷ Global manufacturing capacity and production for selected clean energy technologies by region, 2024



There is substantial surplus manufacturing capacity for some clean energy technologies, much of which is in China

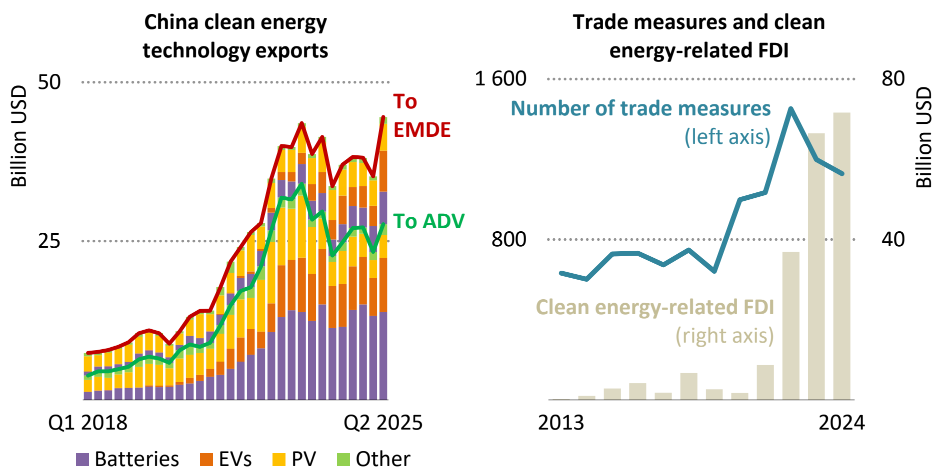
Note: GW = gigawatt; GWh = gigawatt-hour. Production figures are estimates. Production used to supply inventories is only included for solar PV.

Source: *Energy* Technology *Perspectives*, a forthcoming IEA publication, includes information on the data sources used in IEA analysis of clean energy technology supply chains.

Both the STEPS and CPS see continued momentum behind clean energy technology deployment in China driven by economic competitiveness, manufacturing momentum and policy support. Electric cars account for more than 90% of passenger car sales in China in both the CPS and the STEPS by 2035, up from around 50% in 2024; electric freight truck sales account for more than 50% of sales by the same year, up from just over 20% of the market in the first-half of 2025. In 2024, wind and solar PV accounted for 18% of electricity generation in China. In the STEPS, their combined share of total generation reaches roughly 50% by 2035. In the CPS, it is around five percentage points lower because less capacity is added and curtailment rates are higher in this scenario.

China's exports of clean energy technologies have increased by around four-times since 2019 and now account for around 5% of China's total goods exports. In the first-half of 2025, around two-thirds of these exports by value went to advanced economies and around one-third to emerging market and developing economies (Figure 1.32). This mix looks somewhat different by technology. Emerging market and developing economies accounted for over half of China's exports of solar PV equipment in 2025, but only one-quarter of battery exports. Exports by nominal value underplay the continuing growth in the scale of China's clean energy technology exports, as many of these technologies have experienced substantial price deflation in recent years.

Figure 1.32 ▷ Clean energy technology exports from China, 2018-2025, trade measures targeting China, and clean energy-related foreign direct investment by Chinese companies, 2013-2024



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Emerging market and developing economies account for about one-third of China's exports of clean energy technologies; exports values have risen despite falling prices

Notes: Q = quarter; FDI = foreign direct investment; EMDE = emerging market and developing economies; ADV = advanced economies. Exports stated in gross nominal terms. Clean energy-related FDI refers to FDI by Chinese firms.

Sources: IEA analysis based on data from Sinoimex (2025); GTA (2025); Net Zero Industrial Policy Lab (2025). Please see the forthcoming edition of *Energy Technology Perspectives*, an IEA publication, for more information on the data sources used in IEA analysis of clean energy technology supply chains.

These exports have the potential to bring about significant changes in the energy sectors of importing countries. For example, estimated Chinese solar PV panel exports to Pakistan since 2023 could power roughly one-third of its electricity generation, and solar PV may now have surpassed in capacity terms the installed capacity from conventional sources.[3] Chinese

[3] Solar panel imports are estimated in GW terms from the monetary value of imports.

manufactured low-cost electric cars are seeing rapid sales growth in some other emerging market and developing economies, and EV sales shares are now larger than in advanced economies in some cases (IEA, 2025e).

The dominance of China in global clean energy technology manufacturing and its surging exports have triggered concerns among a number of countries. China's manufactured goods surplus increased from around USD 1 trillion in 2019 to around USD 2 trillion in 2024, two-times faster than the rate from 2010 to 2019. Its extensive industrial policies, which are opaque and difficult to quantify, have been estimated to cost around 2-4% of GDP: this is far more than in advanced economies (IMF, 2025).

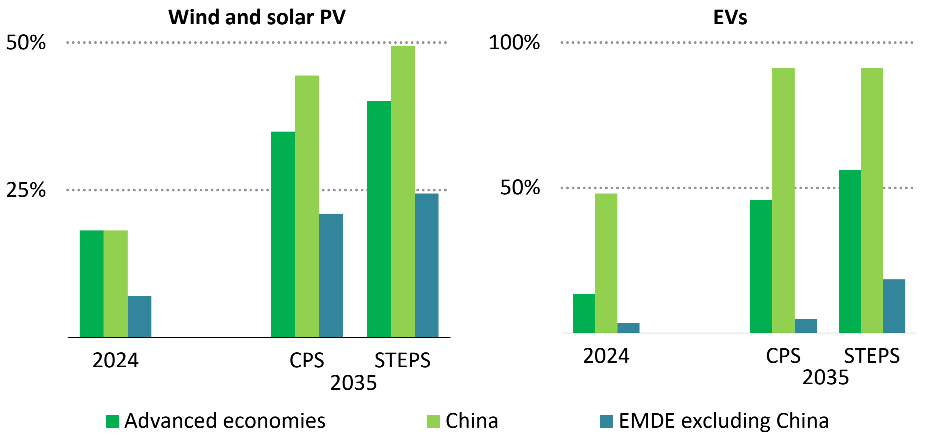
A highly competitive market, high rates of innovation, and extensive government support enable China to produce energy technologies at very low cost. However, in some cases, such as solar PV panels, current low prices are unsustainable, and companies are losing money (IEA, 2025f). Countries have responded by raising trade barriers, including targeting energy technologies such as EVs and solar PV. In response, Chinese companies have pledged around USD 230 billion in clean energy-related manufacturing investments overseas. China has also sought – thus far unsuccessfully – to promote consolidation in some of its clean energy technology manufacturing sectors.

Energy transitions hinge on sound domestic policy frameworks. For example, large-scale imports of solar PV in some cases are driven by defections from a dysfunctional central grid. Distributed solar PV can bring substantial benefits: it can reduce consumer costs, cut fuel import bills, and provide a first rung of energy access for underserved communities. However, distributed generation can also accelerate revenue losses for distribution companies. A fragmented electricity sector, with chronically weak distribution companies, is unlikely to provide a lasting basis for economic growth. In the case of EVs, infrastructure provision is essential to support high and expanding sales levels, and this requires effective policy and planning.

Key questions for the outlook therefore include whether international markets remain open to clean energy technology trade and investment, and whether domestic policy frameworks can learn and adapt to support energy transitions driven by disruptive, commercially available technologies. In the CPS, these obstacles to the diffusion of new technologies loom large, creating significant pressure on new energy industries to consolidate in order to lift utilisation rates and ensure profitability. In the STEPS, these constraints are less binding, and global deployment trends allow for more diversified clean technology value chains to emerge over time. However, only in more rapid energy transition outlooks like the NZE Scenario does the world fully utilise today's manufacturing capacity and then expand it.

Wind and solar PV show how the dynamics play out in the CPS and the STEPS. Together they met around one-fifth of electricity generation in advanced economies in 2024. In the CPS, this rises to around one-third by 2035, building on policy support and market competitiveness in many of these countries (Figure 1.33). Faster transitions in the STEPS see the share rise to two-fifths by 2035. In China, wind and solar PV reach around 45% of total generation by 2035 but are held back from increasing further by rising curtailment rates and challenges of grid integration. In the STEPS, market reforms and additional investment in grids, flexibility and storage see this share rise to nearly 50%, leading to substantial declines in coal generation. In emerging market and developing economies other than China, there is a substantial rise in the share of wind and solar PV in both the CPS and the STEPS, although it is more pronounced in the STEPS.

Figure 1.33 ▷ Wind and solar PV in total generation and market share of EVs in car sales by region and scenario, 2024-2035



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Clean energy deployment expands in all scenarios, but is held back by weaker policy frameworks and growing system integration challenges in the CPS

Note: CPS = Current Policies Scenario; STEPS = Stated Policies Scenario; EMDE = emerging market and developing economies.

EVs are also important in this context. They are highly competitive in the Chinese market, and achieve high levels of penetration in 2035 in both the STEPS and the CPS. In other emerging market and developing economies, EV sales shares essentially flatline in the CPS as many of them lack explicit, longer term supportive policies. In advanced economies, the STEPS sees rapid growth of EV sales, with the sales share increasing from around 15% today to around 55% in 2035; in the CPS, it reaches 45%.

1.10 Where are the gaps in global energy investment?

Energy investment worldwide exceeded USD 3.2 trillion in 2024 and is expected to reach USD 3.3 trillion in 2025 (IEA, 2025g). The future trajectory for energy investment varies by scenario. In the CPS, average annual energy investment between 2025 and 2035 remains similar to 2024 levels; in the STEPS, it reaches over USD 3.4 trillion; in the NZE Scenario, it reaches nearly USD 4.8 trillion. In this section, we analyse what these energy investment projections tell us about potential gaps and risks.

1.10.1 By fuel and technology

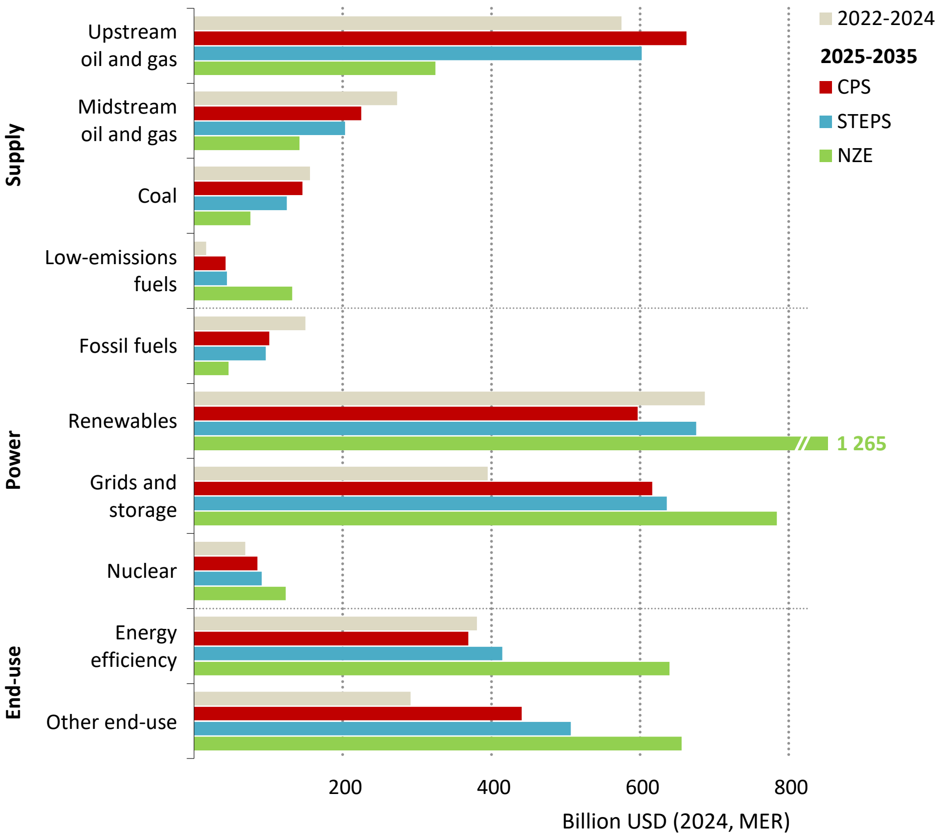
Our analysis of current energy investment flows and future needs by fuel and technology raises three main concerns. First is energy efficiency. The rate at which global energy efficiency is improving, as measured by the energy intensity of global GDP, slowed in recent years. There are several reasons including significant gaps in the coverage of efficiency standards and the lack of stringency in some of the standards that do exist. For example, around 40% of newly built floor area is not yet covered by efficiency requirements, and the regulations in place vary significantly among countries in their scope and stringency. Similarly, just three-out-of-five industrial electric motors in use globally are covered by minimum energy performance standards. While spending on end-use electrification is rising, notably for EVs, investment in technical efficiency improvements to help deliver more efficient housing stock or equipment has been flatter. Additional investment to help deliver such improvements could bring benefits for energy security, cut energy bills and reduce the environmental impact of energy use.

The second concern relates to grids and other investment in electricity security. Overall spending in the power sector has surged in recent years: investment in today's power sector now accounts for over 40% of energy sector spending, and this level rises to over 50% when investment in end-use electrification is included. However, the rise in investment has been uneven. Annual investment in power generation increased from around USD 600 billion in 2015 to over USD 1 trillion today, led by a massive expansion in spending on solar PV. Spending on grids has risen much more gradually to around USD 400 billion. Ten years ago, for every dollar spent on generation, around USD 0.60 was spent on transmission and distribution networks. The comparable figure today is around USD 0.40.

Grid investment is not just a question of money, important as that is. Significant practical impediments to getting grid-related projects off the ground include slow permitting processes and tight supply chains for transformers, cables and other components. Around 1 700 GW of renewable energy projects at advanced stages of development are being held up today because grid connections are not available. Much more needs to be done to ensure that these and other projects can proceed quickly. Adequate investment in networks also needs to be accompanied by spending on dispatchable sources of generation and on other sources of power system flexibility and stability, including storage and demand-side response measures.

Third is the concern more broadly for investment in support of energy transitions. Investment that tackles global emissions typically involves higher upfront costs that are offset over time by much lower operating expenditures, mainly through lower fuel costs. This is a major reason why the investment levels in the NZE Scenario are higher than in the exploratory scenarios (Figure 1.34). The largest gaps over the next ten years are for energy efficiency and other end-use (including electrification of end-uses), where annual investment more than doubles from current levels to reach USD 1.7 trillion on average between 2025 and 2035 in the NZE Scenario. Compared with the CPS and the STEPS, there are also significant increases in the NZE Scenario for annual investment in renewable power and low-emissions fuels. All scenarios see a continued rise in spending on nuclear power.

Figure 1.34 ▷ Average annual investment in fuel supply, power and end-use by type and scenario, 2022-2035



As the Age of Electricity emerges, investment shifts from fossil fuels towards low-emissions power generation and fuels, grids and storage, and end-use electrification

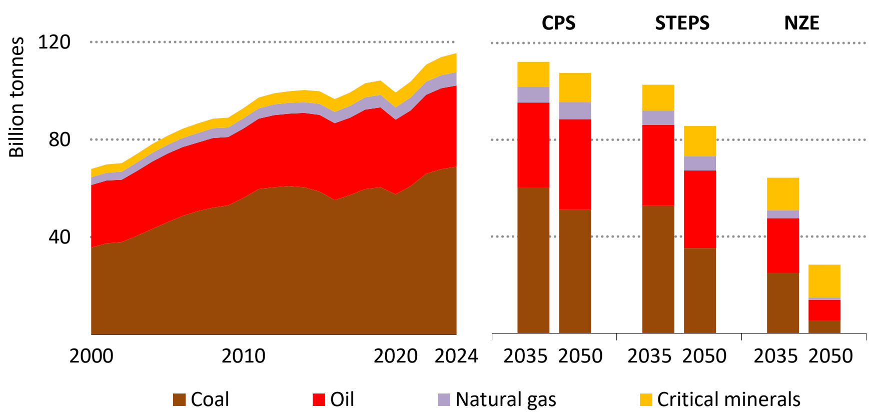
Notes: MER = market exchange rate. CPS = Current Policies Scenario; STEPS = Stated Policies Scenario; NZE = Net Zero Emissions by 2050 Scenario.

In other sectors the gaps between current investment levels and the scenario projections are less pronounced. Recent average spending of about USD 825 billion on oil and gas supply is only marginally below the annual investment needs in the CPS, USD 890 billion, and slightly above what is needed in the STEPS, USD 800 billion, over the next decade. Much less is required in the NZE Scenario. In all scenarios, the vast majority of upstream spending on oil and gas is to offset declines in production from existing fields. All scenarios see a continued need for mining operations, including a rising need for critical minerals. In the NZE Scenario, overall extractive operations fall dramatically, despite the increased call for battery metals, copper and rare earth elements for a more electrified and renewables-rich system (Box 1.6).

Box 1.6 ▷ How much material is extracted in our scenarios?

The global energy system requires the extraction of vast quantities of materials from fossil fuels to critical minerals. The total weight of useful products for the energy system was around 17 billion tonnes in 2024. Even larger quantities of material are extracted to deliver these useful products (Figure 1.35). Operators must remove and handle material such as waste rock, drilling cuttings, slag, water and sludge. On average, around 7 tonnes of material, mostly rock and water, are extracted for every tonne of coal produced. For every tonne of oil produced, nearly 6 tonnes of water and other residues are extracted. Critical minerals require far larger amounts of material to be processed: for typical ore grades, more than 100 tonnes of residue are extracted for every tonne of mineral produced. For example, ore grades are usually below 1% for copper, resulting in more than one hundred parts of material being extracted to obtain one part of copper. Much less material is usually involved in gas extraction, with less than 1 tonne of water and drilling cuttings extracted for each tonne of natural gas produced.

Figure 1.35 ▷ Raw material extraction of fossil fuels and critical minerals by scenario, 2000-2050



Despite the increase in critical mineral extraction, the total amount of raw material for the energy system declines in all scenarios

Notes: CPS = Current Policies Scenario; STEPS = Stated Policies Scenario; NZE = Net Zero Emissions by 2050 Scenario. Critical minerals include lithium, copper, nickel, cobalt, graphite and magnet rare earths.

In total, we estimate that around 120 billion tonnes of raw materials related to fossil fuels and critical minerals were extracted from the earth in 2024, of which coal production accounted for more than half of the total. The weight of energy-related materials extracted falls slightly by 2035 in the CPS, mainly because of declines in coal mining. This reduction is more pronounced in the STEPS and even more so in the NZE Scenario, despite an increase in extraction related to critical minerals. Less raw material extraction implies less land-use change and environmental degradation, lower energy use and a decrease in emissions and water use.

1.10.2 By country and region

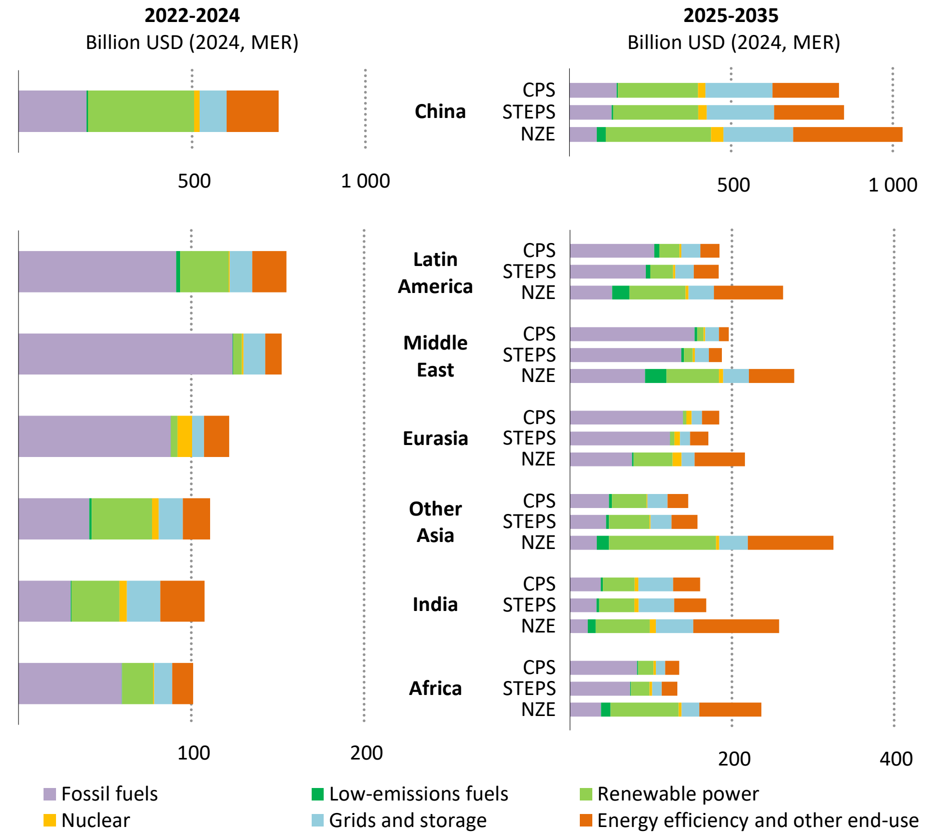
At a country and regional level, many of the most striking gaps in energy investment are in emerging market and developing economies, with the notable exception of China. As detailed in section 1.1.1, these are the economies that take over as the primary drivers of energy demand growth, with India and Indonesia in the lead. In many cases, however, these are also the economies that have faced difficulties to mobilise sufficient capital to meet their increasing needs for energy infrastructure. In Africa, energy investment today is around one-third below where it was ten years ago because a large drop in spending on fossil fuel supply has only been partially offset by a rise in other areas. This is a particular concern given strong expected population growth in Africa and the large number of people that continue to lack access to electricity and clean cooking.

How emerging market and developing economies meet their rising energy needs is a pivotal question for the energy outlook. Analysis and surveys conducted for the IEA Cost of Capital Observatory highlight some of the issues that can deter investment. A key issue is that the cost of capital for power generation projects in emerging market and developing economies is over twice as high as it is in advanced economies. This reflects higher real and perceived risks at the country, sectoral and project levels. A high cost of capital pushes up financing costs and makes it much more difficult to generate attractive risk-adjusted returns, especially for relatively capital-intensive investment in clean technologies.

Broad country-related risks and macroeconomic factors typically explain a large share of country-by-country variations in the cost of capital. For example, investors may have concerns about the rule of law and sanctity of contracts, or about currency fluctuations and convertibility. As the balance of capital spending on energy in emerging market and developing economies shifts from globally traded commodities such as oil towards projects that rely on domestically generated revenues, notably in the electricity sector, the quality and predictability of the business environment are likely to become even more important for investors. There are also risks that can be addressed directly by energy policy makers and regulators, notably regarding the reliability of payment, availability of transmission infrastructure and land, and how these issues are defined in contracts.

A positive aspect of the *Outlook* is that, in our scenarios, most of the required investment in emerging market and developing economies over the next ten years is in mature technologies and in sectors with tried and tested policy formulas for success (Figure 1.36). Nonetheless, scaling up investment remains a major challenge, especially if national energy and sustainability objectives are to be met in full. Success will depend to a large extent on more private sector involvement; on well-co-ordinated, enhanced international financial and technical support; and on the creation of deeper domestic capital markets and financial systems in developing economies that can channel savings towards productive investments.

Figure 1.36 ▷ Average annual energy investment by type, region and scenario, 2022-2035



Huge investment opportunities remain in emerging market and developing economies across all scenarios

Note: MER = market exchange rate; CPS = Current Policies Scenario; STEPS = Stated Policies Scenario; NZE = Net Zero Emissions by 2050 Scenario.

In the NZE Scenario, for example, we estimate that international public finance of about USD 120 billion per year is needed to mobilise both domestic and international private capital. With development finance budgets falling, these limited resources must shift from providing direct funding at senior tranches towards riskier junior and first loss tranches. Where equity is in short supply, they also need to be used to provide more equity capital. To achieve mobilisation at scale, leverage ratios need to rise sharply. Every dollar of international public finance today mobilises USD 0.60 of private capital, and the aim should be to see that ratio rise to at least five to seven dollars. At a regional level, Africa needs to be a priority given the imbalances in current capital flows.

Setting the scene

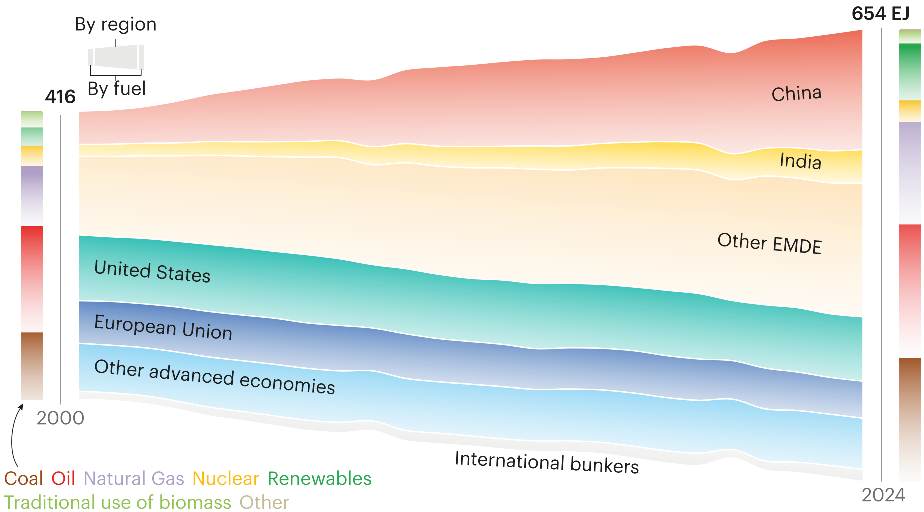
Context and scenario design

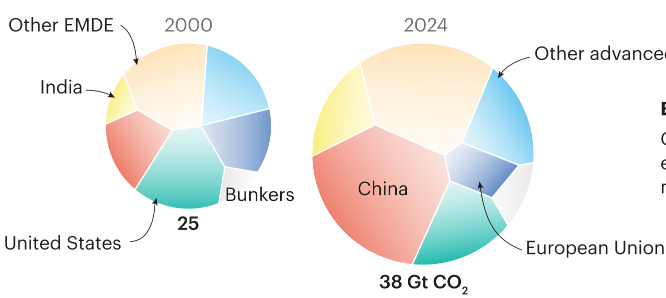
SUMMARY

- All sources of energy increased in 2024 to meet the world's rising energy needs. Electricity use expanded rapidly across a range of sectors. Deployment of renewable power generation again broke records in 2024, meeting more than 70% of the increase in electricity demand. Consumption of each of the fossil fuels rose. Global energy-related carbon dioxide (CO_2) emissions reached another all-time high.
- The energy sector faces many uncertainties. The global economy is projected to grow at an average rate of 3% in the 2024-2030 period, but changes in the global policy environment and trade outlook could lead to different outcomes. In parallel, a drift towards greater fragmentation and increased geopolitical rivalry could have major implications for energy-related trade flows. These uncertainties underscore the value of supply diversification and resilient supply chains, notably for critical minerals.
- Energy policies continue to evolve. The United States enhanced its backing for domestic fossil fuels and nuclear energy, while cutting support for wind, solar and electric vehicles. Many other countries also launched new policy initiatives in the last year, including a boost in policies designed to enhance energy security. Meanwhile, major gaps persist in the world's provision of energy: 730 million people still lack access to electricity and nearly 2 billion are without access to clean cooking.
- These new starting conditions are reflected in a fully revised and updated set of scenarios in this *World Energy Outlook (WEO)*. All take as their starting point the same GDP and population assumptions. None of the scenarios are forecasts.
- The **Current Policies Scenario** (CPS) considers a snapshot of policies and regulations that are already in place and offers a generally cautious perspective on the speed at which new energy technologies can be deployed in the energy system.
- The **Stated Policies Scenario** (STEPS) considers the application of a broader range of policies, including those that have been formally tabled but not yet adopted as well as other official strategy documents that indicate the direction of travel. Barriers to the introduction of new technologies are lower than in the CPS, but this scenario does not assume that aspirational targets are met.
- Further scenarios have normative elements and work towards defined outcomes. The **Net Zero Emissions by 2050** (NZE) **Scenario** maps out an updated global pathway for the energy sector to achieve net zero CO_2 emissions by 2050. An additional scenario, the **Accelerating Clean Cooking and Electricity Services Scenario** (ACCESS), is introduced in this *WEO*, setting out a data-driven roadmap to achieve universal access to electricity and clean cooking.

Global energy demand and emissions continue to grow

Global demand has grown by nearly 60% since 2000, with all the increase coming in emerging market and developing economies. All major energy sources grew over the period.





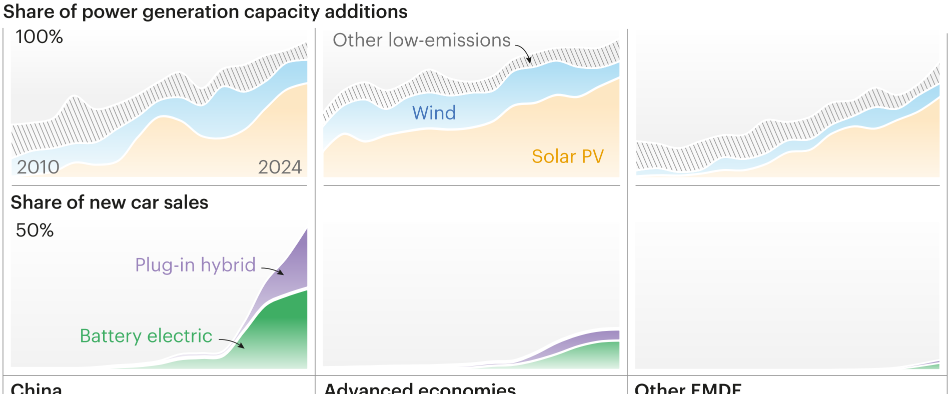
Emissions

Global energy-related CO_2 emissions have increased by more than 50% since 2000.

Energy technology deployment accelerates

Installation of low-emissions power capacity has accelerated since 2010.
EV sales have gathered pace since 2020.

Share of power generation capacity additions



2.1 Introduction

The *World Energy Outlook-2025* (*WEO-2025*) unfolds against an uncertain and unpredictable backdrop. Some key energy-producing countries are either parties to ongoing conflicts, notably Russia following its full-scale invasion of Ukraine in 2022, or vulnerable to spillovers from instability in the Middle East. At the same time, the economic outlook remains clouded by tensions over trade, fiscal weaknesses and high levels of debt. Worries about the security and affordability of energy supply spiked during the global energy crisis in 2022, and governments are reaching different conclusions about the best ways to respond. Meanwhile, rapid technological change continues, accelerating the rollout of energy technologies like batteries and the advance of artificial intelligence (AI).

Despite this turbulence, demand for energy services is rising as the global economy grows and the world's population increases, and electricity is playing an increasingly important role in meeting rising demand. It is also clear that difficult challenges lie ahead. Many people around the world still do not enjoy the benefits that modern energy can bring, while emissions from the energy sector are closely bound up with the risks and impacts of a changing climate, which are becoming clearer with each passing year.

There can be no single or simple view on how the global energy outlook might develop. This is why the *WEO* includes a suite of updated scenarios, each based on a different set of assumptions about the policies, technologies and other factors that shape the outlook. None of these scenarios should be viewed as a forecast. Our aim is not to predict what will happen, but to provide a rigorous, data-driven framework for decision makers to consider their options and the consequences of different choices.

This chapter sets the scene for the *WEO* by providing the broad energy and macroeconomic context, and by noting the new policies and geopolitical developments that shape the starting point for the analysis. It then introduces the revised set of *WEO* scenarios, which reflect a spectrum of possible outcomes, and discusses the inputs and assumptions that underpin them.

There are two exploratory scenarios, the **Current Policies Scenario** (CPS) and the **Stated Policies Scenario** (STEPS), that examine different ways in which existing policies and policy announcements affect the development of the energy system. These scenarios do not assume that aspirational targets or objectives are met.

There are also pathways with normative elements, that map out ways to achieve specific energy or climate goals. The **Net Zero Emissions by 2050** (NZE) **Scenario** provides an updated pathway that brings emissions from the energy sector to net zero by mid-century. Chapter 6 introduces for the first time the **Accelerating Clean Cooking and Electricity Services Scenario** (ACCESS) which charts an ambitious yet feasible pathway to universal access to clean cooking and electricity.

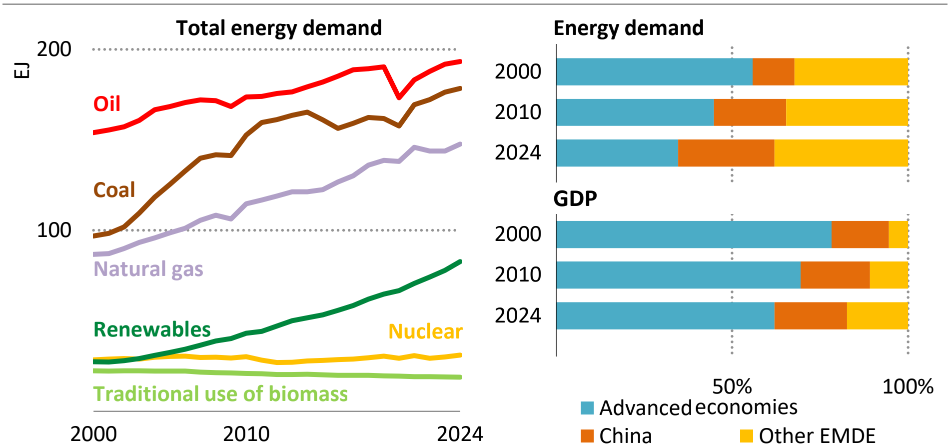
2.2 Context for the *World Energy Outlook-2025*

2.2.1 Energy demand, investment, technology and emissions trends

Energy demand and electricity generation

Total global energy demand continues to increase, rising by 2% in 2024 to more than 650 exajoules (EJ). Fossil fuels accounted for nearly four-fifths of total energy demand – a share that has decreased only marginally since 2000 (Figure 2.1). More substantial changes have occurred in the geographical breakdown of demand. In 2000, advanced economies accounted for more than half of global energy demand, but their demand peaked in 2007 and their share of global demand fell to one-third in 2024, which is much lower than their share of global gross domestic product (GDP) (measured at market exchange rates). By contrast, energy demand in emerging market and developing economies, led by China, has more than doubled since 2000. Overall energy demand increased by over 20% since 2010. Reductions in energy intensity averaged around 2% per year from 2010 to 2019, which mitigated the impact of rising demand, but recent years have seen a deceleration, and energy intensity fell by only 1.1% in 2024.

Figure 2.1 ▹ Global energy demand by fuel, and share in demand and GDP by region, 2000-2024



Global energy demand has increased 20% since 2010, with all the increase taking place in emerging market and developing economies

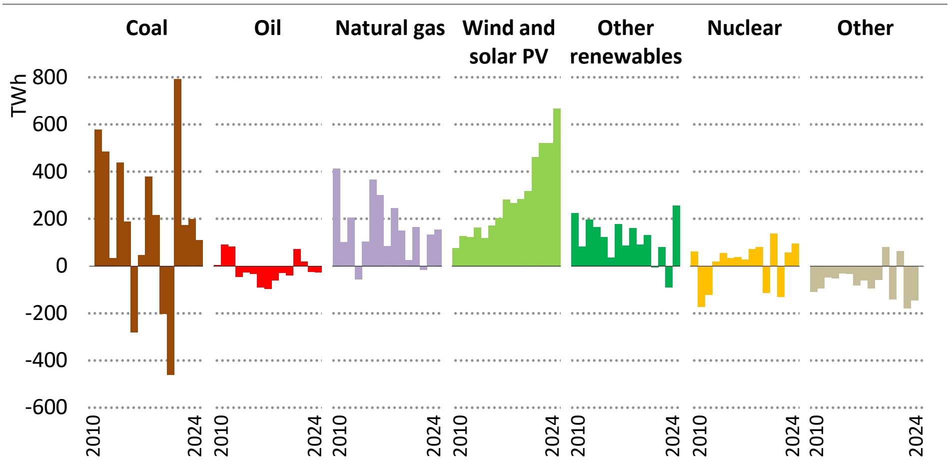
Notes: EJ = exajoule; EMDE = emerging market and developing economies. GDP is measured in market exchange rates.

Demand for fossil fuels has continued to rise, although coal, oil and natural gas have followed different trajectories. Demand for coal grew very strongly to around 2010 and then slowed sharply as China's economy restructured away from energy-intensive industry and as renewables and natural gas began to play a larger role in global electricity generation. Today, coal demand growth is driven by emerging market and developing economies in Asia, while demand in advanced economies has declined by half from its 2007 peak. Oil and natural gas have both grown at a relatively steady rate since 2010, with average annual increases of 1.4 EJ and 2.4 EJ respectively. Growth in demand for renewables has accelerated, increasing by around 3 EJ per year on average over the last decade in primary energy terms.

Total global energy demand increased in 2024 by over 2%, much more than the long-term average of 1.4% (2010-2023), partly as a result of soaring cooling demand amid record heatwaves. Renewables met much of this growth, rising by 5 EJ on the back of significant capacity additions for wind and solar PV (photovoltaics), and the cyclical recovery from a poor year for hydro in 2023. Natural gas demand also rose faster than in recent years.

The jump in energy demand in 2024 was driven in particular by a surge of 1 100 terawatt-hours (TWh) in electricity demand, which was nearly twice the long-term average. Over half of this surge in 2024 was in the buildings sector. The record increase in electricity generation from wind and solar PV in 2024, totalling nearly 700 TWh, was enough to meet 60% of the growth in electricity demand. Other renewables also expanded output well above recent trends. Nuclear power demonstrated a strong increase as a result of reactor restarts in advanced economies and new nuclear power plants in emerging market and developing economies. Long-term trends for electricity generation from fossil fuels indicate a slowdown in the increase of generation both from coal and natural gas (Figure 2.2).

Figure 2.2 ▷ Annual change in electricity generation by source, 2010-2024



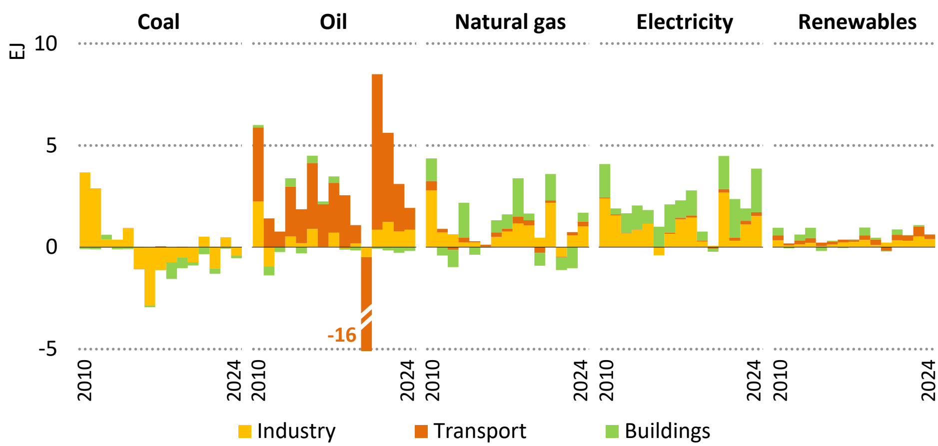
IEA. CC BY 4.0.

Electricity demand increased in 2024 by nearly twice the long-term average, most of which was met by growth in renewables output, capping the upside for fossil fuels

Notes: TWh = terawatt-hour. Other renewables include hydro, bioenergy and renewable waste, geothermal, concentrating solar power and marine power. Other includes non-renewable waste and other sources.

Total final consumption across end-use sectors increased by nearly 2% in 2024, rising faster than the average since 2010 and reaching over 450 EJ for the first time. This reflects, in part, a recent uptick in global energy consumption in industry, especially electricity-intensive manufacturing and oil-based feedstock for petrochemicals (Figure 2.3). The growth of energy consumption in industry, however, slowed markedly over the course of the last decade, not least as a result of economic restructuring in China, where industrial coal consumption peaked in 2014. Energy consumption in the transport sector also increased, though the growth of oil consumption in transport has been slowing as electric vehicles (EVs) and biofuels displace oil demand growth. Aviation and shipping accounted for all the 1 EJ increase in transport oil consumption in 2024, with oil demand for road transport flat. The long-term trend in the buildings sector is one of relatively linear increases in demand, averaging slightly more than 1 EJ per year since 2010. However, 2024 witnessed a larger increase in energy demand from buildings, mostly in the form of electricity. Record temperatures drove higher cooling needs, while demand rose for uses such as data centres and AI services.

Figure 2.3 ▷ Annual change in final consumption by source and sector, 2010-2024



Electricity demand surged in 2024 in the industry and buildings sectors, while oil consumption growth in transport continued to slow

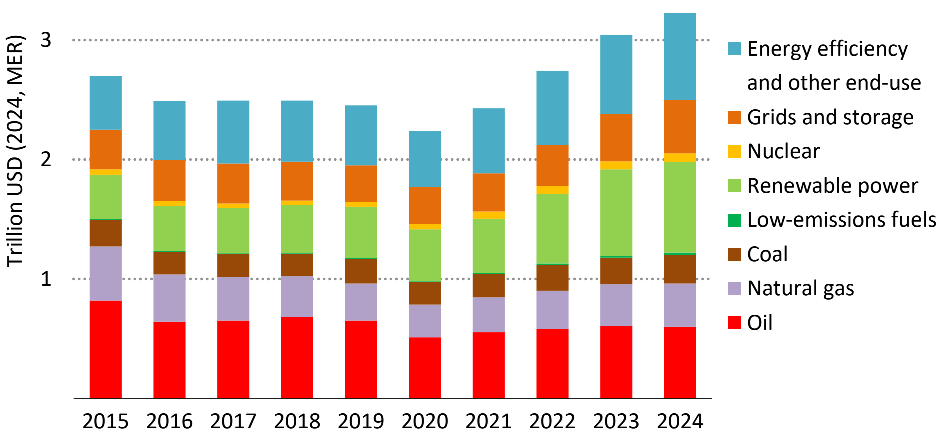
Note: EJ = exajoule.

Major gaps in global energy access persist, with many communities underserved or without any access to modern energy. Some progress has resumed since the disruption caused by the Covid pandemic and the global energy crisis, but the latest tracking data indicate that 730 million people around the world remain without access to electricity, largely in sub-Saharan Africa. Nearly 2 billion people still lack access to clean cooking. Instead, they rely on traditional stoves and open fires, which expose households to harmful smoke and contribute to around 3 million premature deaths each year. The lack of access to modern energy also constrains efforts to increase economic prosperity, improve access to education and meet a range of other objectives.

Energy investment

Investment in the energy sector rose to US dollars (USD) 3.2 trillion in 2024, up from an annual average of USD 2.6 trillion over the previous decade (Figure 2.4). The share of investment for sectors other than fossil fuels has risen quickly: low-emissions power, grids, low-emissions fuels, efficiency and end-use sector spending together accounted for USD 1 trillion ten years ago, which was less than 40% of the global total, but increased to over USD 2 trillion in 2024, accounting for more than 60% of the total.

Figure 2.4 ⊳ Global energy-related investment, 2015-2024



Energy-related investment increased sharply from 2020, led by more spending on renewables, grids and storage, efficiency and end-use sectors

Note: MER = market exchange rate.

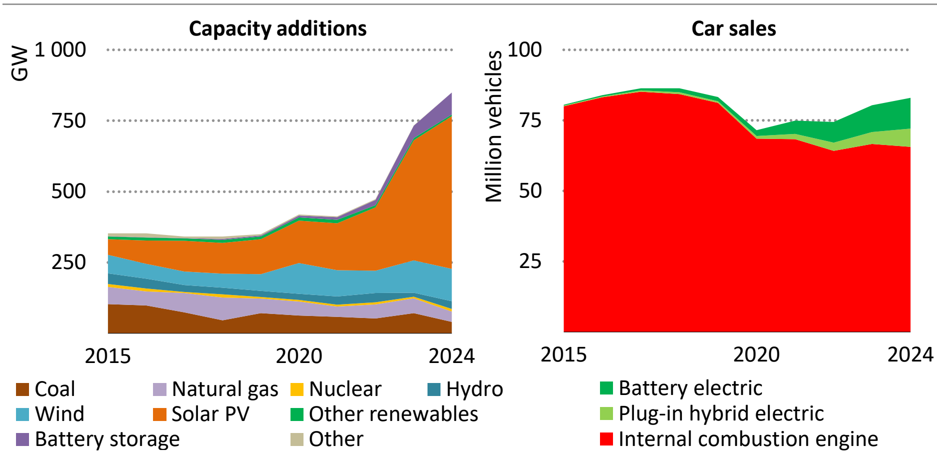
Spending on low-emissions power generation, notably solar PV, has almost doubled over the past five years. Investment in electricity grids is rising too, but is struggling to keep pace with the growth in power demand and rapid deployment of renewables. Nuclear investment is on a smaller scale, but is making a comeback, rising by over 70% over the past five years. Approvals of new gas-fired power have also risen, led by the United States and the Middle East, while fast growing electricity use and concerns about electricity security have spurred a wave of coal plant approvals in China. Weakening oil prices and demand expectations have weighed on upstream oil investment, which remains well below levels seen prior to the Covid-19 pandemic.

The geographic spread of energy investment is uneven and evolving: China is by far the world's largest energy investor. Its share of global clean energy investment rose from around 25% ten years ago to almost 30% today. At the other end of the scale, many developing economies, especially in Africa, struggle to mobilise capital for energy infrastructure.

Energy technologies

Several energy technologies have seen substantial cost reductions and performance improvements in recent years. The global average prices of both solar PV and electric vehicle batteries fell by more than 80% between 2014 and 2024. As a result, the levelised cost of electricity from solar PV is now among the lowest of any power technology in history, although a fuller assessment of competitiveness should also include the value that different technologies bring to electricity systems (see Chapter 4, Box 4.4). Total system costs, including grid infrastructure, provide a comprehensive view of the impact of technology choice on electricity affordability (see Chapter 1, section 1.4). With the fall in battery prices, electric cars often have a lower total cost of ownership than internal combustion engine (ICE) equivalents. In some markets, most notably in China, they often also have a lower upfront purchase cost than equivalent ICE models (IEA, 2025a). On the other hand, capital cost reductions in wind power have been muted in recent years, due to higher commodity prices and supply chain constraints. The upstream oil and gas sector continues to experience some upward pressure on costs, partly as a result of expenses arising from technology development and deployment, though this has been offset to some extent by increases in capital efficiency (IEA, 2025b).

Figure 2.5 ▷ Global electricity generation capacity additions by type and annual sales of passenger cars by type, 2015-2024



Solar PV, battery storage and EVs have expanded strongly as a result of both policy support and significant cost reductions

Note: GW = gigawatts; PV = photovoltaics.

Solar PV capacity additions increased by ten-times from 2015 to 2024, with nearly 540 gigawatts (GW) added in 2024 (Figure 2.5). Capacity additions for wind increased from 65 GW in 2015 to around 115 GW in 2024, although annual trends show some volatility in individual years. Capacity additions of coal and natural gas-fired power plants halved from a total of 160 GW in 2015 to around 80 GW in 2024. However, the announced pipeline for new natural gas-fired power plants has jumped in recent years. Announced project pipelines for coal-fired plants rose after several years in which project cancellations outpaced new announcements. Capacity additions of hydropower and nuclear have been broadly stable at around 26 GW per year and 8 GW per year respectively since 2015.

Sales of electric cars continued to expand in 2024, accounting for over 20% of the global car market. Global sales of ICE cars decreased by 1.5% in 2024 and are now almost one-quarter lower than in 2017, the year in which ICE car sales reached their highest point. Pure battery electric vehicles sales reached over 10 million in 2024, up fivefold since 2020. Building on similar underlying cost reductions, capacity additions of battery storage in the electricity sector in 2024 were more than 60-times higher than in 2015, reaching nearly 80 GW.

Projects to capture energy-related CO_2 emissions have only resulted in an operational capture capacity of around 50 million tonnes per year. Projects under construction look to more than double this capacity by 2030. Hydrogen production worldwide has increased by nearly 20% since 2015, though less than 1% of this was low-emissions hydrogen production. Low-emissions hydrogen production from projects that are operational, under construction or have reached a final investment decision is set to reach 4.2 million tonnes per year by 2030, representing a fivefold increase compared with 2024, but still well below government and industry ambitions at the start of this decade.

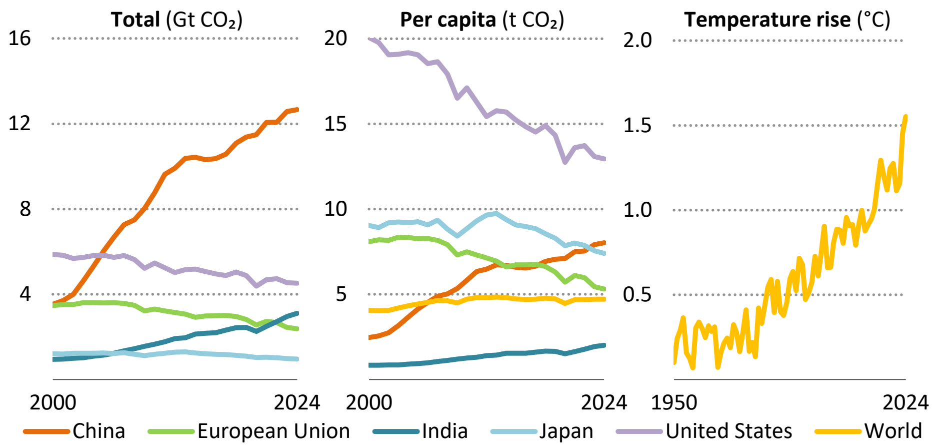
Energy-related emissions and climate change

Global energy-related carbon dioxide (CO_2) emissions reached an all-time high of 38.2 gigatonnes (Gt) in 2024, while energy-related emissions of methane remained at about 4.4 Gt CO_2-equivalent. The annual pace of increase in CO_2 emissions slowed to below 1% in 2024, with emissions continuing to decouple from economic growth at the global level. Most of the increase in emissions in 2024 was from natural gas, followed by coal. Low-emissions energy technologies – solar PV, wind, nuclear, electric cars and heat pumps – deployed since 2019 now prevent 2.6 Gt CO_2 annually, equal to 7% of global emissions (IEA, 2025c).

In advanced economies, total energy-related CO_2 emissions fell by 1% in 2024, 20% below the peak level in 2007, but this decline was more than offset by increases elsewhere. Most of the global 2024 increase came from emerging market and developing economies other than China, where CO_2 emissions rose by 2.4%. Emissions growth in China slowed in 2024, but its per capita emissions are nevertheless now 16% higher than in the advanced economies as a group (Figure 2.6).

It is notable that 2024 was the warmest year ever recorded, with the global mean near-surface temperature about 1.55 degree Celsius (°C) above pre-industrial levels (WMO, 2025). It was also confirmed as the first calendar year in which the average global temperature was more than 1.5 °C above its pre-industrial level.[1] Extreme temperatures and climate change can affect the energy system in a number of ways, for example by pushing up electricity demand for cooling, increasing wildfire risks to energy infrastructure and affecting the efficiency of power plants and transmission lines (see Chapter 5). Extreme heat increased electricity demand in 2024, especially for cooling, contributing to the rise in energy-related CO_2 emissions (IEA, 2025c). If the weather in 2024 had been the same as in 2023, about half of the increase in global emissions would have been avoided.

Figure 2.6 ▷ Energy-related CO_2 emissions by selected country/region and per capita, 2000-2024, and global average annual temperature rise above pre-industrial levels, 1950-2024



Energy-related emissions reached another all-time high in 2024, which was the hottest year ever recorded, with temperatures of over 1.5 °C above pre-industrial levels

Notes: Gt CO_2 = gigatonnes of carbon dioxide; t CO_2 = tonnes of carbon dioxide; °C = degree Celsius. Temperature rise is the average of HadCRUT5, Berkeley Earth, NOAA GlobalTemp v6, GISTEMP, ERA5, and JRA-3Q datasets adjusted by the World Meteorological Organisation so that each dataset is relative to the period 1850-1900.

Sources: IEA analysis and WMO (2025).

2.2.2 Macroeconomic and geopolitical context

Macroeconomic trends

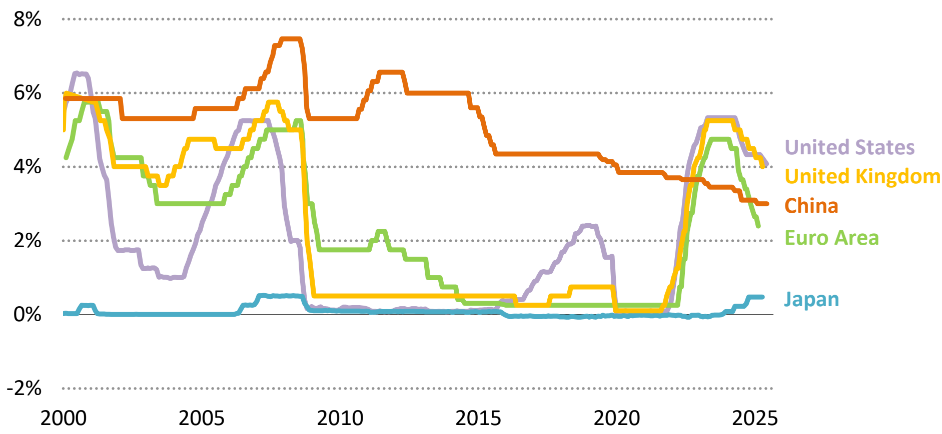
Forecasts for global economic growth have been revised up since earlier in 2025. The International Monetary Fund (IMF) now projects the global economy to grow by 3.2% in 2025 and 3.1% in 2026 (IMF, 2025a). This increase comes despite headwinds caused by geopolitical instability and uncertainty about tariffs, highlighting the robustness of the global economy.

[1] The Paris Agreement goal of limiting warming to 1.5 °C applies to long-term warming, typically measured over 20 years, rather than shorter periods, which can be strongly affected by natural climate variability.

Emerging market and developing economies are projected to grow by 4.2% in 2025 and 4% in 2026, and advanced economies by 1.6% in both years (IMF, 2025a). Poverty reduction in emerging market and developing economies slowed during the Covid-19 pandemic, and stronger inclusive growth will be critical to reversing this (World Bank, 2025a).

Inflationary pressures have continued to ease in many countries, following spikes linked to the easing of lockdowns in response to the Covid-19 pandemic and to the Russian invasion of Ukraine. One important contributory factor has been the continued moderation in global energy prices, despite geopolitical tensions. In part, this reflects adjustments in market balances for oil and gas, as highlighted in the *WEO-2024*. This cooling of inflation has allowed for a relaxation of monetary policy in many jurisdictions (Figure 2.7).

Figure 2.7 ⊳ Central bank policy rates for selected economies, 2000 to July 2025



Since 2024, rates in the United States, Euro Area and United Kingdom have fallen by up to 2%, while the rate in China fell modestly and in Japan it rose slightly

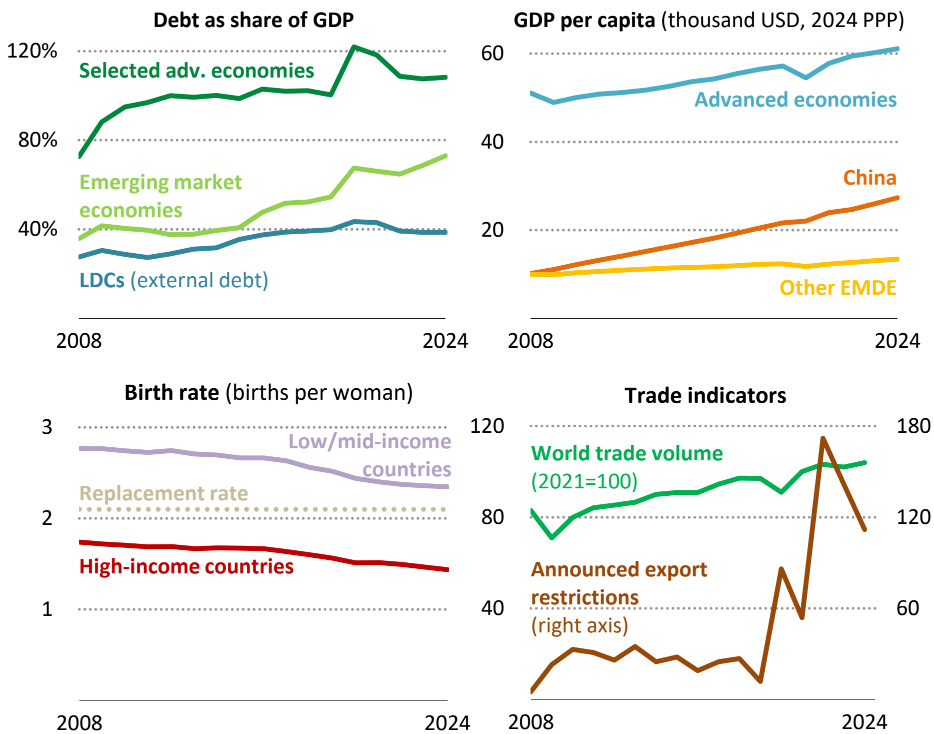
Notes: US = United States Federal Reserve federal funds rate; Euro Area = European Central Bank marginal lending facility rate; Japan = Bank of Japan policy rate; UK = Bank of England bank rate; China = China one year benchmark lending rate (2000 to August 2019), People's Bank of China loan prime rate one year (August 2019 to September 2025).

Sources: FRED (2025a and 2025b); ECB (2025); Bank of England (2025); Bloomberg (2025).

There are plenty of near-term uncertainties that bear on the economic outlook: notably the path for inflation and interest rates; the outcomes of current trade negotiations; the prospects for equity markets, some of which are trading at historically elevated valuations; and the course of political and geopolitical developments. There are also plenty of uncertainties about the global economy in the longer term, but a number of key structural trends have implications for the future (Figure 2.8).

One of these is that the benefits of growth in global GDP per capita over the last decade have been uneven. Emerging market and developing economies other than China, as a group, have not caught up relative to advanced economies through faster growth. Whether this trend can be reversed will have important implications not only for poverty reduction but also for global energy demand trends in the decades to come.

Figure 2.8 ▷ Key trends influencing the global economy, 2008-2024



IEA. CC BY 4.0.

Despite rising levels of debt, falling birth rates and increased protectionism, GDP per capita continued to rise

Notes: GDP = gross domestic product; PPP = purchasing power parity. Selected adv. economies = Australia, Canada, Denmark, Euro Area, Iceland, Japan, New Zealand, Norway, Sweden, Switzerland, United Kingdom and United States. Emerging market economies as tracked by the Bank for International Settlements (BIS). LDCs = least developed countries as classified by the United Nations. EMDE = emerging market and developing economies. High-income countries and low-and-middle-income countries classified as defined by the World Bank.

Sources: BIS (2025); CPB World Trade Monitor (2025); GTA (2025); United Nations Population Division (2024); World Bank (2025b).

Another notable trend is the rise in government debt as a percentage of GDP in both advanced economies and emerging market and developing economies. This risks potentially hampering efforts to invest in key infrastructure and implement energy policies that require a fiscal outlay, such as energy subsidies. It may also have knock-on effects such as higher long-term interest rates.

Birthrates meanwhile have continued to decline across much of the world in recent years, in some cases substantially faster than expected on the basis of official forecasts. Declining birthrates and higher dependency ratios are likely to create a drag on GDP growth and increase fiscal pressures.

Another macroeconomic issue relates to the outlook for geopolitics and its potential impact on trade and growth. Although trade volumes continue to expand, there has been a notable rise in the use of restrictive trade measures, including measures that place restrictions on access to technologies. Future developments in this area could have important implications for the macroeconomic and energy sector outlooks.

Political and geopolitical uncertainties

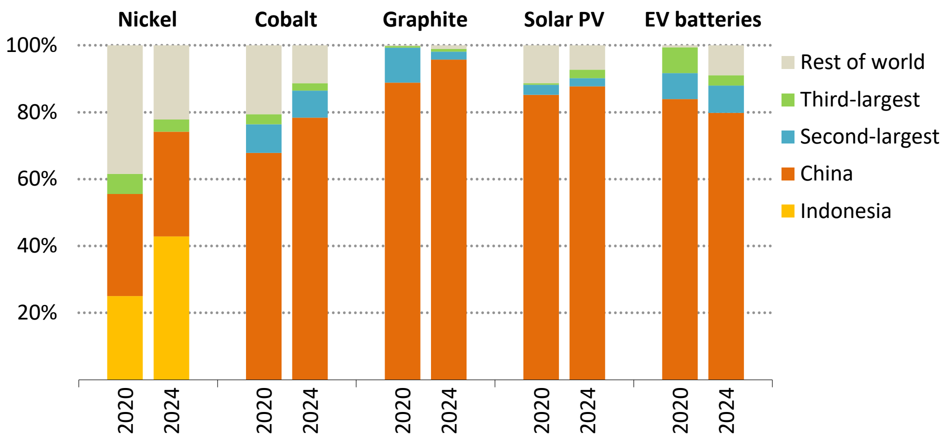
In a fragile international environment, energy-related trade has become increasingly subject to geopolitical considerations. The most obvious example is the reorientation of European energy imports following the Russian invasion of Ukraine, when Russia sought to gain political leverage by withholding natural gas supplies and exposing European consumers to higher energy bills. In response, European Union imports of liquefied natural gas (LNG), picked up sharply, particularly from the United States which accounted for 55% of EU LNG imports in the first half of 2025. The period of energy market volatility that followed Russia's invasion also saw an acceleration in the deployment of renewables and efforts to increase energy efficiency in some key markets as governments sought to reduce fuel import bills.

At the same time, attention is turning to risks in some newer value chains related to critical minerals and key energy technologies. These include risks arising from market concentration: the average market share of the top-three countries undertaking the refining of key energy minerals rose from around 82% in 2020 to 86% in 2024 (Figure 2.9). While many supply chain issues are not related to the geopolitical context, notable vulnerabilities have been exacerbated by recent policy developments. Since early 2025, for example, China has introduced a range of export controls on rare earth magnets, which are key to electric motor and generator components used in various energy-related technologies as well as in other strategic economic sectors. Due to these restrictions, exports from China of these key components fell by 75% between April and June 2025 impacting manufacturing activities in Europe and the United States. Concerns about supply chains – both in the energy sector and more broadly – are leading to a rise in industrial policies and strategies, as well as a series of new international partnerships.

A fragile international environment also heightens potential risks associated with energy infrastructure and transit routes. These include risks related to key maritime routes, undersea infrastructure and electricity grids. International maritime shipping of energy products remains particularly sensitive to potential disruption at key chokepoints, including the Strait of Malacca, the Strait of Hormuz, the Suez Canal and Red Sea, and the Panama Canal. There are also risks to energy infrastructure arising from vulnerabilities in the digital world: as energy systems have become increasingly electrified, integrated and connected, their vulnerability to cyberattacks has increased.

Against this background, governments face a difficult balancing act as they seek to manage potential trade-offs while trying to align as far as possible the goals of energy security, energy transitions, supply chain security, affordability and industrial policy. The approaches they take and the results they achieve will have a critical bearing on the outlook for energy.

Figure 2.9 ▷ Top-three supplying countries of selected critical minerals and clean technologies, 2020 and 2024



Both the supply of refined critical minerals and manufacturing of key energy technologies have become more concentrated in recent years

Notes: Nickel and cobalt are for refining. Graphite is for battery grade production. Solar PV is for solar cell production. EV batteries are for battery cell production.

Sources: IEA (2025a); IEA (2025d); IEA (2025e).

2.2.3 Energy policy developments

Energy policies and regulations have critical influence on the direction of the energy sector. However, their impact is not always clear cut. Policies may have ill-defined or ambiguous objectives, can overachieve or undershoot their original goals, are subject to change over time and may be only near term in focus. Other factors such as market, price and technology trends also play crucial roles in shaping the direction of the energy sector. Nonetheless, given their importance, the International Energy Agency (IEA) tracks energy policies closely and maintains an up-to-date database of policies and measures covering 85 countries (IEA, 2025f).

IEA policy tracking indicates that the last year has seen major new policies emerge in 48 countries covering a wide range of objectives and instruments, from energy performance standards to government financial incentives and pricing schemes. In this section we survey policy initiatives across multiple countries and sectors, including the new direction for energy policy in the United States. We also include a spotlight looking at the burgeoning adoption of measures related to energy security and emergency response.

The United States has made major changes to its federal priorities for energy research, investment and resource development. These changes are focused on removing obstacles to the development and use of domestic oil, natural gas and coal, and supporting nuclear energy and other technologies such as geothermal, while rolling back energy efficiency measures and reducing support for solar and wind power generation, and EVs (Box 2.1).

The number of countries adopting regulations for energy performance standards saw a notable increase in the 2010s. These include emissions and fuel economy standards for vehicles and minimum energy performance standards for appliances and industrial motors. Major energy consuming countries adopted such standards early on, but the level of coverage plateaued in the 2020s (Figure 2.10). The recent repeal of efficiency measures in the United States reduces the policy coverage in several sectors. Renewable energy policies have seen similar trends, with a significant rise in policy adoption for power generation since 2010, and also a shift from use of feed-in tariffs to an increasing role for tendering and auctions.

The scale of funding commitments and disbursements for various energy-related programmes has increased substantially since 2020, thanks in large part to provisions in post-Covid-19 recovery plans put in place by advanced economies. New government support earmarked for the deployment of clean energy technologies and infrastructure since the pandemic totals over USD 2 trillion, although actual disbursements vary across countries and sectors.

Box 2.1 ▷ United States energy policy changes course

In the past five years, the United States has seen very significant federal energy policy changes. The One Big Beautiful Bill Act (OBBBA) of 2025 in several respects represents a substantial change in direction for the energy sector, when compared to legislation such as the Inflation Reduction Act of 2022.

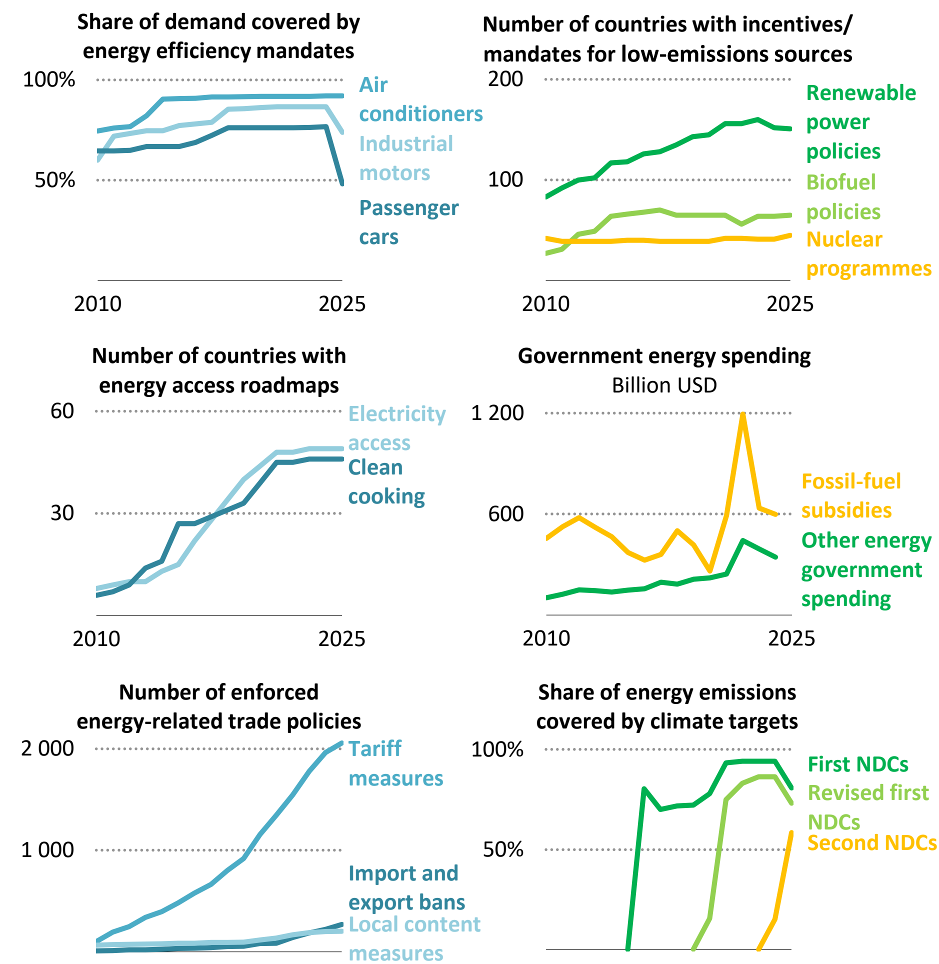
Policy changes in the United States can have a major impact on long-term energy trends globally as well as domestically. For example, together the shale revolution and the 2015 reversal of the US ban on crude oil exports fundamentally reshaped global oil markets and geopolitics, positioning the United States as the world's leading oil producer, and at the same time bringing about lower prices and increased resilience in the face of oil supply disruptions. The rise of US shale is also an example of the way that multiple factors drive change in the energy sector: energy policies played an important role, but private sector innovation, risk-taking capital markets and high global energy prices also helped to drive growth.

Announced and recently enacted policy measures affecting trade, regulation, funding and financing, are set to reshape US energy production, demand, end-uses and exports. The changes are designed to stimulate domestic production across a range of energy sources, focusing on oil, natural gas and coal as well as nuclear, geothermal, hydrogen and biofuels. The changes to energy-related tax credits and grants in the OBBBA (selected provisions summarised in Table 2.1) are reflected in the updated US projections in both the Current Policies Scenario and the Stated Policies Scenario, which also take state-level policies into account.

Table 2.1 ▹ Selected recent changes in federal energy-related incentive programmes in the United States

Tax incentive category	**Infrastructure Investment and Jobs Act** (2021), **and Inflation Reduction Act** (2022)	**One Big Beautiful Bill Act** (2025)
Carbon capture, utilisation and storage (CCUS)	Increased existing credit values for CCUS, direct air capture and enhanced oil recovery through 2033.	Increases credit value for enhanced oil recovery to match permanent storage; new prohibited foreign entity restrictions on components and financing for CO_2 sequestration credits.
Electricity generation	Replaced existing production and investment credits with technology-neutral, zero emissions credits through to 2033 or when US power sector emissions reach 75% below 2022 levels.	Terminates wind and solar credits for facilities starting construction from July 2026 or placed in service after December 2027. Applies new restrictions for foreign entities on components and financing for nuclear power production credits. Relaxes tax credits eligibility for natural gas fuel cells.
Electric vehicles and related infrastructure	Introduced credits for new, used and commercial electric vehicles, plus related charging and fuelling infrastructure through to December 2032.	Terminates credits for new, used and commercial electric vehicles in September 2025 and for charging infrastructure in June 2026.
Energy efficiency	Put in place credits with various values for commercial buildings, new housing, appliances, small solar, wind and geothermal residential generation and storage equipment through to December 2032.	Eliminated credits related to increases in energy efficiency and selected heating appliances and energy audits in June 2025.
Energy manufacturing and critical mineral production	Established new credits for domestic production of solar, wind, battery and critical minerals through to December 2032.	Terminates tax credits for wind components in 2027. Extends tax credits for critical minerals through to December 2033. Applies new restrictions for foreign entities on components and financing for critical mineral tax credits. Extends tax credits to metallurgical coal production through to December 2029. Bars reallocation of energy manufacturing investment tax credit.
Low-emissions fuels	Introduced clean hydrogen production credit. Combined existing biofuel credits into a technology-neutral credit, with increased value for sustainable aviation fuel through to December 2027.	Extends clean fuel production credit through to December 2029. Provides hydrogen production tax credit for projects starting before 2028. Reduced emissions requirements.

Figure 2.10 ▷ Selected energy policies and climate targets, 2010-2025



Over the last decade the energy policy toolkit diversified from energy efficiency mandates to more government spending and trade measures

Notes: NDCs = Nationally Determined Contributions. Renewable power and biofuel policies include: regulatory policies, such as feed-in tariffs and biofuel blending; fiscal incentives; and public financing. Other energy government spending includes: energy technology development and incentive programmes, and short-term energy affordability measures. Trade policies indicate a single instance of a trade measure impacting solar PV and wind energy components, and car batteries.

Sources: IEA data and analyses based on ESMAP (2024 and 2025); IMF (2025b); IAEA (2025); GTA (2025); REN21 (2025).

National energy plans of various kinds have been put in place over the past twelve months by fifteen countries, in many cases including updated goals for energy security and emissions reductions. For example, Japan's 7th Strategic Energy Plan outlined its Safety, Energy Security, Economic Efficiency and Environment (S+3Es) principles, alongside guidance on the envisaged energy mix to 2040. In Brazil, the Energy Transition Acceleration Programme sets new ambitions for the energy sector to promote clean energy employment, innovation and transition in coal mining regions. And in November 2025, an amendment to the European climate law was endorsed by EU Environment Ministers, setting a target to reduce emissions by 90% by 2040, relative to 1990 levels.

Alongside ongoing policy developments, fourteen countries and regions adopted new targets for power generation over the past year. For example, the European Union member states agreed new goals for offshore wind capacity for 2030, 2040 and 2050; Korea set a target to raise the share of renewables and nuclear by 2038; along with its 7th Strategic Energy Plan, Japan referenced a goal for the share of generation to be met by renewables in 2040; both Indonesia and Viet Nam set goals for renewables and nuclear power capacity.

In the buildings sector, several countries including Nigeria, Morocco and Malaysia put in place or announced new efficiency standards for air conditioners. Countries with expanding cooling needs like India and Saudi Arabia are upgrading their building energy codes to ensure new buildings are more resilient to heatwaves and other extreme weather events. Many countries with clean cooking and electricity access deficits, particularly in sub-Saharan Africa, are taking steps to bring about improvements. The IEA has tracked 25 new clean cooking access policies enacted or announced since 2024 in countries that are home to more than a third of people without clean cooking access.

In the transport sector, some new incentives for EVs and charging infrastructure were introduced. Nigeria has started to exempt EVs and charging infrastructure from value-added tax, while India launched an incentive scheme for EVs (PM E-Drive). By contrast, a few countries, such as the United Kingdom, introduced greater flexibility in meeting their zero emissions vehicle (ZEV) mandates by allowing higher shares of plug-in hybrids. Canada paused its 2026 ZEV mandate to give the automotive industry additional time to prepare. Australia is implementing its first fuel efficiency standard and Indonesia increased its biodiesel blending mandates.

In the industry sector, changes to emissions trading systems were announced in the last year related to carbon pricing as well as new support schemes. In February 2025, for example, the European Commission launched its Clean Industrial Deal, aiming to boost EU industrial competitiveness and decarbonisation through efforts to provide more affordable energy, stimulate demand for low-emissions industrial products, mobilise significant financing support, and promote access to critical raw materials.

Some policy shifts come in waves, often in response to specific events or shocks. This has been the case with energy security policies in recent years, as countries have responded to the global energy crisis and emerging security vulnerabilities (Spotlight). However, the direction in which policy settings evolve is not preordained or uniform, and the adoption of specific policies reflects different national circumstances and priorities. The aim of the scenario analysis in the *WEO-2025* is not to anticipate or prescribe changes, but to place them within a broad analytical framework to help understand their implications.

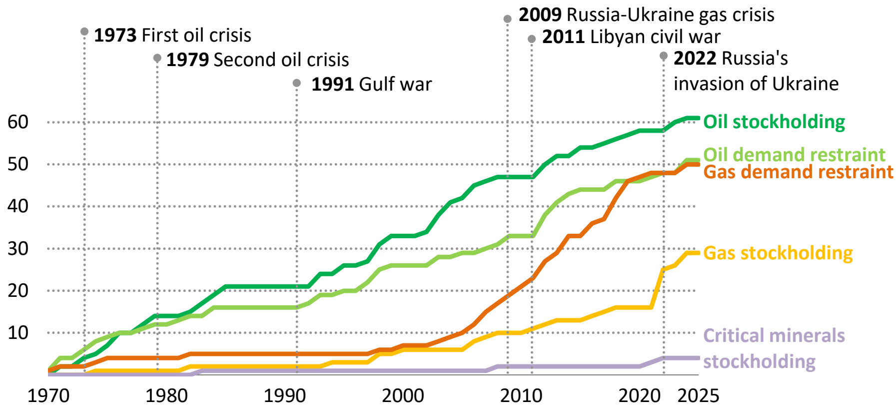
S P O T L I G H T

Are governments better positioned to respond to energy security shocks than in the past?

With geopolitical uncertainty on the rise and renewed volatility in energy markets, energy security has once again become a top priority for governments around the world. They are deploying a wide range of policies to be better prepared in case of an energy emergency.

Since the oil crises of the 1970s, governments in net oil importing countries adopted policies and emergency response measures to mitigate the impacts of potential supply disruptions, while diversifying and increasing the efficiency of their energy portfolios. Virtually all main oil importers now have in place stockholding and demand restraint measures advocated by the IEA. Prior to the first oil crisis in 1973, only a handful of countries – representing less than 1% of net oil imports – had such emergency measures in place. Today, countries responsible for 99% of net oil imports have one or more oil security measure in place, and 61 countries have introduced emergency oil stock requirements (Figure 2.11).

Figure 2.11 ▹ Cumulative number of countries with selected emergency response and energy security policies, 1970-2025



Since the 1970s, global events and energy crises have triggered a rise in emergency response and energy security policies worldwide

Note: The analysis focuses on 85 countries, covering 93% of global primary energy demand, 87% of global oil demand and 95% of global natural gas demand.

The number of natural gas security measures in place has grown rapidly in recent years. In 2015, stockholding requirements only covered countries accounting for 10% of net gas imports, a figure that has now risen to 34%, mostly made up by EU member countries.

Demand restraint measures for natural gas such as fuel switching, interruptible contracts and load shedding have become increasingly common since Russia's annexation of Crimea in 2014. Over 40 net gas importing countries now have legislation in place to implement such measures, with 15 introducing them in the past ten years, including most European Union and Balkan countries.

The focus of policy is expanding to cover emerging energy security threats, including those with a bearing on the supply of critical minerals, technology supply chains, electricity security, cybersecurity and climate resilience. To take one important example, the expanding number of trade restrictions on critical minerals and related manufactured products is leading to efforts to strengthen resilience to potential supply disruption, notably by putting in place strategic reserves of critical minerals, as the United States, China, Japan and Korea have done, and by adopting measures to diversify supply. The rising number of cyber and physical attacks on power infrastructure represents another important threat, especially against the background of rapid growth in demand for electricity. Countries are increasingly taking steps to integrate long-term strategic planning and reform regulatory frameworks and market design to improve operational security and resilience. The IEA supports regulatory discussions in each of these emerging security areas and established a Voluntary Critical Minerals Security Programme in 2022 and an Electricity Security Advisory Board in 2024 to help address these challenges.

2.3 *WEO* scenarios

Analysis in the *World Energy Outlook (WEO)* provides a framework for understanding the future of energy, not by setting out a single vision of the future, but by examining several different potential scenarios for its development. Each scenario has the same starting point and is based on the latest data for energy supply and demand, markets, technology costs and policies, as well as the same pathways for future population and economic growth. None of the individual *WEO* scenarios should be regarded as a forecast.

The energy system described and explored in each scenario evolves in a distinctive pathway that delivers energy services with a different mix of technologies and fuels, with varying implications for energy security, affordability and emissions. This is primarily due to differing assumptions about how energy policies are implemented and evolve, and how these interact with the evolution of energy technologies and markets.

This edition of the *WEO* examines the outlook for the energy system through an updated set of scenarios. The first two, the Current Policies Scenario (CPS) and the Stated Policies Scenario (STEPS) do not target a specific endpoint or objective but rather establish different sets of starting conditions and explore where they may lead.

Of the many factors that can influence the evolution of the energy sector, policies play a profound role, and are the key differentiating factor between these two scenarios. However, policies are generally only a partial guide to the direction of travel. They are sometimes imprecise, can have unintended consequences, and are subject to change. To reflect the wider complexity of factors that can shape the evolution of the energy system, the design of the CPS and STEPS also reflects the speed and extent to which technology challenges and barriers to change in the energy sector are overcome.

- The **Current Policies Scenario** (CPS) returns in this *Outlook*, setting out a pathway for the future of the energy system in which no change in energy-related policies is assumed beyond what is already in place. The CPS therefore builds on a narrow reading of today's policy settings, only considering those that are adopted in legislation and regulation, and assuming no change, even where governments have indicated their intention to do so. Where existing policies target a range of outcomes, it is assumed that the lower end of the range is achieved. In the CPS, policies that are time-bound or that target specific years are not strengthened after they expire. Alongside this view of the policy landscape, the CPS also offers a generally cautious perspective on the speed at which new energy technologies are deployed and integrated into the energy system. It tends to project slower growth in the adoption of new technologies in the energy system than seen in recent years, or than projected in the STEPS.

- The **Stated Policies Scenario** (STEPS) builds on a broader reading of the policy landscape than the CPS, also taking account of those policies that have been formally tabled but not yet adopted as well as other official strategy documents that indicate the direction of travel. These could include, for example, development plans for the power sector that aim to achieve a certain mix of generation assets by a specific date; or plans to reform the regulatory framework for part of the transport sector or to achieve a certain level of efficiency for new or retrofitted buildings. Such targets are not automatically assumed to be met; the prospects and timing for their realisation are subject to an assessment of relevant market, infrastructure and financial constraints.

  Another difference with the CPS relates to time-bound policies. Whereas the CPS assumes no further change in a policy once it expires, the STEPS assumes that time-bound policies are prolonged into the future and retain a similar pace of change. In addition, the STEPS offers a more dynamic perspective on energy technology and market trends, and it allows for a slightly more rapid introduction of new energy technologies than the CPS. However, like the CPS, the STEPS does not assume that aspirational goals, such as those included in the Paris Agreement, are achieved.

In addition, we include scenarios that have normative elements relating to energy access or the achievement of various goals related to emissions. This means that these scenarios work toward a defined outcome and map out a way to achieve it.

- The **Net Zero Emissions by 2050** (NZE) **Scenario** maps out a pragmatic but ambitious global pathway for the energy sector to achieve net zero CO_2 emissions by 2050 and is consistent with a long-term goal of limiting the rise in global average temperatures to 1.5 °C (with a 50% probability). In contrast with previous editions of the *WEO*, the

NZE Scenario is no longer a limited-overshoot scenario, as warming peaks above 1.6 °C and exceeds 1.5 °C for several decades before returning below 1.5 °C by 2100. These changes in the scenario trajectory reflect the reality of persistently high emissions in recent years and slow or uneven momentum behind the deployment of some policies and technologies. In addition to very rapid progress with the transformation of the energy sector, bringing the temperature rise back down below 1.5 °C by 2100 also requires widespread deployment of CO_2 removal technologies that are currently unproven at large scale.

- The **Accelerating Clean Cooking and Electricity Services Scenario** (ACCESS) – an additional scenario included for the first time in this *WEO* – is a data-driven roadmap to achieve universal access to electricity by 2035 and clean cooking by 2040. It is grounded in practical constraints and solutions, examining what historical rates of progress have been achieved in the past, and then prioritises cost-effective, proven means to replicate those successes. It explores all relevant fuels and technologies needed to achieve universal access as well as the infrastructure, policies and financing needed to scale them up.

This year's *Outlook* does not include the Announced Pledges Scenario, which models a future for the energy system in which all national energy and climate targets, such as countries' Nationally Determined Contributions (NDCs) and long-term, low-emissions development strategies, are achieved in full and on time.[2] Our assessment of the new round of NDCs due this year, generally covering the period to 2035, will follow once there is a more complete picture of these pledges.

2.3.1 GDP and population

The global economy is assumed to grow by 2.6% on average annually to 2050 across all scenarios (Table 2.2). Out to 2030, our GDP assumptions at a country and regional level are based on the IMF *World Economic Outlook* (April 2025), with global GDP projected to grow by 3% annually over this period (IMF, 2025c). This projection is similar to the rate of growth in the IMF October 2025 assessment (IMF, 2025a). After 2030, GDP growth assumptions are based on Oxford Economics forecasts (Oxford Economics, 2025) and the application of the Solow growth model (World Bank, 2022). The Solow model estimates future GDP on a country and regional basis by accounting for labour supply, capital stock, and total factor productivity (TFP). TFP growth reflects catch-up dynamics in lower income countries and convergence towards advanced economy levels.[3] Economic assumptions are held constant across the various scenarios to facilitate comparisons between them, although we recognise

[2] NDCs are national climate action plans by each country under the Paris Agreement, submitted every five years to the UNFCCC secretariat. The Paris Agreement provides that successive NDCs will represent a progression compared to the previous NDC and reflect its highest possible ambition.

[3] Details on GDP and other macroeconomic assumptions are available in the IEA GEC-Model documentation (IEA, 2025g).

that decisions taken by policy makers in the energy sector have broader economic implications.

The global population – another major driver of global energy trends – is expected to expand from 8.1 billion in 2024 to 9.6 billion in 2050, based on the medium population projection of the United Nations *World Population Prospects* (United Nations, 2024). This represents a slowing of annual global population growth from roughly 1% over the last decade to 0.6% by 2050, although the population in sub-Saharan Africa increases by 70% over the period. Demographic changes impact GDP growth and therefore energy demand. Regions with rising working age populations, such as India and Indonesia, are set to see stronger energy demand growth, whereas ageing societies, such as Japan and Korea, are likely to experience slower growth or declines in energy demand. These demographic shifts also influence the structure of energy use: younger populations drive energy demand in transport, construction and manufacturing, while older populations tend to increase residential energy consumption.

Table 2.2 ⊳ GDP average growth assumptions by region

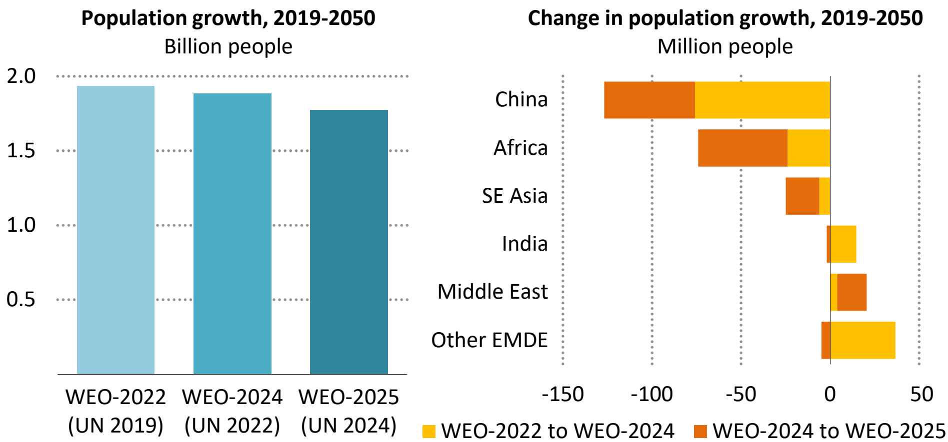
	Compound average annual growth rate			
	2010-24	2024-35	2035-50	2024-50
North America	2.3%	2.0%	1.8%	1.9%
United States	2.3%	2.0%	1.8%	1.9%
Central and South America	1.4%	2.6%	2.1%	2.3%
Brazil	1.3%	2.3%	2.1%	2.2%
Europe	1.7%	1.6%	1.3%	1.4%
European Union	1.4%	1.3%	1.0%	1.1%
Africa	3.1%	4.2%	3.9%	4.0%
South Africa	1.1%	1.8%	2.6%	2.2%
Middle East	2.5%	2.9%	2.7%	2.8%
Eurasia	2.2%	1.8%	1.4%	1.6%
Russia	1.8%	1.0%	0.5%	0.7%
Asia Pacific	4.9%	3.9%	2.8%	3.3%
China	6.3%	3.5%	2.2%	2.7%
India	6.0%	6.1%	4.0%	4.9%
Japan	0.6%	0.6%	0.7%	0.6%
Southeast Asia	4.3%	4.1%	3.0%	3.5%
World	**3.1%**	**3.0%**	**2.4%**	**2.6%**

Note: Calculated based on GDP expressed in year-2024 US dollars at purchasing power parity terms.

Sources: IEA analysis based on IMF (2025c) and Oxford Economics (2025).

UN projections for future global population growth have been successively lowered in recent years. Population growth to 2050 is concentrated in emerging market and developing economies, which are expected to account for over 95% of the global increase over the period, and these regions have seen the most significant downgrades (Figure 2.12). Projections in this *Outlook* are based on a population growth figure for these economies from 2019 to 2050 which is 161 million lower than in the *WEO* in 2022.

Figure 2.12 ▷ Revisions to population growth projections for emerging market and developing economies, 2019-2050



Populations projections for emerging market and developing economies in 2050 have seen significant downward revisions in recent years, especially for China and Africa

Notes: WEO = *World Energy Outlook*. UN 2019, UN 2022 and UN 2024 refer to editions of United Nations *World Population Prospects*. EMDE = emerging market and developing economies. For further details on population assumptions used in this *World Energy Outlook*, see Annex B.

Source: United Nations (2024).

The largest change is in China, whose population in 2050 is now assumed to be 51 million lower than estimated in the *WEO-2024*, and 127 million lower than in the *WEO-2022*. China's population peaked in 2021 and is now in long-term decline. Indeed, China is set to experience the largest absolute decline of any country between 2024 and 2050, with its population falling by nearly 160 million to levels last seen in 1999. This *Outlook* update also includes downward 2050 population revisions for Africa and Southeast Asia, and smaller upward revisions for the Middle East. The downward shift in assumptions about global population growth to 2050 has implications for long-term energy use: it implies fewer additional cars on the road and homes to heat and cool, and lower additional demand for material goods.

2.3.2 Prices

Oil prices

In our scenarios, oil prices function as a balancing mechanism for global supply and demand, ensuring market stability. As such, the trajectories are smooth and show a sustained equilibrium, although in practice volatility and uncertainty are ever-present features of oil markets (Table 2.3).

In the Current Policies Scenario, strong and sustained growth in oil demand leads to oil prices reaching USD 106/barrel in 2050 to incentivise the necessary production of resources.

Market balances in this scenario depend on how major producers in different regions maintain high levels of production and how they manage their costs. In the Stated Policies Scenario, decreasing oil demand brings down the price at which markets find equilibrium, but high levels of investment are still required to compensate for declining output from existing fields and for the development of new resources (IEA, 2025b). Prices remain around 2024 levels over the next decade and decrease modestly to 2050. In the NZE Scenario, robust policies are required to effectively neutralise any increase in demand that might result from lower prices, ensuring that climate objectives remain on track. In the NZE Scenario, oil prices fall to USD 33/barrel by 2035 and USD 25/barrel by 2050 as oil demand declines.

Table 2.3 ⊳ Wholesale fossil fuel prices by scenario

		CPS		STEPS		NZE	
USD (MER, 2024)	**2024**	**2035**	**2050**	**2035**	**2050**	**2035**	**2050**
IEA crude oil (USD/barrel)	79	89	106	80	76	33	25
Natural gas (USD/MBtu)							
United States	2.2	4.5	5.0	3.9	4.6	2.1	2.2
European Union	10.3	9.1	10.6	6.5	8.4	4.2	4.0
China	10.3	9.9	11.2	7.5	9.1	4.9	4.8
Japan	13.5	11.2	12.9	8.4	9.7	4.9	4.9
Steam coal (USD/tonne)							
United States	56	56	53	41	41	25	23
European Union	112	92	82	78	66	47	39
Japan	151	112	105	100	84	57	49
Coastal China	131	115	105	99	84	59	49

Notes: CPS = Current Policies Scenario; STEPS = Stated Policies Scenario; NZE = Net Zero Emissions by 2050 Scenario. MER = market exchange rate; 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 liquefied natural gas (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.

Natural gas prices

In contrast to oil, there is no global natural gas price but rather a series of regional prices that are loosely connected by an increasingly liquid market for internationally traded gas, primarily in the form of LNG. Around 60% of LNG is currently delivered under long-term contracts with oil-linked pricing formulas or indexed to gas market prices: the remainder is traded on the spot market.

Our gas price benchmarks are weighted average prices that incorporate these different pricing methods. They represent an equilibrium between supply and demand that ensures that new projects come online in a timely manner and can cover their long-run marginal cost of supply. They also consider market conditions in the years ahead; in periods of ample supply availability, prices may for a period reflect the short-run marginal cost of supply. For example, the price of LNG in the European Union in 2035 in the STEPS is around USD 6.2 per million British thermal units (MBtu), based on the US Henry Hub price plus a 15% uplift, some capital recovery for LNG liquefaction terminals, variable shipping fees and a regasification charge. The oil-indexation price is just above USD 8/MBtu. Around 90% of gas in 2035 is priced on a gas hub-indexation basis and 10% on an oil-indexation level, meaning the weighted average gas import price is around USD 6.5/MBtu.

Global gas trade is expected to continue shifting toward LNG. Over the period to 2030, around 300 billion cubic metres (bcm) of new LNG export capacity is set to come online, led by the United States, Qatar and Canada – the largest wave of global capacity additions ever. This will put downward pressure on prices over the coming years, but the impacts vary by scenario.

In the CPS, the new supply is absorbed relatively quickly by robust increases in demand. With strong domestic demand growth and a surge in LNG exports, the United States sees its domestic gas price rise from USD 2.2/MBtu in 2024 to USD 4.5/MBtu in 2035; afterwards China, European Union and Japan also see modest price increases to 2050 driven by their increasing exposure to tightening LNG balances. In the STEPS, downward price pressures and a well-supplied global gas market remains into the 2030s. In the NZE Scenario, global demand and prices are both much lower throughout the *Outlook* period: they remain significantly below 2024 levels by 2035 as the rapid expansion of renewables and electrification limits gas demand growth, despite abundant LNG availability.

Coal prices

Over time, demand for steam coal declines across all the *WEO-2025* scenarios, which has implications for price trajectories. In the CPS, prices need to be high enough to maintain existing mines and incentivise the opening of new ones: this maintains prices at relatively high levels, although some major importers nonetheless see significant declines from current levels. In the STEPS, an earlier downturn in demand in China pulls down global prices more quickly. In the NZE Scenario, falling demand brings prices down to very low levels: higher cost mines are forced to close, and no new mines are needed. More than for any other fuel, the global trajectory for coal is determined by a handful of major consuming countries, notably China and India, whose consumption of coal for power generation accounts for nearly half of current coal use worldwide.

Critical mineral prices

Critical mineral prices are increasingly important in today's energy sector. They do not have the same economic influence on near-term energy prices as fuel prices, but they significantly influence the overall cost of key energy technologies. For example, lithium, nickel, cobalt and graphite have a major impact on battery manufacturing; copper is at the heart of a more electrified energy system. Prices for base metals such as copper, aluminium and zinc rebounded in 2024 and have continued to rise in 2025, driven by increasing demand and tightening supply dynamics. By contrast, demand growth for many battery metals has been outstripped by new supply growth, bringing prices down sharply: lithium prices, which had surged in 2021-2022, have fallen by over 85% since the start of 2023.

We do not yet generate equilibrium prices that balance supply and demand of critical minerals in the same way as for fuels, as there are many sources of demand coming from outside the energy sector, but our analysis of current technology trends and future market balances nonetheless provides insights about possible price pressures. Ample supply means that prices for battery metals are likely to remain subdued in the near term, although our project-by-project analysis of lithium supply indicates that further project development will be required to keep pace with strong demand growth. Copper presents a more worrying picture: mined output growth has been relatively slow because of declining resource quality, the increasing complexity and capital intensity of projects, and long project lead times – all factors that are likely to persist in the future. Despite the possibility of some material substitution and additional recycling, there is a significant risk of tighter markets for copper as demand increases for its use not just in energy technologies and power grids but also in construction and industrial applications. Price and volume risks for critical minerals are also linked in many cases to the highly concentrated nature of supply, with China having an exceptionally strong position in refining and processing of many minerals.

Carbon prices

Carbon pricing instruments are increasingly being used to mitigate emissions in the energy sector. Eighty direct carbon pricing instruments are now in place – five more than in 2024. Coverage of these schemes has risen to about 28% of global greenhouse gas emissions, with most of the increase stemming from the expansion of the emissions trading system (ETS) in China to the cement, steel and aluminium sub-sectors. Despite this increased coverage, government revenues of USD 102 billion in 2024 were 1.9% lower than in 2023. This slight decrease in revenue reflects a decline in ETS allowance prices in large systems, including the European Union and United Kingdom emissions trading systems. It also reflects the abolition in Canada from March 2025 of the federal fuel charge, which was introduced in 2019 to price carbon emissions from the transport and buildings sectors. However, Canada's Output-Based Pricing System for power and industry remains unchanged.

The CPS only considers laws and regulations already in place. It excludes carbon taxes, emissions trading systems and reforms to extend existing systems that have yet to be implemented. The STEPS incorporates both existing and scheduled carbon pricing systems. It assumes that ETS allowance prices rise continuously, and that carbon taxes and other non-market mechanisms remain constant unless scheduled to increase. It also includes planned reforms to extend coverage and to phase out free allowances. The NZE Scenario assumes that carbon prices are introduced in all regions and most energy sectors, and that they vary with the level of mitigation required in each region and level of development. Prices reach USD 250 per tonne of carbon dioxide (t CO_2) in 2050 for advanced economies, USD 200/t CO_2 for selected emerging markets, and USD 55/t CO_2 for other emerging market and developing economies, on the assumption that regions also pursue more direct policies to adapt and transform their energy systems.

The level of carbon prices included in our scenarios should be interpreted with caution. A broad range of energy policies and accompanying measures, including energy performance standards and incentive programmes, interact with carbon pricing, lowering the need for a high CO_2 price to reduce emissions. As a result, CO_2 prices in our scenarios do not represent the marginal cost of abatement. (See Annex B for more details of assumptions and coverage).

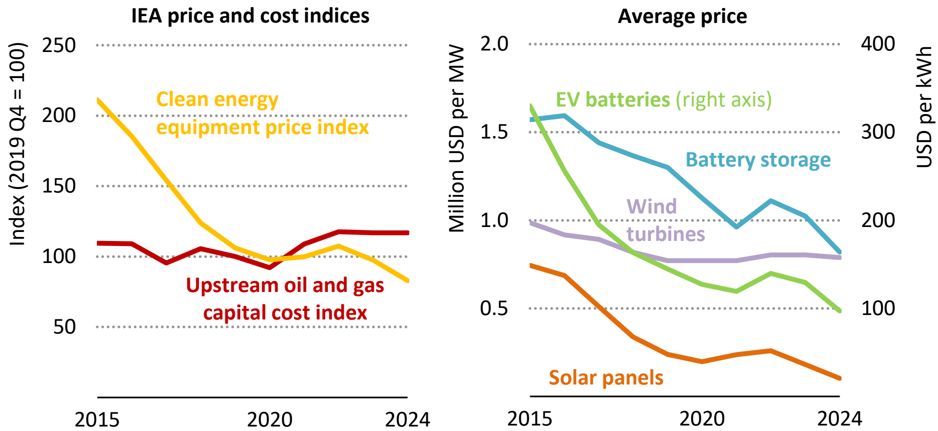
2.3.3 Technology costs

The evolution of technology costs in the *WEO-2025* scenarios is built into the modelling framework via a continuous process of technology improvement and learning over time, offset in some cases – notably for fossil fuels – by upward pressure on costs due to resource depletion. These processes play out differently in each scenario. Technology costs differ from the prices ultimately paid by end-users, which are shaped not only by underlying costs but also by market design, regulatory frameworks, and policies affecting trade and affordability. In the case of energy technologies, costs are linked to cumulative deployment, so they come down more quickly in scenarios where deployment is faster. In the case of fossil fuels, high demand scenarios tend to feature higher costs as more remote, geologically challenging and expensive resources come into play. We do not assume any major new technology breakthroughs in the *WEO* scenarios, but the modelling framework contains a very rich representation of energy technologies across all parts of the energy sector, including those that are judged to be approaching commercialisation.

The IEA Clean Energy Equipment Price Index tracks price movements for a global basket of solar PV modules, wind turbines and lithium-ion batteries for EVs and battery storage, weighted by shares of investment (Figure 2.13). High critical minerals prices and supply chain problems pushed up the cost of a number of key clean energy technologies in 2021 and 2022, but prices for most energy technologies have fallen significantly since then. The index reached its lowest ever level in 2024, thanks in large part to price reductions for batteries and solar PV. This comes after a decade of cost decreases for these technologies, during which prices for solar PV and EV batteries have both fallen by more than 80%.

Battery prices hit a record low of USD 115 per kilowatt (kW) in 2024, with average battery pack prices falling by 20% – the largest annual drop since 2017. This was largely driven by major price declines for lithium, nickel, cobalt and graphite. Other factors include: fierce price competition as battery manufacturers vied for market share amid considerable excess manufacturing capacity, particularly in China; increasing adoption of lithium iron phosphate (LFP) batteries (around 30% cheaper than lithium nickel manganese cobalt oxide (NMC) batteries); and improved economies of scale. Battery prices fell in all markets, but the extent of the drop varied across regions. In China, prices fell around 30% in 2024, compared with 10-15% in the United States and Europe, due to stronger price competition and more rapid adoption of LFP battery technologies.

Figure 2.13 ▷ Indices of clean energy equipment prices and upstream oil and gas capital costs, and global average capital cost of selected energy technologies, 2015-2024



IEA. CC BY 4.0.

Falling critical minerals prices and fierce competition stemming from excess manufacturing capacity have driven major price reductions in batteries and solar PV

Notes: Q4 = 4th quarter; MW = megawatt; kWh = kilowatt-hour. Nominal prices.

Sources: IEA analysis based on company financial reports and BNEF (2024).

Solar PV prices reached historic lows in 2024, almost 45% lower than in 2023 as the cost of panels rapidly decreased. As with batteries and as detailed in previous *World Energy Outlooks*, significant excess manufacturing capacity for solar PV underpinned intense competition between the main Chinese manufacturers, which pushed margins into negative territory across the supply chain from polysilicon production through to module manufacturing. The resulting financial turmoil has since prompted a series of efforts in China to stabilise the market, but these have met with limited success so far, and the overhang of manufacturing capacity is likely to maintain downward pressure on solar PV prices.

Although global wind turbine costs decreased by 2% in 2024 from 2023, western manufacturers maintained higher prices in order to recover from the financial difficulties of previous years in which project profitability fell. Onshore projects generally are proving resilient in the face of higher turbine prices, but the offshore market has suffered considerable setbacks, exacerbated in some cases by policy changes: investment and projects have been scaled back, and some major oil companies have spun off their offshore wind portfolios.

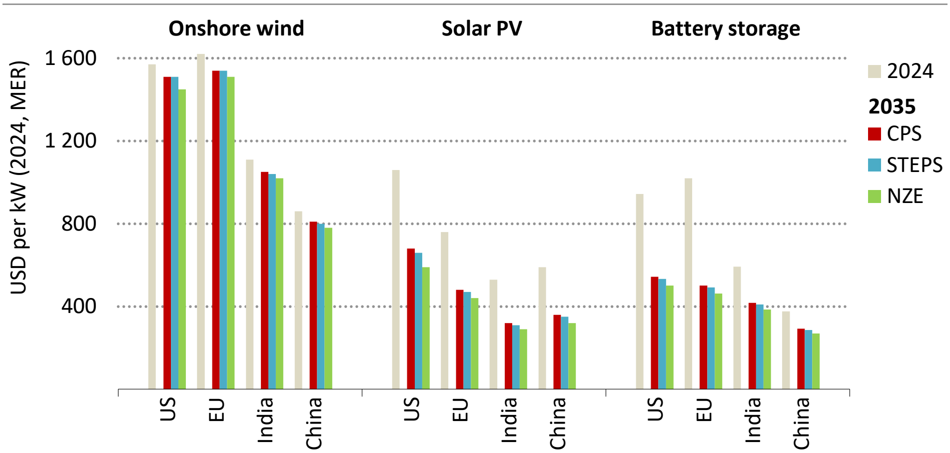
Natural gas turbines, like other mature technologies, have seen comparatively limited underlying cost changes in the past decade, having already benefited from the type of cost reductions that technologies experience as they mature. However, there are indications of recent upward price pressure for some gas turbines, particularly for new orders that incur premiums to avoid the already long queue. For example, in the United States, reported construction costs for new efficient gas turbines to be added in 2030 are roughly double recent costs (GridLab, 2025). While this may affect short-term trends, it is less likely to indicate long-term implications for gas turbine prices.

Nuclear power experienced significant delays and cost overruns in recent years for large-scale reactors in Europe and the United States, which on average have been completed eight years later than planned and cost 2.5-times as much as originally estimated (IEA, 2025h). However, some nuclear projects have been completed closer to original timelines and cost estimates in other countries, including China, Russia and Korea.

Grid investment costs have been pushed up by recent price increases for new transformers and cables; however, new manufacturing facilities are being planned and built that should ease these constraints over time. These include major projects such as a medium-voltage cable manufacturing plant in Morocco that is expected to begin operation in 2026.

Upstream oil and gas operations face some upward cost pressure driven by high utilisation rates for specialised equipment such as drill ships and semi-submersibles. In addition, trade frictions in the United States have raised the price of imported steel and aluminium, both of which are critical inputs to pipelines, rigs and other oilfield infrastructure, further intensifying cost pressures.

Figure 2.14 ▷ Installed costs of onshore wind, solar PV and battery storage by scenario and region/country, 2024 and 2035



Installed costs decline to 2035 for onshore wind, solar PV and utility-scale battery storage across scenarios

Notes: kW= kilowatt; MER = market exchange rate; US = United States; EU = European Union. CPS = Current Policies Scenario; STEPS = Stated Policies Scenario; NZE = Net Zero Emissions by 2050 Scenario. Battery storage is based on four-hour storage.

Looking ahead, the installed costs of renewables such as solar PV, onshore and offshore wind are set to continue to decline, as are costs for battery storage (Figure 2.14). The extent of these declines varies by country, region and scenario, depending on starting points and global deployment trends. The IEA Global Energy and Climate (GEC) Model incorporates a technology-specific, local learning-by-doing process for projected capital costs – particularly for technologies such as renewables whose markets are maturing – as well as global learning through technology innovation. By contrast, oil and gas resources are generally set to become more expensive to extract over time, with continued upstream innovation and technology improvements more than offset by the effects of resource depletion (IEA, 2025b). However, recent experience provides a reminder that cost trajectories are unlikely to be smooth and linear, and that governments need to pay close attention to potential vulnerabilities and imbalances in supply chains.

PART B
OUTLOOKS BASED ON EXISTING TRENDS AND POLICIES

Part B describes the trends for energy demand, emissions, power generation, and fuels in our exploratory scenarios. Neither of which is a forecast or prediction.

Chapter 3 explores the Current Policies Scenarios, which considers a snapshot of policies and regulation that are already in place and offers a generally cautious perspective on the speed at which new energy technologies can be deployed and integrated into the energy system.

Chapter 4 examines the Stated Policies Scenario, which considers the application of a broader range of policies, including those that have been formally tabled but not yet adopted as well as other official strategy documents that indicate the direction of travel. Barriers to the introduction of new technologies are lower than in the Current Policies Scenario, but this scenario does not assume that aspirational targets are met.

Chapter 5 compares the outcomes of the Stated Policies Scenario and the Current Policies Scenario, examining both elements of continuity and change across all fuels and technologies. It assesses the implications of the two scenarios for energy security, emissions and the environment, as well as investment and affordability trends.

Current Policies Scenario

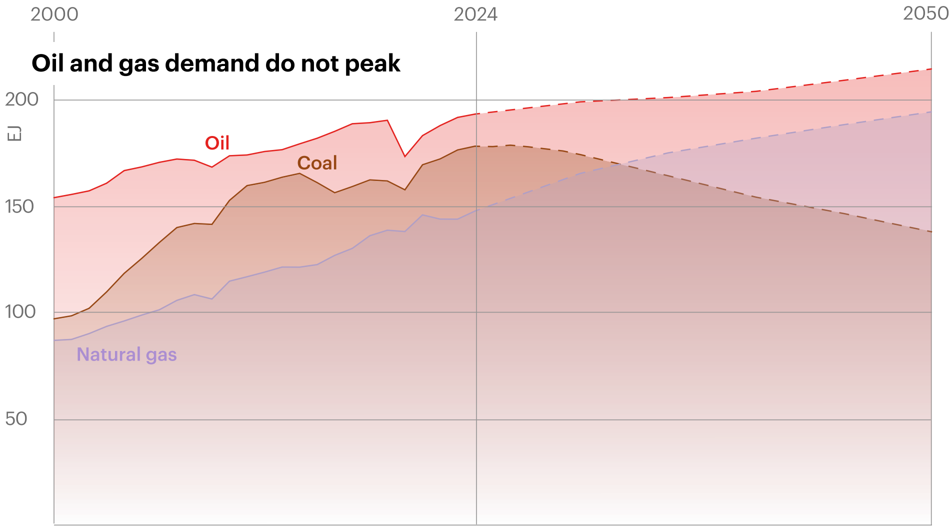
Expanding the world we know

SUMMARY

- Total final consumption rises in the Current Policies Scenario (CPS) by around 1.3% each year over the next decade, similar to the average annual increase over the last decade: global industrial output, appliance ownership and demands for mobility all increase, while energy efficiency gains are modest.
- Demand for oil rises to 113 million barrels per day by 2050, mainly due to its increased use in emerging market and developing economies for road transport, petrochemical feedstocks, and aviation. Electric vehicle (EV) uptake stalls in regions lacking strong policy support: China and Europe are the main exceptions, and they see continued growth in EV sales. Global natural gas demand rises to 5 600 billion cubic metres by 2050: demand in the Middle East increases strongly, but developing economies in Asia are the largest source of demand growth, and their rising supply needs are met by new pipelines from Russia to China and by increased flows of liquefied natural gas.
- Oil and gas prices rise to 2050 in the CPS. The United States remains the world's largest oil and gas producer through to 2050, but oil production of the OPEC+ in 2050 is 15% higher than at any point in history. The CPS assumes that, by the latter part of the projection period, constraints on oil production and trade in countries currently subject to sanctions ease, so their output is determined by the underlying economics. If this is not the case, and geopolitical constraints remain in place, demand could be met through increased production in other countries, but this would entail increased investment, and would probably also mean higher prices.
- Electricity demand rises in all countries and regions, with the strongest growth in India and Indonesia, but the push for a much more electrified energy system does not gain broad momentum in the CPS. Solar photovoltaics (PV) and wind are cost competitive in many regions, but deployment faces integration challenges that slow further growth: annual solar PV capacity additions average 540 gigawatts to 2035, similar to the level in 2024. Coal remains the largest single source of global power generation for the next ten years. Construction of new nuclear facilities accelerates in the 2030s. Global electricity grids increase by 25 million kilometres (km), a 30% increase, to 2035, and by a further 40 million km to 2050.
- Annual global energy-related CO_2 emissions rise slightly from current levels and approach 40 gigatonnes of carbon dioxide per year in the early 2030s, remaining around this level through to 2050. Emissions fall in aggregate in advanced economies, most substantially in Europe, and decline in China from 2030 onwards, but they increase elsewhere. Total greenhouse gas emissions lead to a global average surface temperature rise of around 2 °C in 2050 and 2.9 °C in 2100.

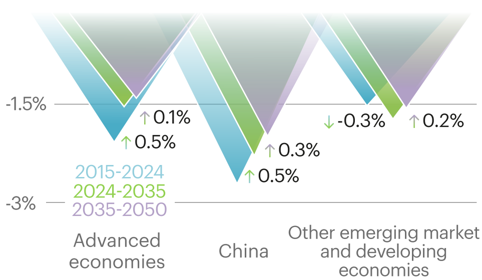
The Current Policies Scenario

Oil and gas demand do not peak

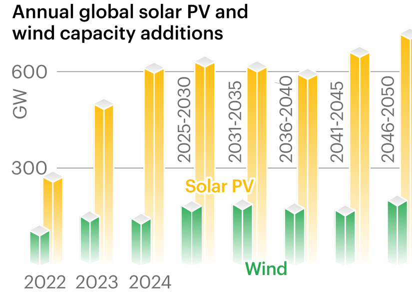


Several regions see a slowdown in energy intensity reductions and renewable energy growth

Reductions in total final consumption per unit of GDP

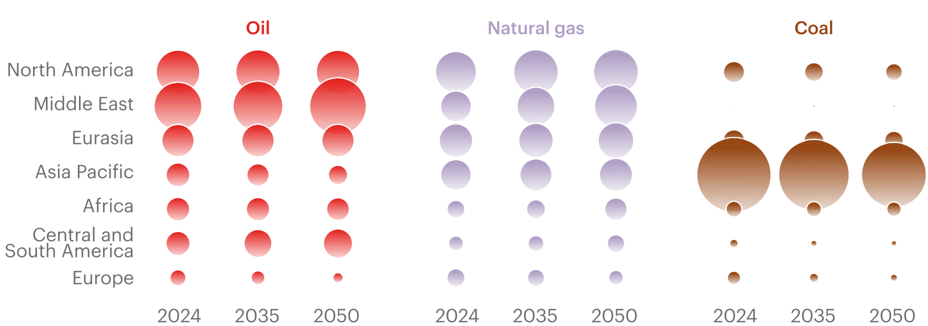


Annual global solar PV and wind capacity additions



Established producers dominate fossil fuel supply through to 2050

The United States remains the world's largest oil and gas producer through to 2050, but production in the Middle East grows robustly.



3.1 Introduction

This edition of the *World Energy Outlook* (*WEO*) reintroduces the Current Policies Scenario (CPS). It was a regular feature of the International Energy Agency suite of scenarios until the *WEO-2020*, when it was discontinued amid turmoil in energy markets and rapid changes in the policy landscape during the Covid-19 pandemic. Now that the world has passed through the pandemic and the global energy crisis triggered at the outset of the Russian invasion of Ukraine, there is merit in revisiting the CPS, a scenario that relies only on measures that are formally written into existing legislation and regulation, and which does not consider any additional changes to policy, even where governments have announced an intention to enact them. (Details of the Current Policies Scenario design are in Chapter 2).

The CPS is not a forecast or a prediction of the way the energy system will unfold. Nor should it be interpreted as a "business-as-usual" scenario. There are several parts of the energy system today where innovative technologies are already being deployed at scale, underpinned by robust economics and mature, existing policy frameworks. In these areas, business-as-usual would imply continuing the current process of change. However, in the CPS, we assume that potential constraints, whether due to insufficient infrastructure, a lack of institutional capacity or financing, or the absence of continued policy support, slow the uptake of these new technologies.

The CPS sees higher levels of total energy demand and carbon dioxide (CO_2) emissions than our other scenarios. This should not be taken as a sign that more energy needs are met in the CPS than in the other scenarios. Slightly higher prices curtail energy service demands in some cases, for example, reducing the distances projected to be travelled by car, while the slowdown in efficiency measures means that more energy is used in the CPS to deliver the same level of energy service compared with other scenarios, for example for space cooling.

This chapter describes the key outcomes of the CPS projections. It starts with an overview of the headline findings for energy demand and emissions, and moves on to review consumption in the main end-use sectors, exploring policy and technology assumptions.

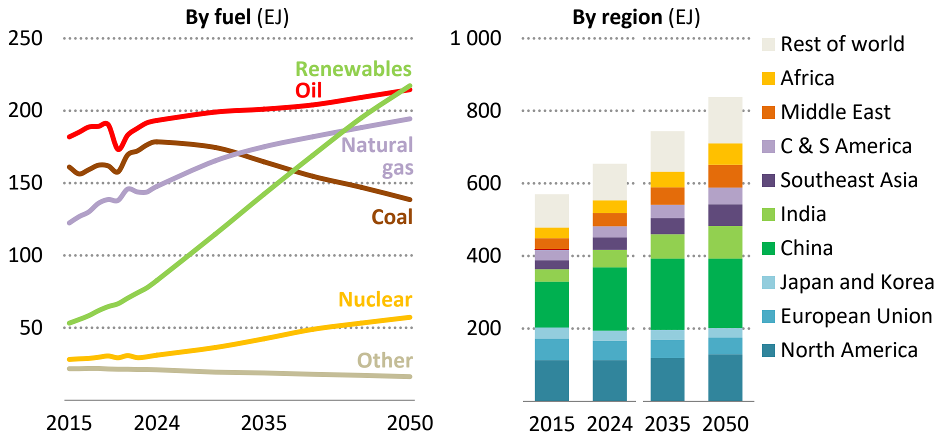
The electricity sector discussion examines the interplay between new and traditional sources of generation in various markets, as rapid electricity demand growth is met by expanding the use of almost all sources of electricity, including nuclear power. The concluding section is the outlook for fossil fuels, with a focus on the wide range of production sources and the supply dynamics that are needed to satisfy continued growth in demand for oil and natural gas.

3.2 Overview

3.2.1 Total energy demand

Global energy demand rose by 1.6% per year between 2015 and 2024. In the CPS, it increases by 1.2% annually to 2035, adding demand equivalent to that of the United States today. Emerging market and developing economies account for 90% of the increase. After 2035, the annual average increase in demand slows to 0.8% (Figure 3.1).

Figure 3.1 ⊳ Total energy demand by fuel and region in the CPS to 2050



Around 90% of global energy demand growth comes from emerging market and developing economies, and global oil and natural gas use rises through to 2050

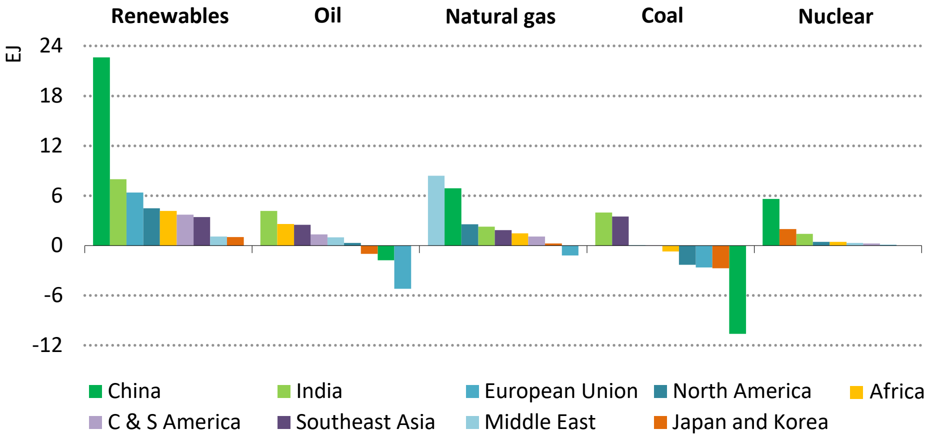
Notes: EJ = exajoule; C & S = Central and South America. Other includes traditional use of biomass and non-renewable waste.

Among emerging market and developing economies, energy demand in India grows the fastest, increasing by 3% each year on average to 2035. Energy demand increases by 2.6% per year in Southeast Asia, 2.4% per year in the Middle East, and 2.1% per year in Africa. China was responsible for more than half of the global increase in total energy demand over the past 25 years, but as its economy changes shape, demand grows by 1.1% each year on average to 2035, much lower than the 3.6% annual increase seen between 2015 and 2024.

Energy demand in advanced economies increases by around 0.15% on average each year to 2035 in the CPS. Demand rises in the United States in all end-use sectors, but falls in Europe and Japan, where rising demand, notably from data centres and space cooling, is more than offset by efficiency and electrification policies that drive down overall energy use.

Deployment rates of clean energy technologies and efficiency measures stagnate or decline in many regions in the CPS, but continue to rise in a number of countries, including those where efficiency measures have short payback periods, where clean energy technologies are the most affordable option, or where current policies point towards increased deployment of particular clean energy technologies, including nuclear. More than 40 countries have policies in place to expand the use of nuclear power, investment has doubled since 2015, and there is a growing pipeline of projects under development: as a result, global nuclear capacity in the CPS expands by one-third by 2035. The rapid growth seen in recent years in solar photovoltaics (PV) and wind capacity additions fades in the CPS. Yet, renewable energy expands by around 70% to 2035, with two-thirds of the global solar PV and wind capacity additions installed in China in the next decade (Figure 3.2).

Figure 3.2 ⊳ Increase in global energy demand by fuel and selected region/country in the CPS, 2024-2035



IEA. CC BY 4.0.

Renewables and nuclear rise fastest to 2035 in China; India leads oil and coal growth; and the Middle East sees the largest increase in natural gas

Note: EJ = exajoule; C & S America = Central and South America.

Coal use starts to decline globally before 2030. Today power generation accounts for two-thirds of worldwide coal consumption, but continued deployment of solar PV, wind and nuclear starts to outpace electricity demand growth in most regions, driving down the use of coal in power generation in nearly all regions, with the main exception of Southeast Asia. Coal use in industry falls in China and most advanced economies but it expands in India and other emerging market and developing economies, and it remains broadly flat globally through to 2050.

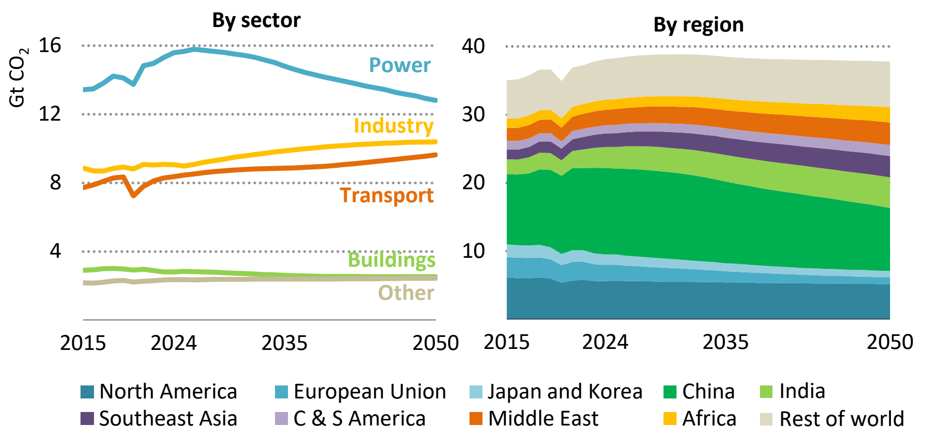
Oil demand, excluding biofuels, rises by more than 5 million barrels per day (mb/d) to reach 105 mb/d in 2035 in the CPS, mainly because of increased use of oil in road transport in emerging market and developing economies, for aviation and shipping, and as petrochemical feedstock. Meeting this demand leads to increased production from a wide range of countries, including countries currently subject to sanctions, and low-cost producer countries that expand beyond announced capacity limits. It also brings about an increase in oil prices to facilitate new development in regions where production costs are relatively high. If today's geopolitical constraints were to remain in place to 2050, other countries could increase supply in place of those subject to sanctions, but this would require additional investment and might well raise oil prices further.

Natural gas demand increases by 800 billion cubic metres (bcm) to around 5 000 bcm in 2035 in the CPS, with volumes traded as liquefied natural gas (LNG) expanding by 60% to 880 bcm.

3.2.2 CO_2 emissions

Annual global energy-related CO_2 emissions rise from 38 gigatonnes (Gt) in 2024 to 39 Gt in the early 2030s and remain around this level to 2050, with increasing CO_2 emissions from fossil fuel use in the industry and transport sectors offset by declining emissions in the power sector. The share of total emissions accounted for by the power sector declines from 40% in 2024 to less than 35% in 2050 as coal-fired generation is replaced by renewables and natural gas. However, emissions from coal use in industry rise marginally to 2050, and coal remains the largest single source of CO_2 emissions.

Figure 3.3 ▷ CO_2 emissions by sector and region in the CPS, 2015-2050



CO_2 emissions increase in industry and transport but decline in power, leading to a broad plateau in emissions through to 2050

Note: Gt CO_2 = gigatonnes of carbon dioxide; C & S America = Central and South America.

Large differences in emissions trends emerge (Figure 3.3). CO_2 emissions in advanced economies – accounting for about 30% of today's global total – decline by around 1% per year, as they have on average over the last decade. To 2050, CO_2 emissions drop by around 60% in the European Union and by 10% in North America. CO_2 emissions in China, which accounts for a further one-third of the global total today, rise marginally to 2030, before starting a slow decline. The rest of the world – accounting for just under 40% of global emissions today – increases CO_2 emissions by around 1% per year, and accounts for more than half of total emissions in 2050. In 2050, per capita emissions in emerging market and developing economies excluding China are around 2.7 tonnes of carbon dioxide (t CO_2), which is a fraction of the level in the rest of the world in 2050: 5.7 t CO_2 per person in advanced economies and 7.5 t CO_2 per person in China.

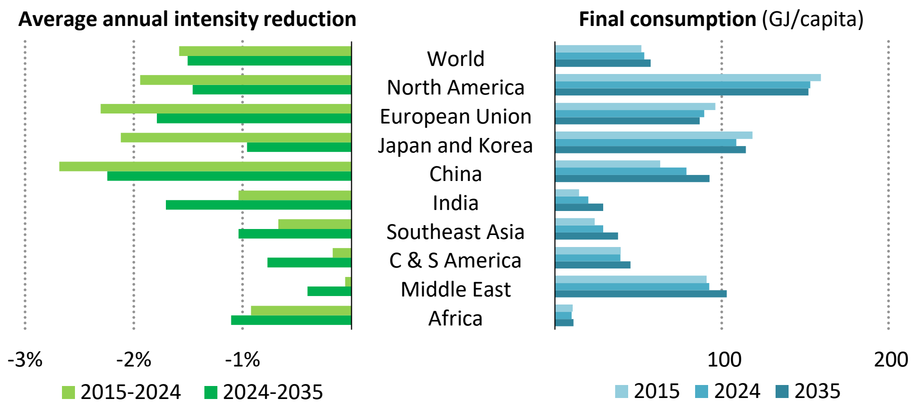
Methane emissions from the energy sector decline from around 145 million tonnes (Mt) today to 140 Mt in 2035, with emissions arising from increased fossil fuel use more than offset by continued efforts in some countries to reduce the emissions intensity of production.

Taken together, the level of CO_2, methane and other greenhouse gas (GHG) emissions would lead to a global average surface temperature rise of around 2 degrees Celsius (°C) in 2050 and 2.9 °C in 2100 (see Chapter 5).

3.3 Total final consumption

Total final consumption rose by an average of 1.3% each year over the past decade to reach just over 450 exajoules (EJ) globally in 2024. In the CPS, it continues to increase by around 1.3% per year through to 2035. The average annual reduction in end-use energy intensity, measured as total final consumption excluding the traditional use of biomass per unit of gross domestic product (GDP), was 1.7% over the past decade. In the CPS, it averages 1.6% to 2035 and 1.4% between 2035 and 2050 (Figure 3.4). Current policies, such as those that have energy efficiency standards for new vehicle and appliance sales, contribute to some of these future reductions in intensity, and so does the gradual replacement and updating of the existing stock. In the CPS, however, policies are not renewed or strengthened after they reach the end of the current policy period, which means that increases in efficiency and electrification slow over time. In most advanced economies, per capita total final consumption has been declining since the 2000s. In the CPS, it remains at around today's level to 2035. In many emerging market and developing economies, per capita total final consumption, excluding the traditional use of biomass, has been rising in recent years, and in the CPS it rises at the same pace to 2035 than over the last decade. Even so, average per capita consumption of emerging market and developing economies in 2035 (44 GJ/capita), remains well below the current global average of 54 GJ/capita.

Figure 3.4 ▹ Reductions in energy intensity and total final consumption by region in the CPS, 2015-2035



Over the next decade, reductions in energy intensity are smaller than recent years, while total final consumption increases at a faster rate in many regions

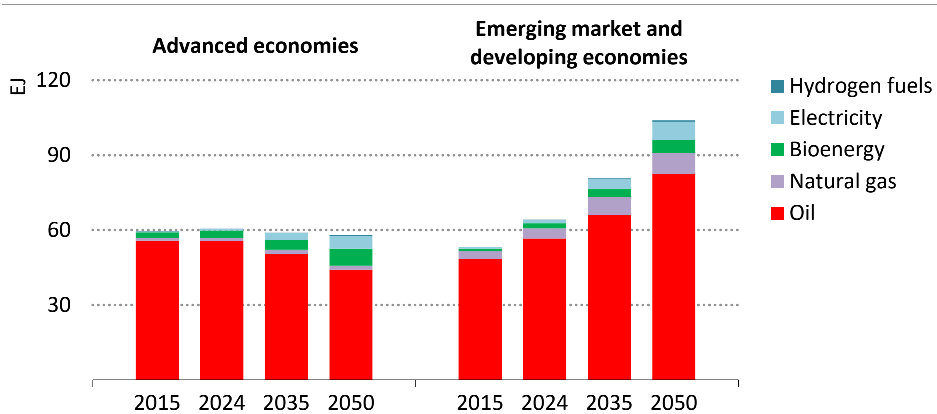
Notes: GJ/capita = gigajoule per capita; C & S = Central and South America. Total final consumption excludes the traditional use of solid biomass. Energy intensity is the ratio of total final consumption per unit of GDP, excluding the traditional use of biomass.

Industry accounts for the largest share of growth in total final consumption, around 45%, with demand for base materials and other industrial outputs continuing to rise. The buildings sector is responsible for almost 30% of the increase, in particular reflecting increasing ownership of appliances and air conditioning. The transport sector accounts for more than 20%, in large part because of rapid rises in car ownership and freight transport in emerging market and developing economies.

3.3.1 Transport

With rising demand for passenger and goods transport, especially in emerging market and developing economies, transport energy demand increases in the CPS by more than 10% through to 2035 (Figure 3.5). Oil currently accounts for 90% of transport energy consumption, and it continues to dominate energy use in the sector through to 2050. Electric car sales have surged in recent years as a result of policy support and declining battery prices. Electric vehicles (EVs) are expected to account for more than one-quarter of new cars sold worldwide in 2025, although uptake has slowed in the United States and Canada in the first-half of 2025. In the CPS, the share of the market taken by EVs continues to rise, though not as rapid as in recent years, with EVs accounting for around 40% of the over 100 million passenger cars sold worldwide in 2035. China accounts for more than 50% of total electric cars sold globally in 2035, and Europe for another 30%. EV deployment is much more subdued elsewhere, with sales shares remaining close to current levels through to 2050. Increases in efficiency of conventional technologies – cars, trucks, aircraft and ships – also slow from historical levels, as the CPS assumes that standards are not strengthened any further after their specified policy period.

Figure 3.5 ⊳ Energy demand in transport by fuel and economic grouping in the CPS to 2050



Electric car sales and fuel economy gains stall, while aviation and road transport demand rise sharply in emerging market and developing economies

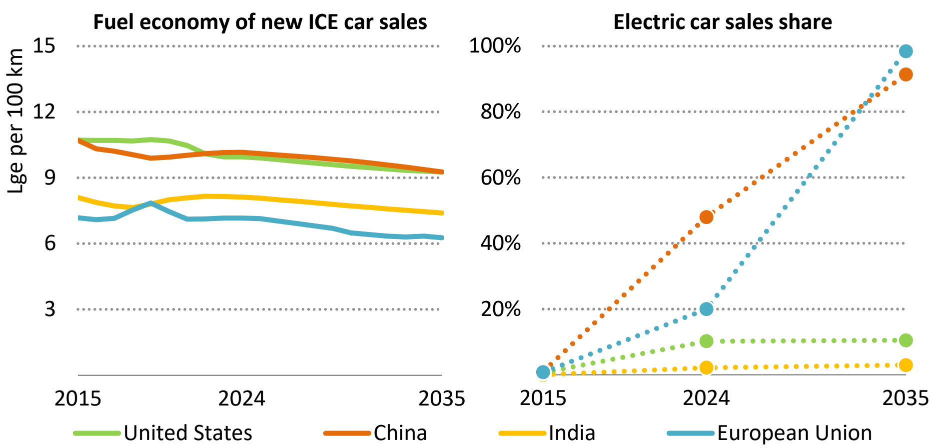
Notes: EJ = exajoule. Includes international bunkers. Hydrogen fuels include low-emissions hydrogen and hydrogen-based fuels.

Road transport

The road transport sub-sector is responsible for around 45% of global oil use today, mostly used in passenger cars. Today there are around 1.4 billion cars on the road, and around 80 million new cars are sold each year. Rising demand for cars is concentrated in emerging market and developing economies, where the level of ownership, (one car per ten people), is much lower than in advanced economies, (five cars per ten people). This rise in demand takes the number of cars in emerging market and developing economies from nearly 0.7 billion today up to 1.3 billion in 2050, which is the largest source of energy demand growth in road transport.

The size of new vehicles sold in recent years has grown. Sports utility vehicles (SUVs),[1] which use about 15% more fuel than an average medium-size car, are now around 30% of the global car fleet and account for about 50% of all new car sales. Around 60% of new electric cars sold in 2024 were SUVs, though around 95% of the SUV fleet still runs on oil. Absent policies to limit the size and use of SUVs, their share of sales continues to rise in the CPS.

Figure 3.6 ▹ Fuel economy of new conventional cars and electric car sales by selected region/country in the CPS to 2035



Fuel economy of ICE cars slowly improves; electric car sales rise in China and the European Union, but are muted in other major car markets

Note: ICE = internal combustion engine; Lge = litre of gasoline equivalent.

Sources: Historical numbers for electric car sales are based on ACEA (2025); EV Volumes (2025); European Commission (2025); Marklines (2025).

[1] The definition of an SUV varies by country. Here we include small SUVs, sometimes known as crossovers, as well as large SUVs such as those with off-road features. Crossovers are the most popular options in the European market. The average SUV in North America is considered to be a large SUV.

Today in China, two-thirds of electric cars on the market are cheaper to buy than their conventional equivalents. In other countries, measures such as subsidies and fuel economy standards have underpinned EV sales. In the CPS, electric car sales continue to rise in some markets: the vast majority of cars sold in the European Union in 2035 are electric as a result of existing CO_2 standards, and around 90% of those sold in China are electric as a result of their low prices and operating costs (Figure 3.6). However, EV sales stall elsewhere, especially in regions that lack policy support or have limited charging infrastructure available. Globally, the market share of EVs rises from around 25% in 2025 to over 40% in 2035 in the CPS: it then falls slightly to 2050 as more global car sales take place in countries with relatively low EV adoption rates.

Over the past decade, the fuel economy of new internal combustion engine (ICE) cars, (measured as fuel consumption per distance travelled), has improved in countries and regions with established policies, including China, European Union, Japan and United States. This reflects advances in gasoline and diesel engine technology together with widening use of hybrid vehicles. The rising share of heavier and less efficient vehicles, such as SUVs, however, has offset some of these gains. In the CPS, ICE car fuel economy continues to improve broadly in line with historical trends, though in some advanced economies it does so a little more slowly than in the past.

Global total oil demand for passenger cars declines by more than 1 mb/d to 2035 in the CPS. An increase of 1.2 mb/d in emerging market and developing economies is more than offset by a 2.5 mb/d decline in advanced economies which reflects mainly fuel economy standards and zero emissions car mandates in Australia, Canada, Europe, Japan and Korea.

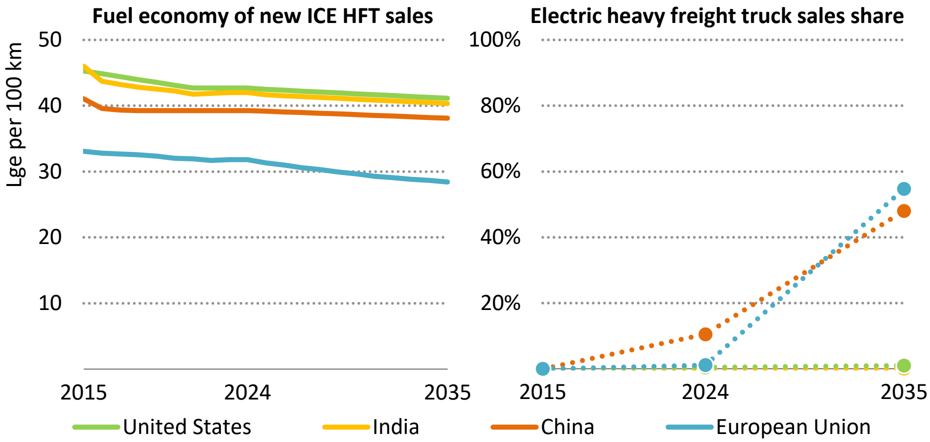
Road freight is responsible for around 40% of road transport energy demand today, more than 90% of which is fuelled by oil.[2] Global annual average fuel economy improvements for ICE heavy freight trucks slow to around 0.1% to 2035, down from 0.5% over the past ten years. Energy use in heavy freight trucks rises nearly 25% to 2035, which accounts for over 80% of the total growth in road freight energy demand.

Electric heavy freight trucks accounted for just under 3% of global heavy freight trucks sold in 2024 and this rises to around 15% of global sales in 2035, mainly in China and the European Union (Figure 3.7). The growth of electric heavy freight trucks in these regions is driven by cost competitiveness in China and by CO_2 standards in the European Union. Alternative powertrains such as hydrogen comprise a further 1% of global sales.

Sales of LNG heavy freight trucks have been rising, mainly in China, where around 1 million were on the road in 2024. The market dipped slightly in the first-half of 2025, but in the CPS, the LNG heavy freight truck fleet more than doubles to 2035.

[2] Road freight includes light commercial vehicles, which have a gross weight of less than 3.5 tonnes, medium freight trucks, which have a gross weight between 3.5 and 15 tonnes, and heavy freight trucks, which have a gross weight of more than 15 tonnes.

Figure 3.7 ⊳ Fuel economy of new ICE heavy freight trucks and electric heavy freight truck sales by region/country in the CPS to 2035



IEA. CC BY 4.0.

Conventional heavy freight trucks see limited improvement in fuel economy; electric heavy freight truck sales rise sharply in the European Union and China

Note: Lge = litre of gasoline equivalent; ICE = internal combustion engine; HFT = heavy freight truck.

Sources: Historical numbers for electric truck sales are based on data from EV Volumes (2025); China Commercial Vehicles Dealers Association (2025); Shandong Institute of Hydrogen Energy Technology (2025); and DaaS-Auto (2024).

Aviation

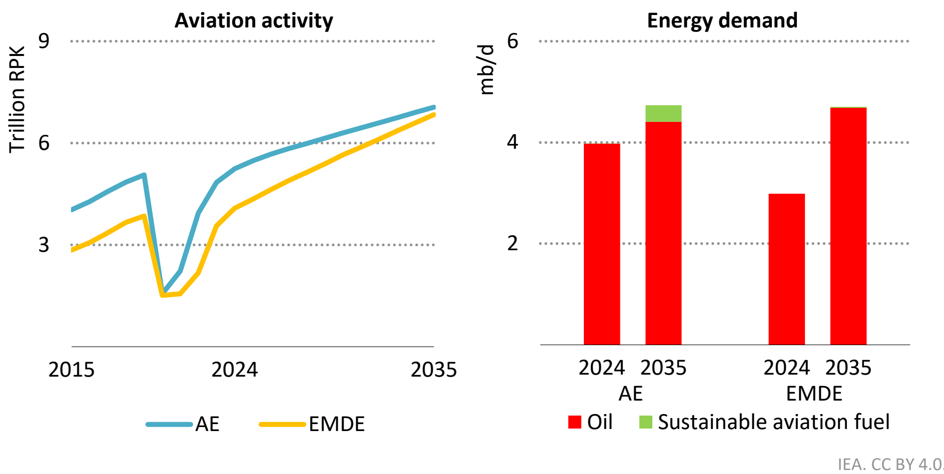
Aviation is a fast-growing sub-sector of transport: activity levels are up over 35% in the past decade. In the CPS, aviation activity increases by a further 50% to 2035. Around 80% of energy demand in aviation is for passenger transport; the rest is mainly for freight, military use and private flights. Increases are led by emerging market and developing economies, where its energy demand rises 4.2% per year to 2035, compared with around 1.5% in advanced economies (Figure 3.8). Soon after 2035, aviation demand in emerging market and developing economies rises to more than 7.5 trillion revenue passenger-kilometres each year, which is greater than the level in advanced economies.[3] Aviation activity swells 70% in China over the period and more than doubles in India.

Aircraft fuel efficiency improved by around 2.5% per year on average over the last decade. Consequently the 35% increase in aviation demand over the period led to a much smaller increase of nearly 20% in energy demand. In the CPS, few new aircraft models are developed and introduced, and the annual average rate of improvement in aircraft fuel efficiency falls to 0.9% through to 2035.

[3] Revenue passenger kilometres is a measure of airline passenger traffic, calculated by multiplying the number of paying passengers by the distance flown in kilometres.

The use of biofuels and other sustainable aviation fuels has expanded in recent years, supported by policies such as ReFuelEU in the European Union, but oil still accounted for more than 99% of total aviation fuel consumption in 2024. The CPS sees some limited further expansion of sustainable aviation fuels, just under 60% of the current pipeline of projects are developed, and the share oil in the aviation fuel market stays above 95% to 2035. Oil use in aviation increases from 7 mb/d in 2024 to over 9 mb/d in 2035.

Figure 3.8 ⊳ Aviation activity and energy demand by economic grouping and fuel in the CPS to 2035



By 2035, aviation activity in emerging market and developing economies is similar to levels in advanced economies; global oil demand in aviation rises by 2 mb/d to 9 mb/d

Note: RPK = revenue passenger kilometre; mb/d = million barrels per day; AE = advanced economies; EMDE = emerging market and developing economies.

Shipping and rail

Shipping activity increased by almost 30% in the 2015 to 2024 period. Thanks in large part to efficiency gains, oil demand rose by much less, just under 5% to 5 mb/d in 2024. In the CPS, projected changes in patterns of trade mean that growth in shipping activity slows, but shipping tonne-kilometres still rise by a further 15% by 2035, and oil demand increases by another 3%. Although turnover in the shipping fleet remains gradual, more LNG-powered ships enter the fleet, and the fuel mix adjusts to meet the requirements of FuelEU maritime regulation in the European Union. As a result, the share of oil in shipping drops from more than 90% in 2024 to around 80% in 2035, and the share of LNG rises to nearly 15%. Some energy efficiency technologies that offer a positive return on investment are introduced for new ships. This leads to a 4% decline in shipping energy use per tonne-kilometre by 2035 in the CPS.

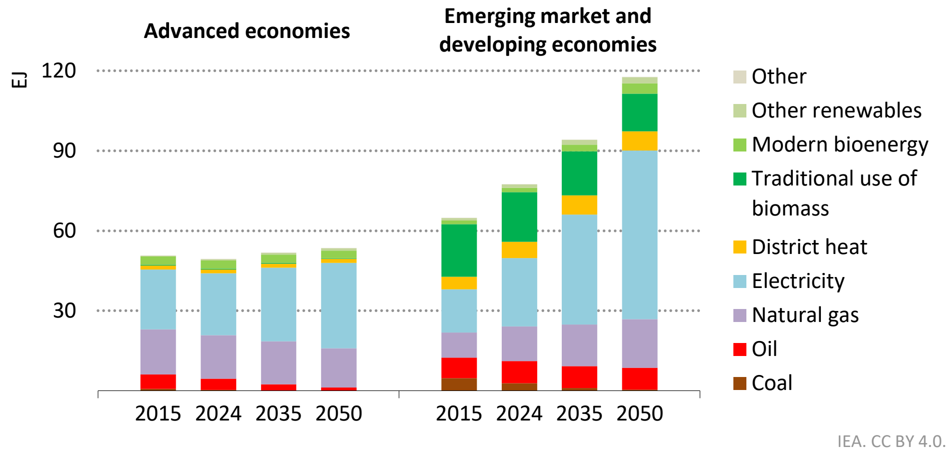
Oil demand for rail rises by 2.5% to 2035 in the CPS to reach 0.6 mb/d. This rate of increase is eight-times faster than in the previous ten years: it reflects sharply rising demand for rail transport and fewer efforts to electrify railways in emerging market and developing economies, where passenger rail activity increases by 30% to 2035 and freight rail activity increases by 15%.

3.3.2 Buildings

Energy use in the buildings sector increased 1% per year between 2015 and 2024, with rapid growth in the demand for energy services, such as heating, cooling and appliances, outweighing the impacts of efficiency gains, electrification and reductions in the traditional use of biomass. In the CPS, minimum energy performance standards (MEPS) and building codes are not strengthened beyond their current levels, and sales of more efficient appliances, such as heat pumps, remain flat to 2050 except in markets where they are already cost competitive without subsidy support. As a result, energy demand in the buildings sector increases by around 1.3% each year on average to 2035 in the CPS (Figure 3.9).

3

Figure 3.9 ⊳ Energy demand in buildings by economic grouping and fuel in the CPS to 2050



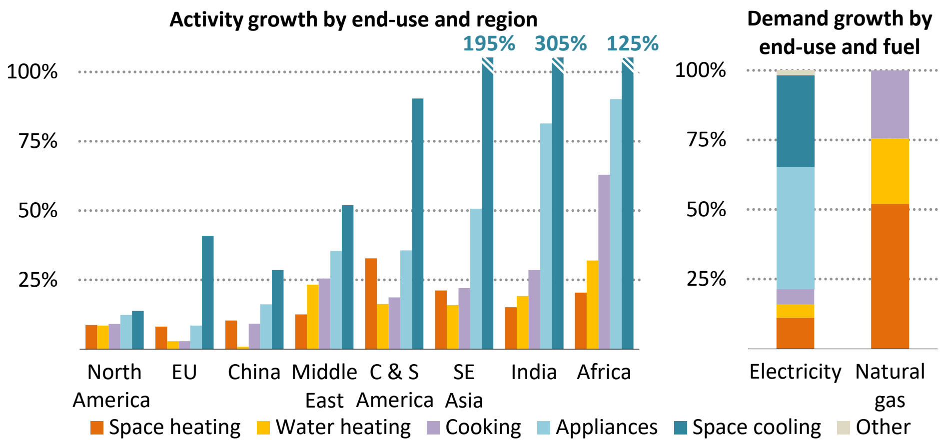
Electricity use in buildings increases rapidly in all regions, though fossil fuel use in the sector decreases in advanced economies

Notes: EJ = exajoule; Other = non-renewable waste and hydrogen; Other renewables = solar thermal and geothermal. Buildings sector includes energy consumption for data centres and desalination.

Nearly all of the growth in energy demand in the buildings sector is from emerging market and developing economies. There are large increases in demand for air conditioning and appliances in Southeast Asia, India and Africa, driven by socioeconomic development and rising temperatures. Although the efficiency of new air conditioners has increased by more than 3% annually since 2015, it does not improve further in the CPS because MEPS are not reinforced. Globally, electricity demand for space cooling climbs by almost 1 500 terawatt-hours (TWh) by 2035.

In advanced economies, energy use in buildings fell an average of 0.3% per year over the last decade. This decline comes to an end in the CPS, and demand rises by 0.4% each year to 2035. Much of the increase stems from the use of electricity by artificial intelligence (AI) and data centres, notably in the United States. Some of it reflects the tendency of households to acquire larger appliances over time (e.g. televisions, refrigerators) and since the CPS sees no major change in efficiency standards, the larger appliances sold in 2035 in advanced economies consume more electricity than the ones sold today.

Figure 3.10 ⊳ Change in activity and demand by end-use in the CPS between 2024 and 2035



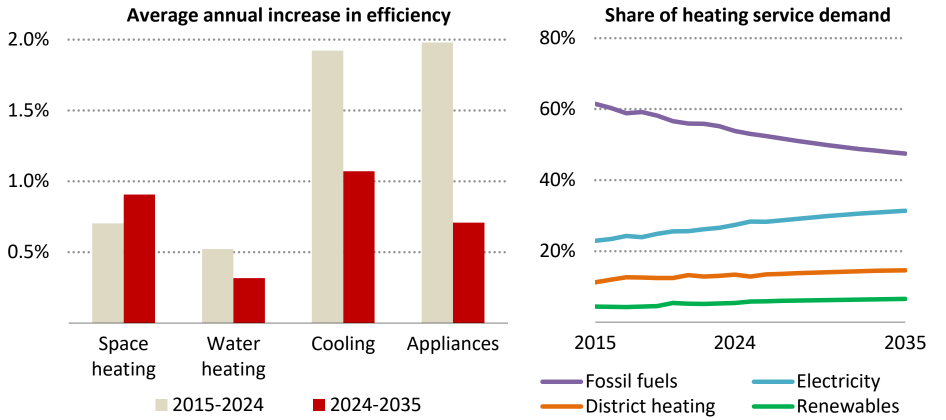
Activity increases in all regions; all end-uses push up demand for both electricity and natural gas, notably for cooling, appliances and heating

Notes: EU = European Union; C & S America = Central and South America; SE Asia = Southeast Asia. Activity driver for space cooling is air conditioner ownership.

Coal use in the buildings sector has fallen by around 6% on average each year since 2015, and oil use by an annual average of 0.4%. In the CPS, their use declines at slightly faster rates to 2035, mostly as a result of a shift to other fuels in advanced economies and China. In contrast, natural gas demand in the buildings sector increases by around 0.7% on average each year to 2035, by when demand totals around 32 EJ (910 bcm). All of this increase is in emerging market and developing economies, where natural gas meets 45% of the increased demand for space and water heating, and cooking (Figure 3.10). In regions where networks are available or where countries have current plans to expand them, e.g. China, India and across much of Eurasia, natural gas helps to meet new energy service demand. In advanced economies, there is a 0.1% annual decline in natural gas use, lower than the 0.4% annual decline seen in the last decade. Since the CPS does not assume any increase in retrofit rates, further strengthening of mandatory building codes, or new gains from voluntary building codes, energy efficiency in buildings increases at a slower pace than it has done over the last decade.

Electricity demand in the buildings sector increased by 2.6% each year on average over the last ten years, and this rises to an average of 3.2% over the next decade in the CPS. Space cooling and appliances contribute 60% of the growth in demand. In emerging market and developing economies, electricity use increases by close to 400 TWh per year to 2035, accounting for more than 90% of the total increase in energy demand in buildings; the number of appliances increases by 35% to 2035, and the number of air conditioning units increases by 70%; the new air conditioners purchased are on average about 20% less efficient than those in advanced economies. In advanced economies, rising demand for AI and other information technology services push electricity consumption in data centres to increase by an annual average of 50 TWh to 2035, while space cooling and appliances increase annual electricity demand in buildings by a further 45 TWh each year.

Figure 3.11 ▷ Efficiency improvements of key end-uses and demand for heating services by fuel in the CPS to 2035



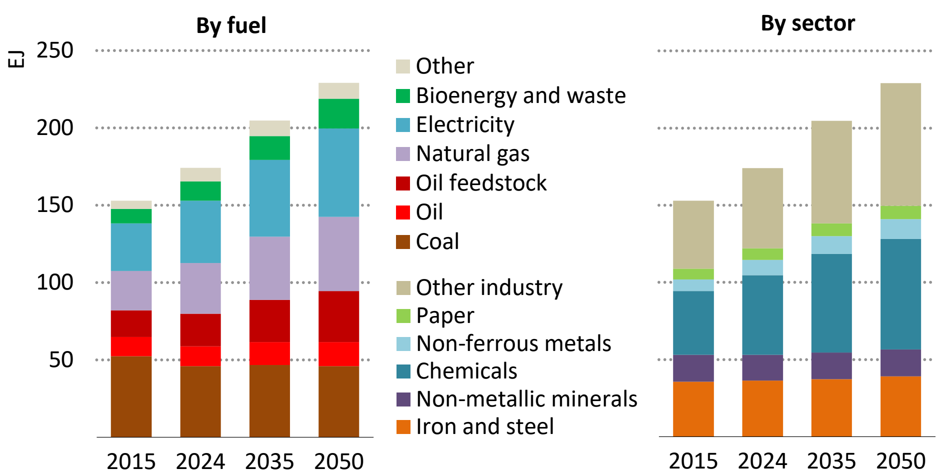
Slower increases in efficiency improvements for appliances and cooling equipment mean faster growth in energy demand in buildings

In the CPS, the global average annual increase in equipment efficiency in the buildings sector falls from 1.2% over the last decade to 0.7% through to 2035 (Figure 3.11). Much of the efficiency gain that occurs in the CPS stems from natural turnover, as the existing stock of equipment and appliances is gradually renewed with new and often more efficient models. Only space heating efficiency increases above historical trends as heat pump sales rise in markets where such systems are already cost competitive (mostly air-to-air heat pumps in China and the United States), helping electricity to account for a rising share of total energy use for heating in buildings. While air-to-water heat pumps can offer similar costs to gas boilers over their lifetimes, current policies are not sufficient to persuade many households to accept the higher upfront costs that they entail, and sales remain flat.

3.3.3 Industry

Energy demand in the industry sector increased by 1.3% each year on average over the past ten years. In the CPS, recycling rates for plastics and aluminium increase at a slower rate than over the past decade, and industrial facilities invest in efficiency projects only if they have a short payback period. In addition, there is limited switching to electricity, infrastructure development is delayed, and funds from industrial financing support schemes are only disbursed if they are already earmarked. So, for example, the USD 1.1 billion auction for industrial decarbonisation from the EU Clean Industrial Deal is not disbursed. As a result, continued growth in demand for basic materials and industrial products drives a 1.5% average annual increase in energy use to 2035 in the CPS (Figure 3.12).

Figure 3.12 ▷ Energy demand in industry by fuel in the CPS to 2050



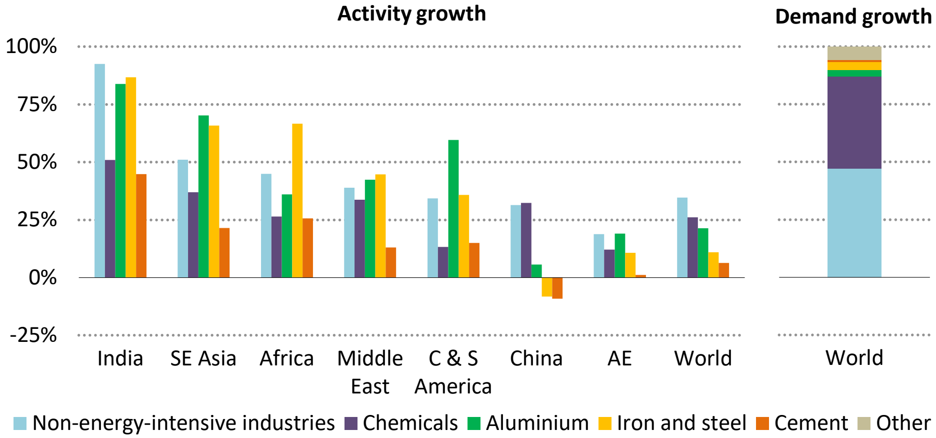
Increasing activity and slower reductions in energy intensity lead to substantial industrial energy demand growth, with demand for virtually all fuels rising to 2035

In emerging market and developing economies, energy demand in industry rises by 1.8% per year on average to 2035 as activity increases. Advanced economies see an average annual increase of around 0.6% to 2035 as industry gradually recovers from the suppressed demand levels seen after the Covid-19 pandemic and the global energy crisis.

Coal use in industry rises marginally between 2024 and 2035 in the CPS, but remains well below its 2014 peak: increased materials production fuelled by coal in many emerging market and developing economies is almost offset by declining demand in advanced economies and China. Oil demand in industry increases by 2.1% per year to 2035, up from 1.9% per year since 2015, mainly for use in petrochemicals. Natural gas demand rises by 2% on average per year to 2035, and electricity demand by 1.9%, in both economy groupings mainly as a result of demand from rapidly growing non-energy-intensive industries, especially the machinery sub-sector.

Energy intensity, measured per unit of value added, of the global industry sector decreases by around 1.2% each year to 2035 in the CPS, compared with a 1.1% annual reduction over the past decade. This stems mostly from a continuation of the global structural shift towards higher value added and less energy-intensive industries, rather than from efficiency gains: there is only a limited increase in global average recycling rates for most materials in the CPS, and the reduction of clinker use in cement manufacturing only advances marginally. All sub-sectors contribute to the increase in global energy demand in industry to 2035 in the CPS, but the chemicals and non-energy-intensive industries together account for around 85% of the total (Figure 3.13).

Figure 3.13 ⊳ Industrial production growth by region/country and contribution of sub-sectors to energy demand growth in the CPS to 2035



Chemicals and non-energy-intensive industries in emerging market and developing economies drive energy demand growth in industry

Note: SE Asia = Southeast Asia; C & S America = Central and South America; AE = advanced economies.

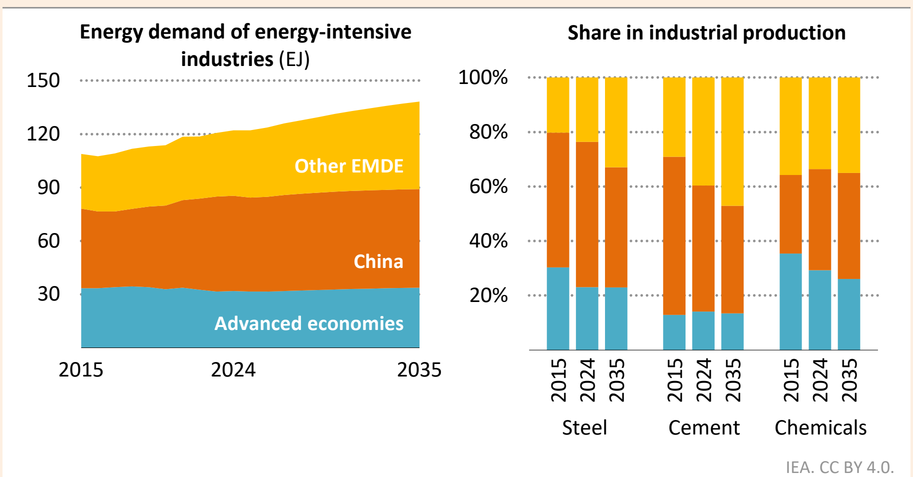
Petrochemical production rises by around 30% to 2035, mainly in emerging market and developing economies, notably China, India, and some countries in the Middle East and Southeast Asia. A number of countries have announced targets to increase recycling rates or restrict single-use plastics. In the CPS, these measures are not strengthened after their implementation deadlines, and the global average plastics collection rate, 19% in 2024, rises only marginally to 21% in 2035.

The share of non-energy-intensive production in total industrial energy demand increased from around 29% in 2015 to 30% today. It rises to around 32% in 2035 in the CPS. Non-energy-intensive industries include sub-sectors such as machinery, textiles and food processing, all of which are growing rapidly. This shift is most visible in China, where most energy-intensive industries apart from chemicals are plateauing or declining, and it leads over time to other countries increasingly becoming the engines of growth for energy-intensive industries (Box 3.1).

Box 3.1 ▷ Switching growth engines for energy-intensive materials: other countries take the lead as China shifts gear

China accounted for more than half of the global energy demand growth in the industry sector since 2015, of which more than 75% is in its energy-intensive industries. More recently, lower domestic material demand slowed the rate of growth in some energy-intensive sub-sectors and caused industrial production in others to peak. For example, with a slowdown in its real estate sector, cement production fell by more than 25% in 2024 from its peak in 2014. It continues to decline in the CPS, but per capita cement demand in China remains far above the level seen today in advanced economies in Asia. Steel production in China peaked in 2020, and it too is set to fall further to 2035. As a result of such changes, in the CPS, energy demand in energy-intensive industries in China rises by just 0.3% each year on average to 2035, well below the 2% annual increase seen over the past decade, and its industrial coal use falls by around 1.6% per year (Figure 3.14).

Figure 3.14 ▷ Energy demand of energy-intensive industries, and industrial production in selected sub-sectors in the CPS to 2035



As industry in China moves towards higher value production, other emerging market and developing economies start to drive growth in energy-intensive industries

Note: Chemicals = primary chemicals production; EMDE = emerging market and developing economies.

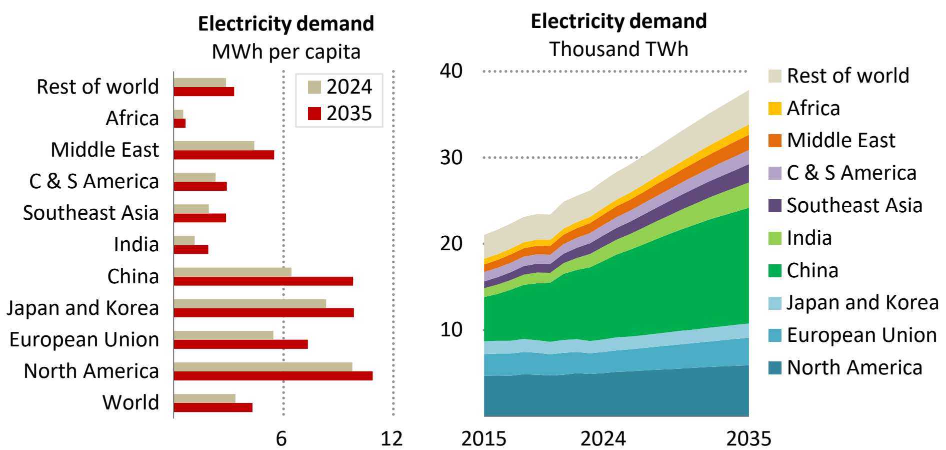
China retains its dominant position in energy-intensive industries in the CPS: it accounts for 40% of global demand in energy-intensive industries in 2035. Nevertheless, its shift towards less energy-intensive industries means that other emerging market and developing economies drive future industrial energy demand growth. In the CPS, they account for almost two-thirds of global demand growth in industry to 2035, of which most is in energy-intensive industries. India and Southeast Asia contribute almost half of the global growth: for example, around a quarter of currently announced new steel plant capacity is located in these regions, and steel production there almost doubles by 2035.

3.4 Electricity

3.4.1 Demand

Global electricity demand rose 2.9% on average each year over the last decade. China accounted for two-thirds of this growth. Demand for electricity also grew rapidly in India and Southeast Asia, both of which registered annual average growth rates of over 5%. In the CPS, global electricity demand increases by 3% per year to 2035 (Figure 3.15). Some countries and regions, including Japan and the European Union, have seen a plateau or decline in electricity consumption over the last decade, but this changes: in the CPS, every region sees growth in electricity demand to 2035.

Figure 3.15 ▷ Electricity demand by region/country in the CPS to 2035

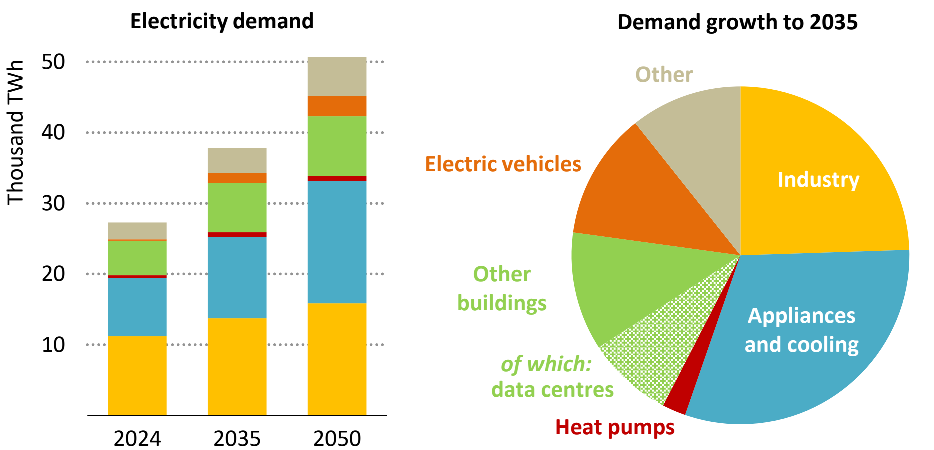


Electricity demand per capita rises to 2035 in all regions, and global electricity demand increases rapidly, predominately in emerging market and developing economies

Note: MWh = megawatt-hour; TWh = terawatt-hour; C & S America = Central and South America.

Global electricity demand increases by almost 1 000 TWh each year to 2035 in the CPS, which is roughly equivalent to adding Japan's current total demand every year. Demand from appliances and cooling equipment account for 30% of the global increase, reflecting boosts in appliance ownership and in average temperatures. This is only offset in part by improvements in MEPS, which remain at their current level except where legislation is already in place to strengthen standards. Industry accounts for 25% of the increase. New uses of electricity, such as EVs and data centres, contribute a further 20% increase: demand for such uses is largely concentrated in advanced economies and China (Figure 3.16).

Figure 3.16 ⊳ Electricity demand by end-use, 2024-2050, and demand growth by end-use in the CPS to 2035



IEA. CC BY 4.0.

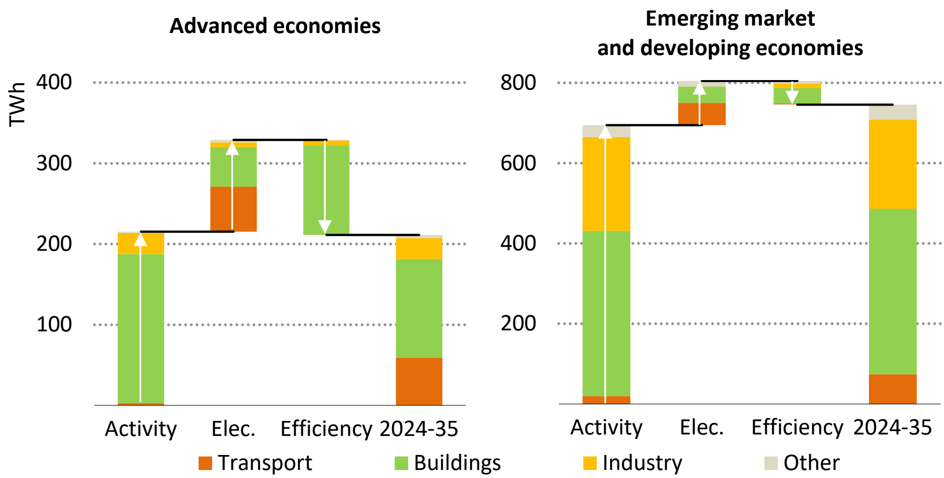
Electricity demand increases by almost 1 000 TWh each year, mostly driven by appliances, cooling and industry

Notes: Other buildings include electric space and water heating excluding heat pumps, lighting, cooking, desalination and data centres. Other includes agriculture, non-road transport and other energy sector.

Today, electricity demand per capita in advanced economies is almost three-times higher than in emerging market and developing economies: higher incomes tend to increase residential electricity consumption, and advanced economies in general rely heavily on electricity for their economic output. Increases in efficiency and slow growth or declining production in certain industries have tempered the increase in electricity demand in advanced economies over the past decade. Yet, new sources of demand such as EVs, AI and data centres mean that demand in advanced economies rises in the CPS by around 200 TWh in aggregate each year to 2035. Electricity demand in emerging market and developing economies increases by much more, surging by around 750 TWh each year to 2035. It increases by 50% between 2024 and 2035 in China, where electricity consumption increases to 10 megawatt-hours (MWh) per capita – a higher level than in Japan and Europe. India has the fastest rate of growth of any region, with an increase in demand of 80% to 2035, driven by the rising use of air conditioners and appliances: despite this, it still has one of the lowest rates of electricity demand per capita among major economies in 2035. The second-fastest increase is in Indonesia, which sees a 70% increase in demand for electricity in the CPS, for broadly similar reasons as in India.

Electricity demand growth in the CPS stems mainly from population increases and higher levels of economic activity, e.g. a 50% increase in the stock of air conditioning units, a 20% increase in floorspace in buildings, and a 35% increase in industrial value added. The electrification of end-uses that have previously relied on other fuels, notably the uptake of EVs in Europe and China, also contributes to more demand for electricity. Efficiency gains, notably in appliances, housing and industry, reduce overall growth in electricity demand to 2035 by around 15% in the CPS. Electrification and efficiency gains are strongest in advanced economies, while in emerging market and developing economies, their impact is marginal relative to the impact of increased activity (Figure 3.17).

Figure 3.17 ▷ Annual average growth in electricity demand by economic grouping, driver and sector in the CPS, 2024-2035



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Most growth in electricity demand reflects higher activity; increased electrification boosts demand while efficiency gains subdue it, but both have a relatively minor impact

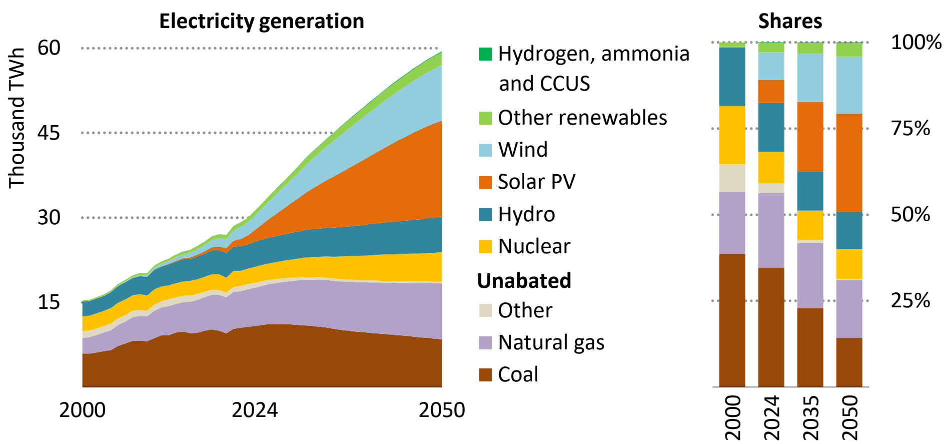
Note: TWh = terawatt-hours; Elec. = electrification; Other includes agriculture and other energy sector.

3.4.2 Electricity generation

Over the past five years, annual capacity additions of solar PV and wind expanded by 30% per year. Both technologies remain competitive in many markets in the CPS, and an average of almost 700 gigawatts (GW) of new capacity is added each year to 2035 – about 5% more than the amount added in 2024 – but the pace of growth slows. Existing procurement mechanisms are not expanded and indeed are rolled back in the case of the United States. In addition, countries with higher shares of wind and solar PV in the generation mix are assumed to make relatively slow progress in ensuring their cost-effective integration in the CPS, which leads to grid congestion and higher rates of solar PV and wind curtailment.

Coal-fired power generation increases in the near term and remains the largest source of electricity through to 2035 in the CPS. Natural gas remains the second-largest source of electricity into the 2030s, and its use continues to rise through to 2050 in the CPS, providing both bulk power and flexibility in many markets. Nuclear output meanwhile rises by about 35% to 2035 and over 80% by 2050 as over 40 countries have policies in place to expand their use of nuclear power (Figure 3.18).

Figure 3.18 ⊳ Global electricity generation by source in the CPS to 2050



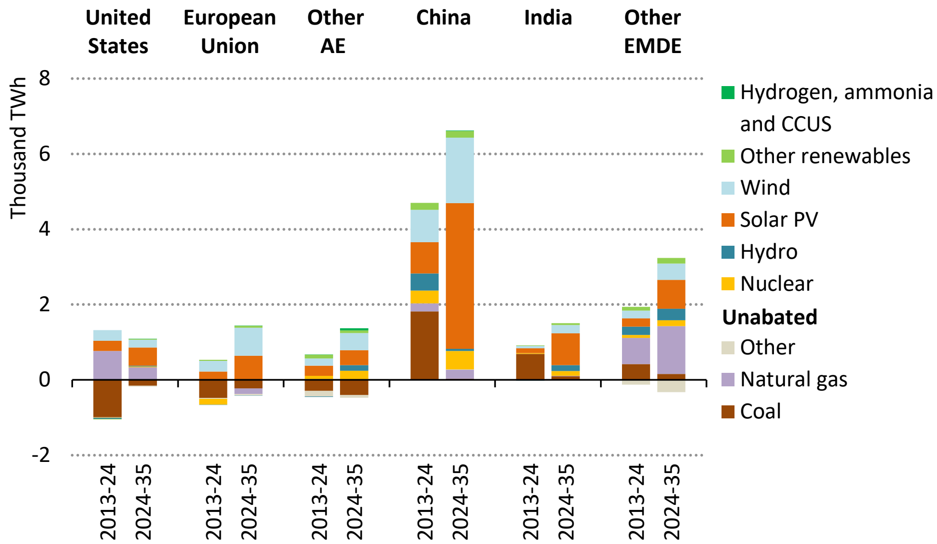
IEA. CC BY 4.0.

Coal and natural gas continue as the bedrock of global electricity supply into the 2030s, complemented by a nuclear comeback and fast deployment of renewables

Notes: TWh = terawatt-hour; CCUS = carbon capture, utilisation and storage. Other renewables include bioenergy and renewable waste, concentrating solar power, geothermal and marine. Other includes oil, non-renewable waste and other sources.

In advanced economies, electricity demand growth through to 2035 is met in the CPS primarily by solar PV, wind, and nuclear (Figure 3.19). This is despite recent policy changes that lead to a notable reduction in the pace of solar PV deployment in the United States compared with 2024 levels. Solar PV sees the largest increase in electricity generation in advanced economies to 2035, followed closely by wind mainly because of robust growth in the European Union. Geothermal energy for power generation in advanced economies expands by more than 50% to 2035, led by its further development in the United States (IEA, 2024a). Nuclear power meets more than 10% of demand growth, supported by reactor restarts in Japan and new units in the United States, Japan, Korea and France. Natural gas plays an important role to meet electricity demand growth in the United States in the CPS, notably to provide power for data centres. Gas-fired power generation rises modestly in aggregate in advanced economies, peaking around 2030 and then declines slightly to just below current levels just after 2040. Coal-fired generation falls by 40% over the period to 2035, continuing its long-term decline. From 2035 to 2050, nuclear and renewables each expand by over one-third, while natural gas declines by about 10% and coal by nearly 35%, further shifting the generation mix toward low-emissions sources.

Figure 3.19 ⊳ Change in electricity generation by region/country and source in the CPS, 2013-2024 and 2024-2035



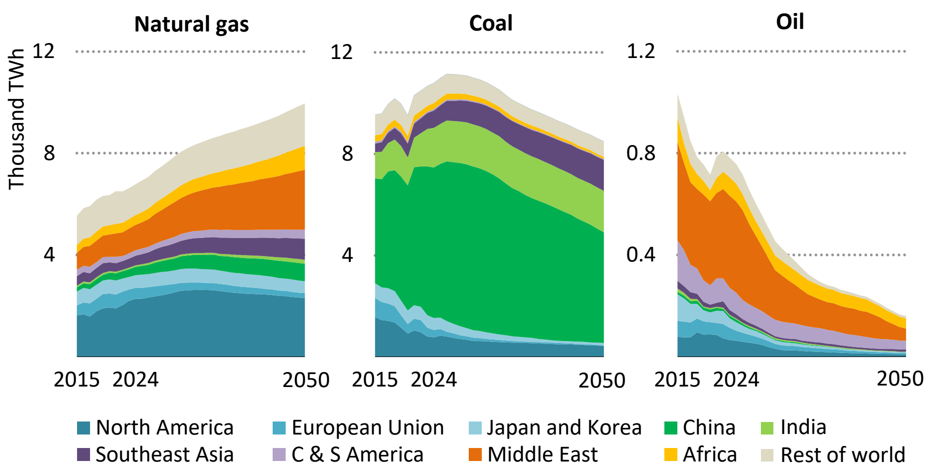
Nuclear and renewables expand to meet most new demand in advanced economies; virtually all sources of generation expand in emerging market and developing economies

Notes: TWh = terawatt-hours; AE = advanced economies; EMDE = emerging market and developing economies. Other renewables include bioenergy and renewable waste, concentrating solar power, geothermal and marine. Other includes oil, non-renewable waste and other sources.

In emerging market and developing economies, rapid electricity demand growth is met by expanding the use of virtually all sources of electricity. Solar PV accounts for half of the total increase in electricity generation to 2035: much of the new capacity is located in China – the global leader in solar manufacturing – and India (IEA, 2024b). Wind accounts for about 20% of the increase in electricity supply, and nuclear power for just over 5%, with China again in the lead in terms of capacity additions for both technologies. Coal-fired generation peaks before 2030 but it remains the largest source of electricity until 2040. Natural gas-fired generation increases by more than 45% from 2024 to 2035, meeting a sizable portion of new electricity demand. Oil is the only source of electricity that sees a decline to 2035.

Fossil fuels accounted for nearly 60% of global electricity generation in 2024, compared with 66% in 2015. In the CPS, fossil fuel generation increases by 5% to 2035, but its share of total generation continues to decline, falling to around 40% in 2035 and 30% by 2050 (Figure 3.20). The share of coal-fired power declines steadily over time, and the share of oil continues to fall; the share of natural gas remains close to 20% through 2035.

Figure 3.20 ▻ Electricity generation by source and region/country in the CPS to 2050



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Gas-fired generation continues to expand, particularly in emerging market and developing economies, while coal generation peaks before 2030 and oil continues to decline

Note: TWh = terawatt-hours; C & S America = Central and South America.

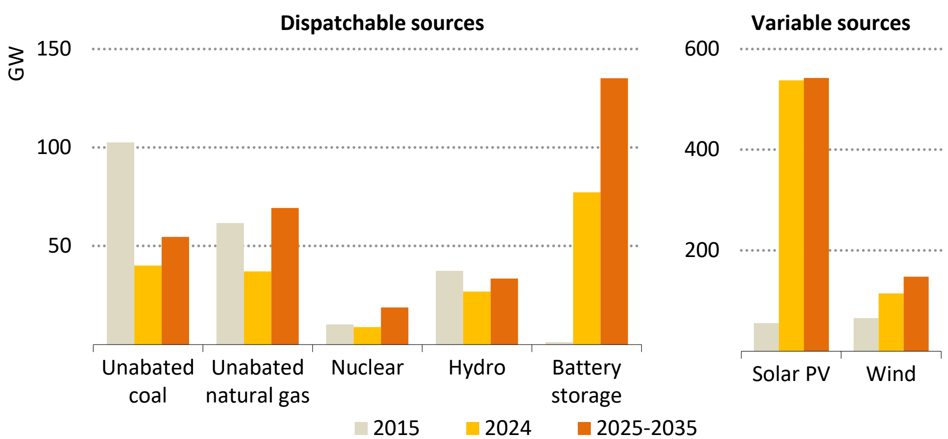
Coal-fired power generation is projected to peak before 2030, and in 2035 it is around 5% below 2024 levels, as robust electricity demand in several of its largest markets – China, India and Southeast Asia – is offset by declines in coal generation elsewhere. In China, coal remains its largest source of electricity to 2035, though by then its overall share of generation is in decline as the deployment of additional solar PV, wind and nuclear power outpaces electricity demand growth. In India, coal-fired generation rises in the near term before reaching a plateau by 2035 as renewables and nuclear advance. In Southeast Asia, coal use continues to grow to support economic development and rising demand. Meanwhile, several advanced economies, including Canada and many member states of the European Union, are on track to phase out unabated coal by 2035 in favour of renewables, nuclear and natural gas. In addition, Japan and Korea reduce unabated coal-fired generation to 2035 in the CPS.

Natural gas remains a key contributor to global electricity supply growth in the CPS, though regional trends diverge. The United States generates more electricity from gas today than any other country, and that continues to be the position through to 2050. The Middle East remains the second-largest user of gas-fired electricity to 2035, with gas use increasing in order to meet rising demand and to displace oil-fired generation. Major growth is also projected in China, Southeast Asia, Africa and India, where natural gas helps meet rising electricity demand. In Japan, natural gas rises 15% to 2035 before reaching a plateau. In contrast, countries such as Canada and Korea reduce gas-fired generation as its role shifts from bulk supply to the provision of system flexibility.

Oil-fired power generation in the CPS remains heavily concentrated in the Middle East, which accounts for around 40% of the global total through to 2035, even though Saudi Arabia and several other countries in the region are actively reducing oil use in the power sector to free up supply for export. In Africa, oil continues to play a major role to provide electricity access, particularly in remote areas through mini-grids and off-grid systems (see Chapter 6). While many countries around the world are working to phase out oil in power generation, its use persists in remote areas where alternatives remain limited or costly to deploy.

Renewables increase from one-third of global power generation in 2024 to nearly half by 2035 in the CPS. Solar PV and wind continue to expand, but they face mounting integration challenges in the CPS in the absence of additional government policies, which slow their deployment. Annual solar PV capacity additions average 540 GW to 2035, holding steady at roughly the 2024 level, and halting the trend that has seen deployment rise ten-fold from 2015 to 2024. Annual wind capacity additions average about 150 GW to 2035, which is 30% above the level in 2024, largely thanks to the pipeline of wind projects in the European Union; while many other markets, including the United States, see deployment stagnate.

Figure 3.21 ▷ Global annual average capacity additions by selected power technology in the CPS to 2035



A wide range of dispatchable capacity is added to meet increasing electricity demand, while additions of variable generation sources is relatively stable

Note: GW = gigawatts.

The rising share of variable renewables in the power mix of many countries alters the operational dynamics of power systems, increasing the need for flexibility, storage and enhanced grid management (see Chapter 5). Ensuring that sufficient dispatchable capacity[4] is available to meet hours of peak electricity demand is critical to overall electricity system security. Nearly all dispatchable sources of electricity increase to 2035 in the CPS (Figure 3.21). Coal-fired power is the largest dispatchable source of electricity in the world today, with over 9 000 units in operation in close to 80 countries, over 280 GW of additional coal-fired power units are currently under construction around the world, including over 200 GW in China, and many more coal plants are at the planning stage. In the CPS, global coal-fired capacity additions average almost 55 GW per year to 2035, which is one-third more than additions in 2024, while capacity additions of other dispatchable sources of electricity accelerate, including gas-fired power, hydropower, nuclear and geothermal power, which is set to benefit from recent advances in drilling and stimulation techniques (Box 3.2). Battery storage is the fastest growing power technology, averaging 90% market growth over the past five years: around 135 GW of new battery capacity is added per year to 2035 in the CPS, 75% above the level of deployment in 2024.

Box 3.2 ⊳ Nuclear power is making a comeback

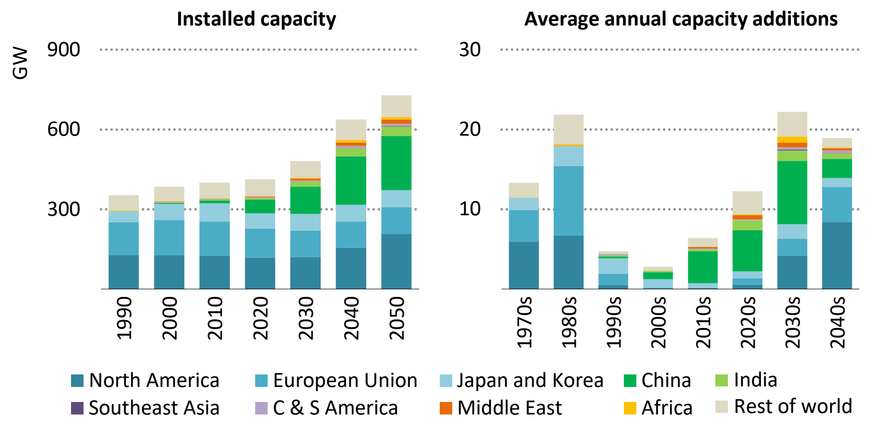
Several prominent nuclear energy projects in the United States and Europe face project delays and cost overruns, and the industry is still grappling with various public concerns, notably about long-term waste disposal challenges. Yet momentum for nuclear power is building, driven by concerns about rising CO_2 emissions or energy security, or both. Over 40 countries now include nuclear in their energy strategies and have taken concrete steps to develop new projects. Investment in nuclear power is rising. A record high in nuclear power output is expected in 2025. Technology advances – particularly in small modular reactors – are improving the outlook for nuclear power (IEA, 2025). As demand surges and the need for reliable, low-emissions baseload electricity increases, nuclear is increasingly seen as a critical part of a secure, affordable and diverse electricity mix.

Global nuclear power capacity increases by three-quarters from the current level by 2050 in the CPS, as the current pipeline of projects helps raise deployment in the 2030s to levels not seen since the 1980s (Figure 3.22). China leads the way, having steadily built up its nuclear supply chain to enable it to deliver a stream of new reactor projects. China accounts for close to half of all nuclear capacity under construction today, and is on track to become the world's largest nuclear power operator around 2030. In the United States, recent policy developments are revitalising the nuclear industry after nearly three decades of limited construction, supported by strong interest from technology companies in developing small modular reactors to provide power to data centres. US nuclear capacity begins increasing by 2035 in the CPS, and expands by over 80% by 2050.

[4] Dispatchable sources of electricity are generally available around-the-clock and can be controlled or scheduled to meet demand.

In Europe, nuclear power is increasingly viewed as essential to achieve both energy security and climate goals: several countries, including France, Poland, Czech Republic, Hungary and Sweden, have established policies, agreements with vendors and project plans, and are securing investment to start, expand or restart nuclear construction activities. Efforts to diversify the nuclear fuel supply are also underway in the United States, Europe and China.

Figure 3.22 ⊳ Nuclear power capacity and capacity additions by region/country in the CPS to 2050



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Global nuclear power capacity increases by 75% to 2050 as a growing number of countries aim to bolster electricity security and diversify their electricity mixes

Note: GW = gigawatt; C & S America = Central and South America.

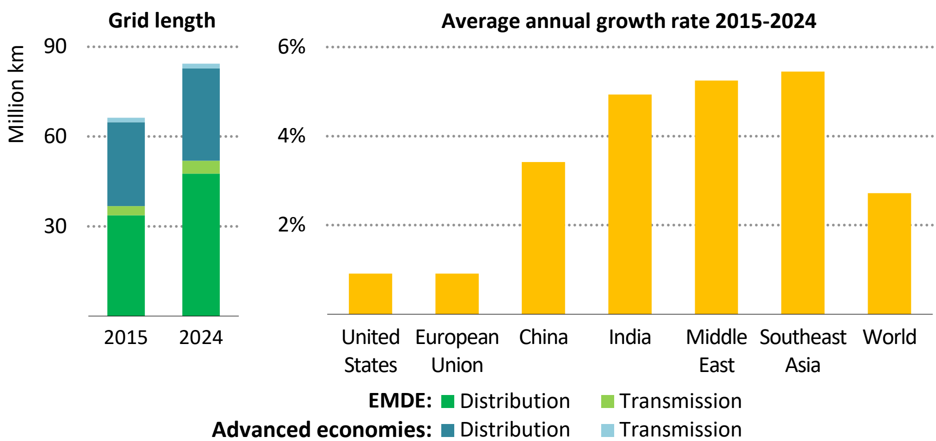
3.4.3 Electricity grids

Status of grids today

Grids are the backbone of electricity systems, serving as the bridge between power generation and end-use demand. They are essential to deliver secure and affordable electricity to consumers, support economic development and enable the evolution of electricity systems. Without resilient and modern electricity grids, achieving policy goals, such as providing sufficient volumes of secure, affordable and low-emissions electricity, or expanding electricity access, would remain out of reach. Today's global electricity networks stretch more than 84 million kilometres (km) – nearly 52 million km in emerging market and developing economies, and over 32 million km in advanced economies (Figure 3.23).

Over the past decade, global transmission grids have expanded by nearly 30% to almost 6 million km. Most of this expansion has been in emerging market and developing economies, where total line length increased by almost 40%, compared with 8% in advanced economies. Grids have expanded in lockstep with electricity demand, which rose 30% worldwide over the last decade, over 50% in emerging market and developing economies, and 4% in advanced economies. Electricity demand in China surged by 80%, spurring the construction of an additional 490 000 km of lines, over one-third of the global transmission network increase. Fast-growing electricity demand in other emerging market and developing economies led to the length of transmission systems increasing by 75% in Indonesia, 60% in India and 45% in Africa. By contrast, advanced economies, where electricity demand was more stable, extended their transmission grids by 120 000 km in aggregate. The United States added just 2% to its total, while the European Union enlarged its grid by over 10%, driven less by rising electricity demand than by the need to connect new variable renewables, which are often sited far from existing lines.

Figure 3.23 ▷ Global electrical grids by region/country and type, and growth rates by region, 2015-2024



IEA. CC BY 4.0.

Electricity networks expand in all regions, creating opportunities for modernisation to support evolving power systems

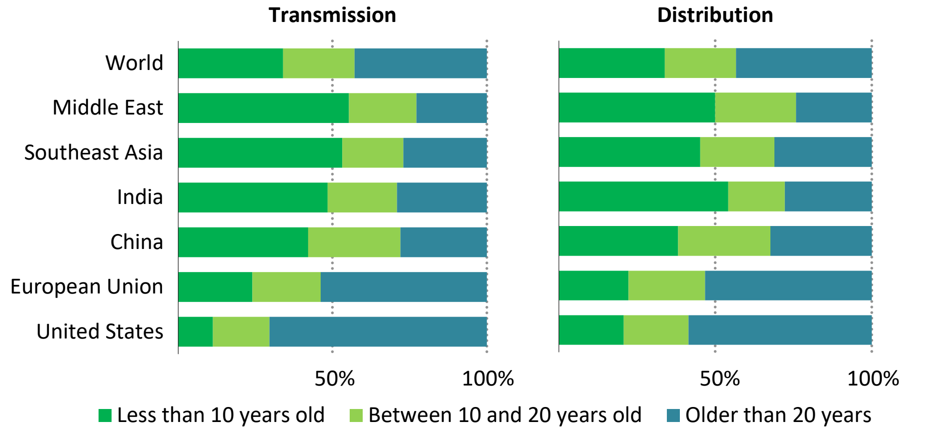
Note: km = kilometres; EMDE = emerging market and developing economies.

Distribution grids have experienced similar growth patterns over the past decade. Driven by rising electricity demand, they have increased rapidly in emerging market and developing economies. In India, grids extended by more than 50%, by 4.6 million km, and in China by around one-third, by 2.2 million km. They have nearly doubled in Indonesia, which has added nearly 0.8 million km of additional lines, connecting many households and other customers for the first time. Mature distribution systems in advanced economies have seen modest additions as well, with an increase of close to 10% in both the United States and European Union, together totalling 1.8 million km.

Electrical grids face several challenges. These include regional congestion, supply chain bottlenecks, public opposition and siting challenges. The risk of delay in grid expansion is evidenced in the growing interconnection queues: some 2 800 GW of solar and wind projects, more than half of them at an advanced stage, are waiting for a connection. Meanwhile, demand hotspots such as data centre clusters can strain local grids: in parts of the United States, they already draw over 10% of electricity demand, and in Ireland around 20%.

Another pressing issue is ageing of grid assets, particularly in advanced economies. Older grids tend to be more vulnerable to faults and to require investment to extend their operational lifetimes. Large parts of the transmission and distribution networks in Europe and North America date back to the mid-twentieth century: only around 20% of the grid infrastructure is less than ten years old, while more than 50% has been in service for more than twenty years. In emerging market and developing economies, in contrast, roughly 40% of the grid infrastructure was commissioned in the last decade, and around 35% is more than twenty years old (Figure 3.24).

Figure 3.24 ▷ Grid length by type, age and region/country, 2024



Many advanced economies have ageing grid infrastructure in need of modernisation, emerging market and developing economies have newer grids

Purchase and installation of new power lines and transformers are costly, involve long lead times and require complex planning. Faced with these challenges, grid operators have tended to opt for digital and power electronic upgrades rather than new lines in recent years, especially in advanced economies. Flexible alternating current transmission systems, known as FACTS, especially enhanced static synchronous compensators, known as STATCOMs, can provide fast, dynamic reactive power that stabilises voltage and short-term inertia during periods of high variable renewable electricity generation and free up additional transmission capacity. At the same time, tools such as dynamic line rating can increase thermal limits in real time, and large-scale monitoring and control systems can provide comprehensive visibility of what is happening in grid systems, optimise the use of existing assets, prevent cascading power outages, and accelerate system restoration if needed.

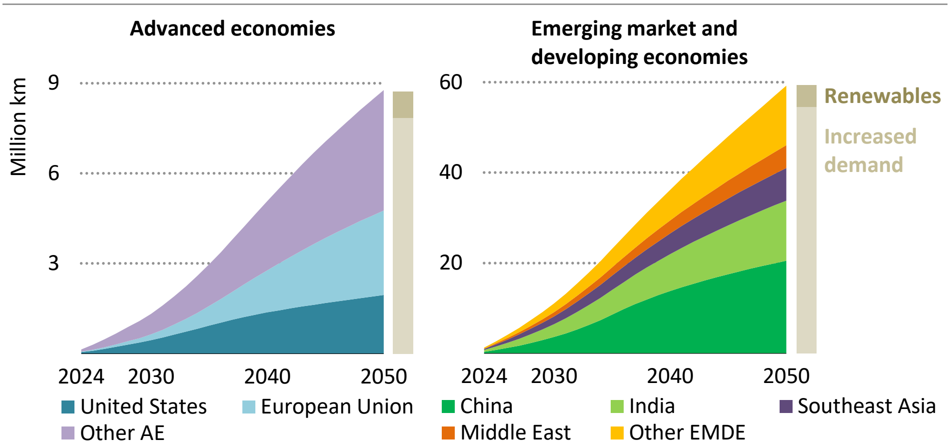
Grid operators are also making use of high-voltage direct current (HVDC) transmission technology, which has become essential for modern grid operations. HVDC can transport large amounts of electricity over long distances and offers complete bidirectional flow control and valuable black start capability. Its use has increased notably in parallel with the growth of offshore wind farms, which are often connected via HVDC links because of their remote locations. HVDC can also connect national grids in neighbouring countries or geographic regions, helping them to pool reserves, balance renewable energy variability, and reduce the overall capacity required to ensure reliability.

Grid expansion and replacement

Grid systems need to develop in tandem as electricity systems expand to provide electricity to new demand centres and to connect new generation sources. In the CPS, global electricity grids increase by 25 million km from 2024 to 2035, becoming 30% more extensive than today, and by a further 40 million km to 2050.

Increasing electricity demand is responsible for over 90% of total grid expansion to 2050. Most of this is in emerging market and developing economies, which in aggregate add over 20 million km to their grids by 2035. China accounts for close to 40% of this total, extending its grid to 2035 by nearly three-times as much as advanced economies combined (Figure 3.25).

Figure 3.25 ▷ Expansion of grid lines by driver in selected region/country in the CPS, 2024-2050



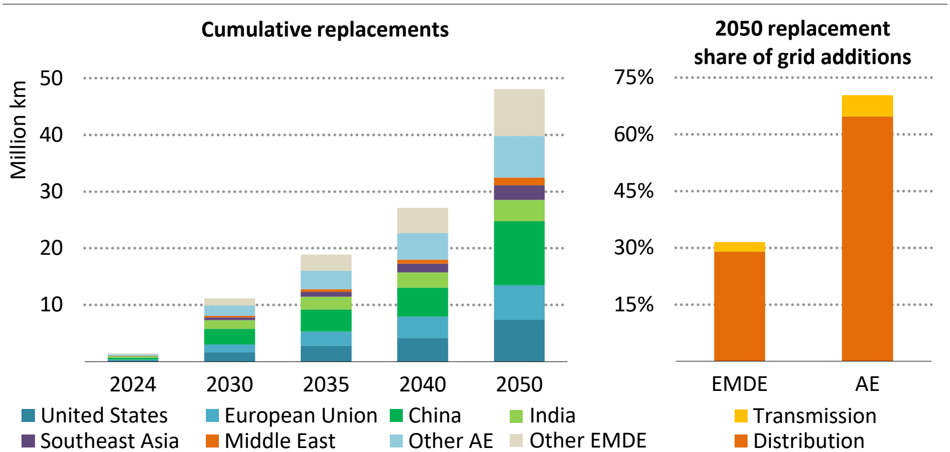
Most new lines are installed to meet increased demand; nearly 90% of all new lines are in emerging market and developing economies

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

Grid expansions are also driven by the deployment of variable renewables such as solar PV and wind, which are often located far from demand centres. Connecting additional variable renewables in advanced economies requires a half million km of new lines; connecting them in emerging market and developing economies, many of which have less developed grids, requires 1.5 million km of new lines by 2050 in the CPS. However, all electricity network projects, especially high voltage interconnections, are complex in terms of both permitting and construction. Line route plans and reports have to be drawn up covering the entire length, conditions and specifications have to be assessed, and stakeholders need to be engaged. People living near the proposed line routes may oppose their development. Longer distances between power generation and demand centres and other technical issues can make high-voltage direct current (HVDC) transmission attractive in some cases, especially for connecting offshore wind farms.

A growing number of electricity network lines and cables will need to be replaced or refurbished in the years ahead as they reach the end of their typical lifetime of around 40 years. In some areas, such as Germany, the distribution grid is mostly underground, and extensive ground works will be needed for replacement. In others, such as the United States, the widespread use of more accessible overhead lines means that line replacement planning primarily involves tasks such as replacing masts and conductors, without the need for extensive earthworks.

Figure 3.26 ⊳ Grid line replacement by selected region/country and replacement share of grid additions in the CPS, 2024-2050



More than 45 million km of grid line are replaced by 2050, accounting for 40% of all cumulative grid additions, of which more than two-thirds are in advanced economies

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

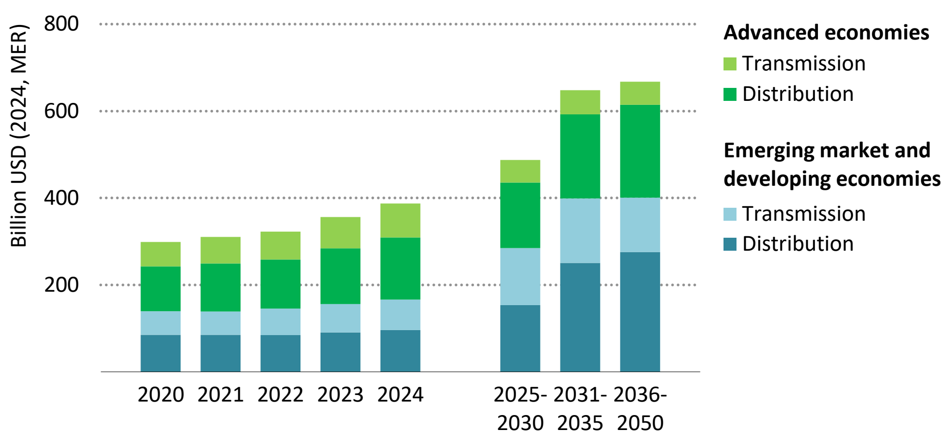
In the CPS, grid line replacements worldwide total nearly 20 million km by 2035. This rises to more than 45 million km by 2050, 20 million km in advanced economies, mostly in the United

States and Europe, and over 25 million km in emerging market and developing economies. In all cases, 90% of the replacements are for distribution lines (Figure 3.26). Replacements account for over two-thirds of all grid additions in advanced economies, where future grid expansion is limited and the existing grid network is ageing. In emerging market and developing economies, where the existing grids are newer and expanding rapidly, replacements comprise about 30% of total grid additions to 2050.

Grid investment needs

Global investment in electricity transmission and distribution networks is set to continue to increase in the years ahead, driven by rising electricity demand and changes in the generation mix. Annual spending on grids rose by 2.5% a year on average between 2013 and 2024, increasing from under USD 300 billion to nearly USD 390 billion in 2024. In the CPS, it is projected to increase at 5% a year on average through to 2035, with annual grid-related investment spending reaching about USD 650 billion in 2035.

Figure 3.27 ▷ Average annual grid investment by economic grouping in the CPS to 2035



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Grid investment rises in nearly all regions to modernise and expand transmission and distribution to meet rising electricity demand and to connect new sources of generation

Note: MER = market exchange rate.

Advanced economies and China have largely driven recent growth in grid investment. In the United States, investment in grid infrastructure more than doubled to nearly USD 110 billion between 2013 and 2024, supported by federal incentives and streamlined permitting processes. The European Union saw a 60% rise over the same period to nearly USD 70 billion, much of which was focused on the integration of variable renewables and cross-border grid development (Figure 3.27). China invested more than USD 80 billion in grids in 2024.

However, investment in emerging market and developing economies as a whole, excluding China, has declined by over 10% in recent years, despite rising electricity demand. Annual spending has increased in Africa by around USD 4 billion from 2013 levels, but it has contracted in Southeast Asia and India by 15% and 8% respectively.

The picture needs to change. Grid investment in China more than doubles by 2035 in the CPS, as electricity demand continues to rise and renewables growth is much higher over the next decade than they were the last ten years. Investment in other emerging market and developing economies, which have recently lagged, nearly doubles to USD 160 billion annually by 2035, increasing at an annual rate of about 6%. By the mid-2030s, roughly two-thirds of global grid investment is in emerging market and developing economies. Grid investment levels in advanced economies in the CPS, which have risen at a relatively rapid rate in recent years, stay at elevated levels and increase at an annual rate of around 2%, rising from USD 220 billion in 2024 to USD 275 billion in 2035.

The rapid expansion of investment in electricity networks is already straining supply chains. Lead times for large power transformers and high-voltage cables have nearly doubled in many regions and wait times for HVDC systems stretch into the 2030s. Prices for key materials such as copper and aluminium remain high. European cable manufacturers are operating at full capacity, with order books committed for the next several years due to strong demand from interconnection and offshore wind projects. Labour shortages, especially of skilled technicians, engineers and project managers, alongside permitting hurdles, are also causing considerable delays and driving up costs.

3.5 Fossil fuels

Oil and natural gas demand increase by 16% to 2035 and continue to rise through to 2050 (Figure 3.28). Their prices also generally rise over this period. Oil demand in 2050 is 113 mb/d and natural gas demand is 5 600 bcm. To meet this demand, high levels of new resource development are necessary together with new fossil fuel infrastructure such as upstream facilities, pipelines, export and import terminals, and ships. The CPS also assumes that, by the latter part of the projection period, constraints on oil production and trade in countries currently subject to sanctions ease, so their output is determined by the underlying economics. This brings additional potential sources of supply into the picture, but their availability cannot be taken for granted if geopolitical constraints remain in place.

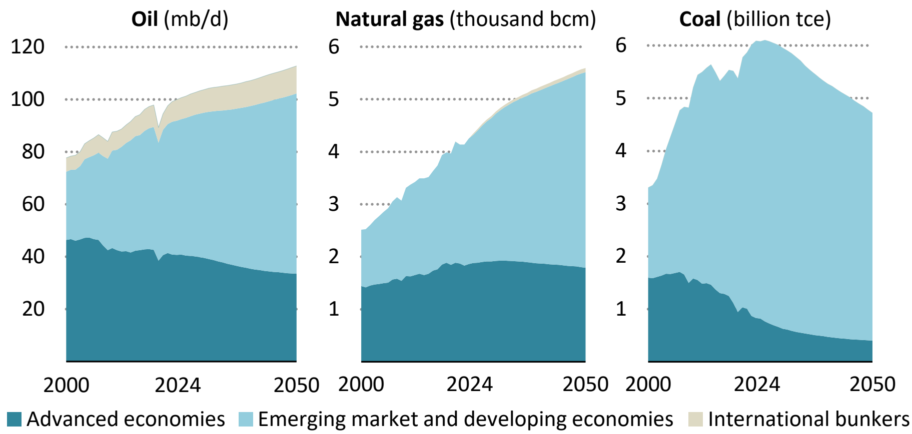
Oil remains the dominant fuel to 2050 in the CPS. China accounted for more than 75% of oil demand growth over the past ten years, but this picture is changing, and India becomes the new epicentre of growth in oil demand.

Half of the increase in demand for natural gas to 2035 is from the power and industry sectors in emerging market and developing economies in Asia Pacific and the Middle East. The global LNG market increases from around 560 bcm in 2024 to 880 bcm in 2035 and to 1 020 bcm in

2050. By 2035, the United States is both the world's largest natural gas consumer at just over 1 000 bcm and the world's largest LNG exporter at 250 bcm.

Coal use starts to decline globally before 2030, and by 2035 demand is around 8% lower than in 2024. Coal use in advanced economies declines by 35% to 2035 and it declines by 10% in China as renewable electricity expands and coal use in industry falls, although this drop is partially offset by continued growth in coal demand in other emerging market and developing economies.

Figure 3.28 ▷ Fossil fuel demand in the CPS to 2050



Oil and natural gas demand continue to rise to 2050; coal use falls, mainly as a result of reductions in the power sector in China and advanced economies

Note: mb/d = million barrels per day; bcm = billion cubic metres; tce = tonne of coal equivalent.

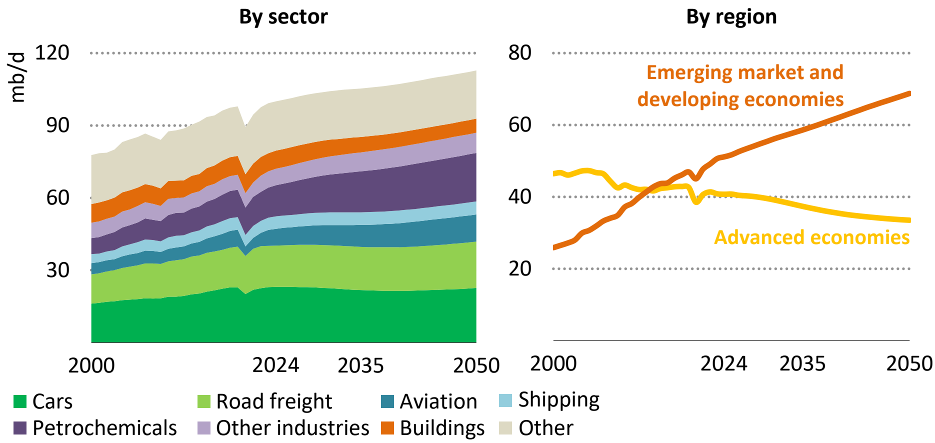
3.5.1 Oil

Demand

Global demand for oil was 100 mb/d in 2024. In the CPS, it rises to 105 mb/d in 2035 and 113 mb/d in 2050, an average annual increase of around 0.5 mb/d (Figure 3.29). The largest increases to 2035 are for oil use as petrochemical feedstock and other industrial activities, and in aviation. Demand in road transport in 2035 is similar to levels in 2024: by 2035, there are 430 million electric cars on the road worldwide – 60% of which are in China and 25% in Europe – and these avoid more than 6 mb/d of oil demand. Oil use for power generation falls by 2 mb/d to 2035, led by declines in countries in the Middle East. Nearly all of the growth in oil demand takes place in emerging market and developing economies, with some of the largest increases coming in India, Southeast Asia and Africa, and there is a continued decline in oil use in advanced economies.

China accounted for more than 75% of oil demand growth globally between 2015 and 2024, but the outlook for its future is changing with the rapid electrification of its vehicle fleet and its gradual shift to a less energy-intensive form of economic growth (Figure 3.30). Total oil demand in China falls slightly from around 16.2 mb/d in 2024 to 15.8 mb/d in 2035, mainly as a result of reduced oil use in road transport, although a large portion of this decline is offset by increased oil use as petrochemical feedstock.

Figure 3.29 ▷ Global oil demand by sector and economic grouping in the CPS to 2050



Global oil demand rises to 105 mb/d in 2035 and 113 mb/d in 2050 led by increases in petrochemical feedstock and aviation

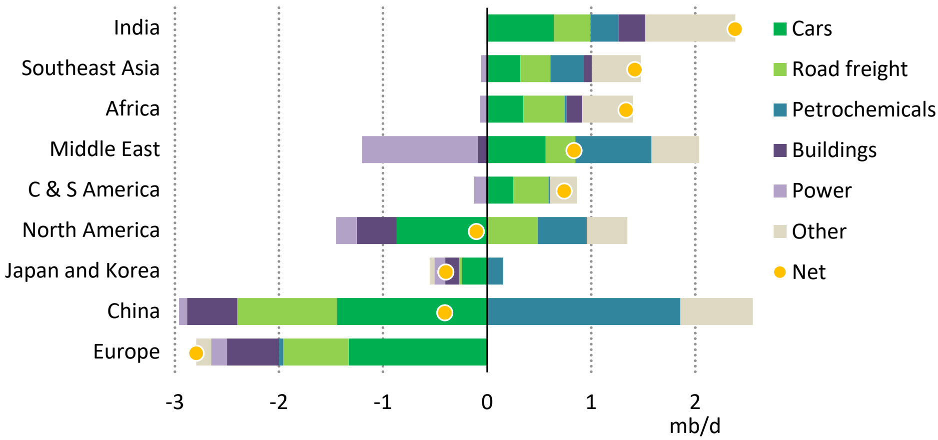
Notes: mb/d = million barrels per day; Other industries = industry sector excluding petrochemicals; Other = other non-energy use, other energy sectors, power, agriculture and other transport. Excludes biofuels.

India leads global oil demand growth over the next ten years, with almost half of the additional barrels produced globally to 2035 heading in its direction. Its oil use increases from 5.5 mb/d in 2024 to 8 mb/d in 2035 as a result of rapid growth in car ownership, increasing demand for plastics, chemicals and aviation, and a rise in the use of liquefied petroleum gas (LPG) for cooking.

Oil demand in Africa rises by one-third to around 6 mb/d in 2035. Road transport accounts for about three-quarters of the increase, while oil use in the buildings sector – mainly in the form of LPG to replace the use of traditional solid biomass – also rises marginally, as does oil use in aviation and industry.

Oil demand in the Middle East was around 8.5 mb/d in 2024 and increases by close to 1 mb/d to 2035 in the CPS. There is limited uptake of electric cars, partly because many countries in the region subsidise the use of gasoline and diesel, and efforts to expand the oil-to-chemicals value chain cause oil use as petrochemical feedstock to rise substantially. Increases in demand are partially offset by a 1 mb/d drop in oil use in power, mainly as a result of current policy plans in Saudi Arabia.

Figure 3.30 ▷ Change in oil demand by selected region/country and by sector in the CPS, 2024-2035



India leads oil demand growth, followed by Southeast Asia and Africa, while oil demand growth for petrochemicals in China is fully offset by electrification in transport and buildings

Notes: mb/d = million barrels per day; C & S America = Central and South America. Other = aviation, other industries, shipping, other non-energy use, other energy sectors, agriculture and other transport.

Oil demand in advanced economies falls by around 3.5 mb/d to 2035, but there are large differences between countries. Around 80% of the drop occurs in Europe, and there are also reductions in Japan and Korea, Canada, and Australia and New Zealand, mainly as a result of current road transport electrification and space heating policies. Oil demand in other advanced economies increases slightly to 2035: there are some reductions of oil use in passenger cars as older cars are gradually replaced by more efficient versions, but these are more than offset by increases in freight transport and oil use as petrochemical feedstock.

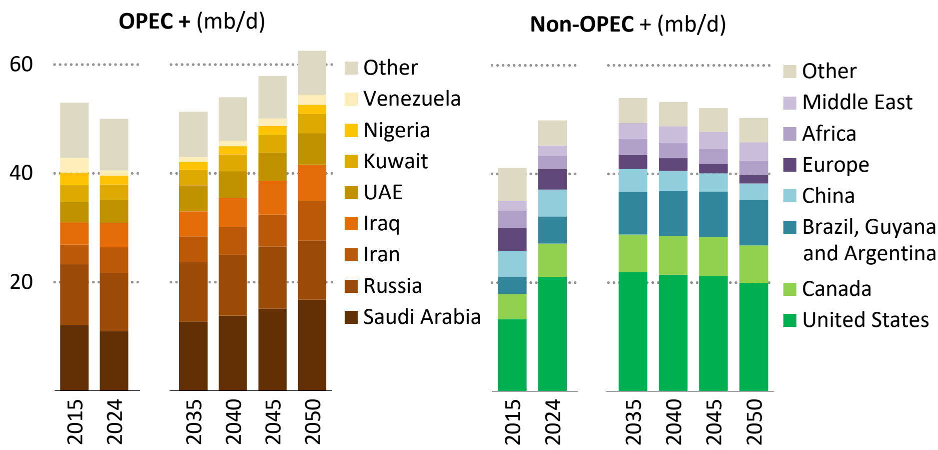
Supply

Between 2015 and 2024, the United States increased supply by 8 mb/d while global oil demand increased by 6.5 mb/d (Figure 3.31). Meeting the rise in oil demand in the CPS to 2050 requires contributions from a much wider range of supply sources. This includes more output from countries currently under sanctions, a willingness among low-cost producers to expand beyond announced capacity limits, and a substantial rise in oil prices to incentivise new exploration and development in higher cost regions.

Non-OPEC+ supply rises by 4 mb/d to 2035 – three quarters of the increase in global oil demand over this period – led by increases in the United States, Canada, Guyana, Brazil and Argentina. Supply then falls back to 2024 levels by 2050.

US oil supply reached a record high of 21 mb/d in 2024, and it increases by 0.8 mb/d to 2035 in the CPS. The pace of growth to 2035 is slower than in recent years as an increasing amount of new drilling is required to offset declines in existing shale plays. Total US production falls marginally after 2035, but the United States remains the largest producer worldwide to 2050 in the CPS.

Figure 3.31 ▷ Oil supply by producer in the CPS to 2050



United States, Canada, Brazil, Guyana and Argentina all increase oil supply, while OPEC+ production grows markedly and in 2050 it produces 15% more than historic highs

Note: mb/d = million barrels per day; UAE = United Arab Emirates.

In Canada, oil supply increases from 6.1 mb/d in 2024 by 0.8 mb/d to 2035, driven mainly by debottlenecking oil sands operations and rising NGLs output from shale plays. Higher prices and expanding pipeline trade with the United States support a new wave of large-scale mining and in-situ extra-heavy oil and bitumen projects after 2035.

Offshore production in Guyana rises from 0.6 mb/d in 2024 by 1.2 mb/d to 2035, with further increases thereafter, reliant on further exploration success. Output in Brazil increases by from 3.5 mb/d in 2024 by 1 mb/d to 2035, despite some delays in the commissioning of new floating production storage and offloading units. Output in Argentina rises to 1.4 mb/d in 2035, its highest level ever, driven by tight oil development in the Vaca Muerta formation. Suriname's first offshore barrels are assumed to come online in 2028 from the Sapakara and Krabdagu fields, and to be followed by additional developments.

Africa produced more than 7 mb/d of oil in 2024. Production dips slightly to 2035, and then picks up again to 7 mb/d in 2050 in the CPS. Several countries in Africa, including Algeria, Libya, Nigeria, Cameroon and Angola, have launched new licensing rounds and are revising fiscal terms to attract new investment. There have been a number of major recent discoveries, including two large, liquids-rich discoveries in Namibia and Côte d'Ivoire, although these will take time to generate new supply.

OPEC+ supply increases from 50 mb/d in 2024 to 51 mb/d in 2035 and 63 mb/d in 2050 in the CPS. OPEC+ production in 2050 is 15% higher (8 mb/d) than at any point in the history of oil markets. Annual real revenues for members of OPEC+ from oil production rise from USD 1.4 trillion in 2024 to 1.7 USD trillion in 2035 and USD 2.5 trillion in 2050, which is around 25% higher than the level in 2022 during the global energy crisis.

Saudi Arabia leads production growth to 2035 as it develops new onshore and offshore fields, increases natural gas liquids (NGLs) production, and draws on its giant unconventional Jafurah field. Conventional crude oil production from Saudi Arabia, excluding NGLs and production from the neutral zone, rises beyond its current announced maximum sustainable capacity level of 12 mb/d from the mid-2040s and exceeds 13 mb/d by 2050 in the CPS.

Supply in Iraq grows marginally from today's level to 4.6 mb/d in 2035, which depends on progress in water injection capabilities to maintain production. The United Arab Emirates boost production by 0.6 mb/d to 4.8 mb/d in 2035, most of which comes from increased NGLs production.

A gradual normalisation of the international situation in countries subject to sanctions – notably Russia, Iran and Venezuela – is assumed in the CPS. Supply from these three countries remains flat to 2035 and then increases over the longer term by 4 mb/d to 2050, reaching 20 mb/d in 2050. However, sanctions could remain in place on these countries for longer, in which case additional supply would need to come from elsewhere. Increases above the levels of the CPS may be possible from the United States, Canada, Brazil and other major resource-holders in the Middle East, but this would require additional investment and would very likely entail higher prices (Box 3.3).

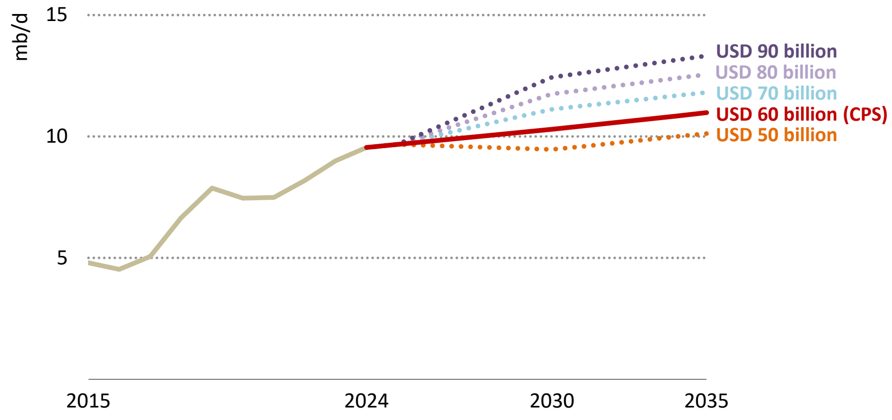
Russian oil supply fell by 0.3 mb/d in 2024 to 10.7 mb/d, largely due to sanctions, rising costs and infrastructural challenges. Supply remains around this level through to 2050 in the CPS, supported by progress in the Vostok Oil Project in the 2030s and increased output from currently hard-to-access resources which offset declines in its legacy supergiant fields.

Box 3.3 ▷ How high and for how long can US tight oil production rise?

The growth of tight oil production in the United States in recent years has far surpassed anything seen previously in the history of oil supply. Production rose by 0.5 mb/d each year on average between 2015 and 2024 to 9 mb/d, which was roughly equivalent to adding current oil production in Guyana to the global balance every year. Tight oil wells are characterised by high initial production followed by steep decline, with continued drilling essential to maintain and extend production. US tight oil production is particularly sensitive to the oil price, and the dip in prices at the beginning of 2025 had an immediate impact on future production projections.

In the CPS, the oil price rises to around USD 90 per barrel in 2035, unlocking around USD 60 billion average annual investment to 2035 as the price moves up (around 20% less than was invested in the sector in 2024). Tight crude oil and condensate production rises by around 1.4 mb/d to 2035 in the CPS. This increase depends on increased investment and on the timely development of new infrastructure to avoid bottlenecks (Figure 3.32).

Figure 3.32 ⊳ US tight crude oil and condensate production at various average annual levels of investment in the CPS to 2035



US tight oil production rises by 1.4 mb/d to 2035; it could rise by an additional 2.5 mb/d if investment averages around the highest levels seen in recent years

Higher investment levels than in the CPS would lead to larger production increases. Nonetheless, higher spending and drilling activity tend to be associated with rising input costs, production levels are limited by the overall level of oil that can be recovered,[5] and recent evidence suggests that wells in a number of the key US tight oil plays are becoming more gas-rich. The industry is increasingly focused on maximising returns to shareholders and maintaining capital discipline. If annual investment averaged USD 90 billion to 2035 – similar to the highest ever levels seen in tight oil in 2018 and 2019 – then we estimate that tight oil production could rise to around 13 mb/d in 2035.

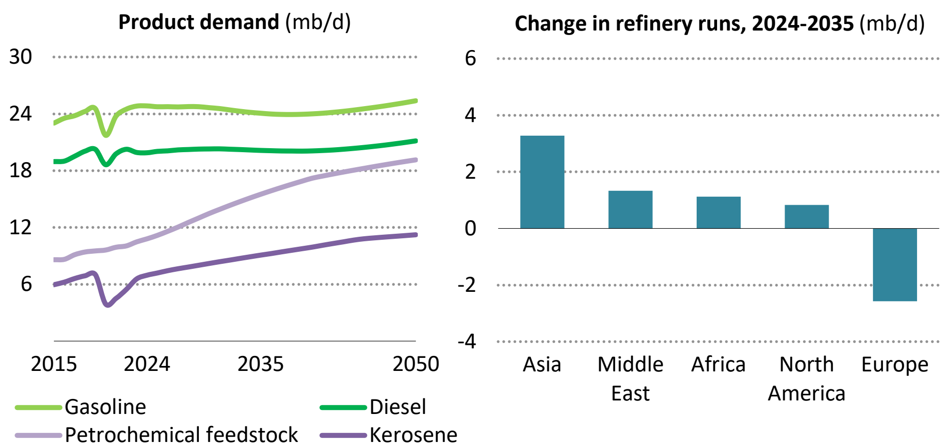
Refining

Oil use as petrochemical feedstock and jet fuel consumption increase by 2% each year on average to 2035 in the CPS. Aggregate gasoline and diesel demand stays broadly flat to 2035, with declines in advanced economies and China broadly offsetting increases in other emerging market and developing economies: the balance changes after 2040, leading to a 5% rise in road transport fuel demand to 2050 (Figure 3.33).

[5] The US Energy Information Administration indicates 220 billion barrels of resources remaining (EIA, 2025).

Around 9 mb/d of new refining capacity comes online in the CPS between 2024 and 2035. With around 5 mb/d in closures over this period, net refining throughput increases by 4 mb/d. Asia sees a net increase of around 3 mb/d in refining capacity between 2024 and 2035, led by increases in India. Since 2022, India has emerged as a global swing supplier, refining volumes of Russian crude oil exports that previously flowed to Europe. India's refining capacity grows from 6 mb/d in 2024 by 1.5 mb/d to 2035 which solidifies its role as a key exporter of transport fuel. The refinery and petrochemical rationalisation programme in China shuts down some capacity, but additions and retrofits keep overall capacity levels broadly flat at just under 19 mb/d to 2035, and falling domestic demand drives a rise in oil product exports.

Figure 3.33 ⊳ Demand for selected refined and fractionated products, 2015-2050 and refinery runs by region in the CPS, 2024-2035



Demand for petrochemical feedstock rises much more strongly than demand for other refined products, while Asia increasingly cements itself as a refining hub

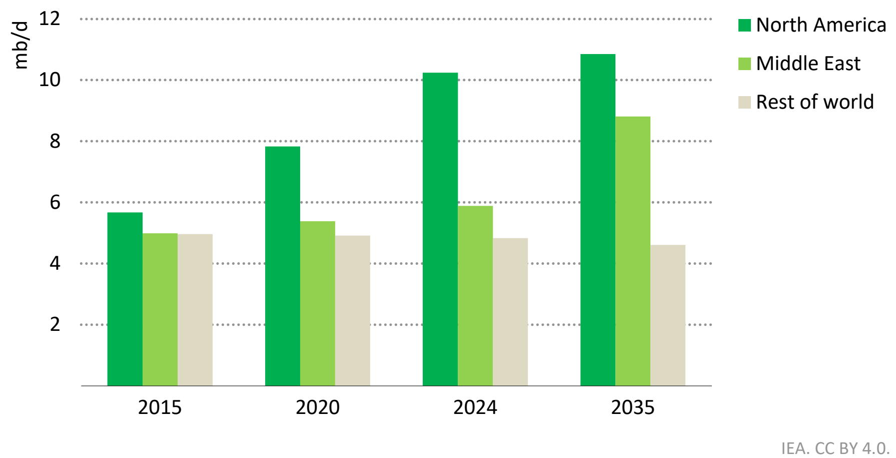
Note: mb/d = million barrels per day; Petrochemical feedstock = naphtha, liquefied petroleum gases and ethane used as a feedstock; diesel, gasoline and kerosene includes transport use only.

Refining capacity in the Middle East increased notably in recent years (to 11.5 mb/d in 2024), largely driven by Saudi Arabia, reflecting a strategic focus on increasing downstream integration. In the CPS, it rises by an additional 1.7 mb/d to 2035. In Africa, around 0.7 mb/d of new capacity comes online by 2035, including the Dangote refinery in Nigeria, (not yet at full capacity in early 2025). In North America, new refining capacity mostly comes online after 2035, increasing its total capacity to just over 22 mb/d in 2050, driven by rising domestic demand for petrochemical products, kerosene and diesel. Refining capacity in Europe falls from 16 mb/d in 2024 by 2.5 mb/d to 2035, reflecting both lower demand and a loss of competitiveness.

Box 3.4 ▷ How could natural gas liquids momentum shift?

Natural gas liquids (NGLs) are hydrocarbons separated and extracted from natural gas streams during processing. They include both condensates and natural gas plant liquids. NGLs production increased by one-third over the past decade, reaching 21 mb/d in 2024. As production rose, NGL-derived ethane and LPG increased in importance as low-cost competitors to crude oil-derived chemical inputs, sources of petrochemical feedstock and fuels for cooking.

Figure 3.34 ▷ NGLs production by region in the CPS to 2035



NGLs help meet growing demand for petrochemical feedstock, with Saudi Arabia and Qatar production set to accelerate over the next decade

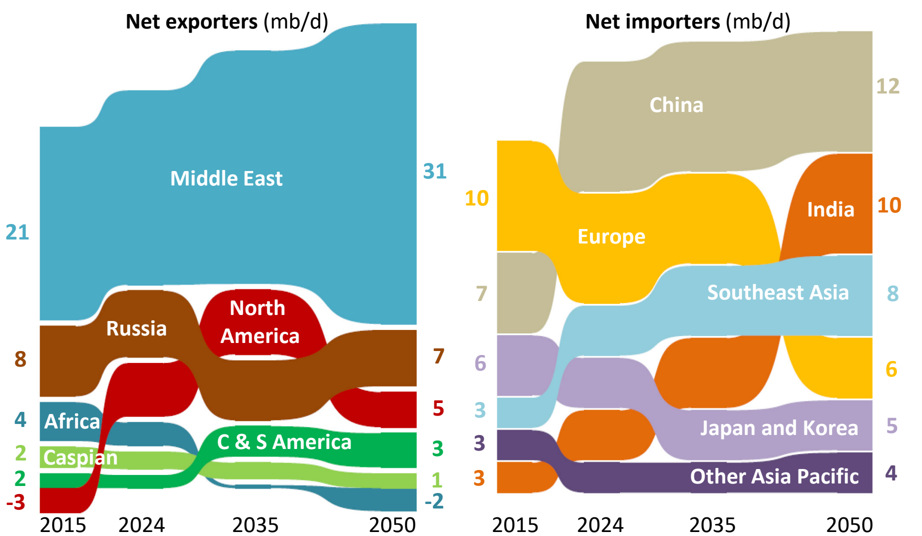
Note: mb/d = million barrels per day.

Production of NGLs expands to 24 mb/d by 2035 in the CPS (Figure 3.34). Two-thirds of this is from Saudi Arabia and Qatar, where it is supported by the ramp-up of the Jafurah field and increases in output from the North Field. A further 20% of the increase is from North America, mainly from increased shale gas production: many US shale basins deliver high NGLs yields. NGLs production in the Middle East rises more rapidly to 2035 while North American output sustains the highest volumes even as the rate of growth stabilises. This means that the main supply centres for NGLs will be increasingly balanced between the Atlantic basin and east of Suez, which has important implications for the geography of oil product trade flows.

Trade

The Middle East exports 21 mb/d of oil today – around 50% of global net oil exports – and it remains by far the world's largest oil exporter through to 2050 in the CPS (Figure 3.35). Net exports from North America increase by around 1.5 mb/d to more than 7 mb/d in 2035 and then fall in the 2040s as domestic supply declines slightly. Net exports from Russia in 2035 (7 mb/d) are about 0.2 mb/d lower than those of North America, but Russia becomes the world's second-largest net oil exporter again by 2050 as North American exports decline in the 2040s. Exports from Central and South America more than double between 2024 and 2050, driven by surges in production from Guyana and Argentina, and later by Venezuela. Africa stops being a net oil exporter soon after 2035, following gradual declines in production and a 2.8 mb/d increase in demand between 2035 and 2050.

Figure 3.35 ▷ Net oil trade for exporters and importers in the CPS to 2050



IEA. CC BY 4.0.

Middle East dominates global net exports today and it remains by far the largest exporter to 2050; India and Southeast Asia have rapidly rising import needs

Note: mb/d = million barrels per day; C & S America = Central and South America.

China overtook Europe as the world's largest crude oil importer in 2020, and it keeps this position in the CPS through to 2050, even though its imports do not increase materially. Its import dependency increases from 73% in 2024 to nearly 80% in 2035, while import dependency in India rises from 87% in 2024 to 92% in 2035, despite government efforts to promote domestic production. Oil imports to Europe have remained around 10 mb/d over the last decade, but its demand for oil falls by more than 20% to 2035 and halves by 2050 in the CPS. As a result, oil imports to Europe drop to around 6 mb/d in 2050, even though domestic production drops by 2 mb/d to 2050.

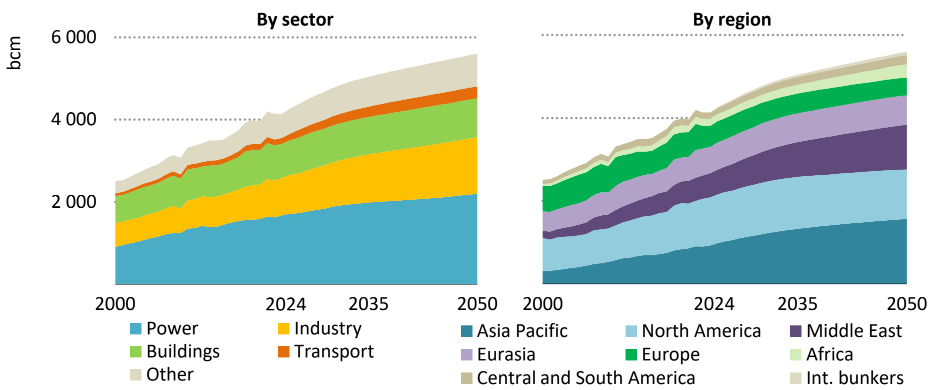
Global oil trade shifts eastward, boosting the strategic importance of the Strait of Malacca, where the volumes of oil handled in the CPS rise from 24 mb/d in 2024 (30% of global oil trade) to 28 mb/d by 2035. Volumes through the Strait of Hormuz also rise by just under 1.5 mb/d to 2035, reaching 21.5 m/d.

3.5.2 Natural gas

Demand

Natural gas demand has increased on average by around 80 bcm per year over the last ten years. In the CPS, it increases by around 70 bcm every year to 2035, and by 2035 natural gas overtakes coal to become the second-largest fuel in terms of demand. Emerging market and developing economies are responsible for nearly all of this growth – their collective needs increase by 700 bcm to 2035 – with demand in advanced economies remaining broadly flat (Figure 3.36). By 2050, global natural gas demand in the CPS reaches 5 600 bcm, a 30% increase compared with 2024, and emerging market and developing economies account for two-thirds of global demand, up from 55% today.

Figure 3.36 ▷ Global natural gas demand by sector and region in the CPS to 2050



Natural gas demand increases by 20% to 2035 and by 30% to 2050, driven by expanding use in power generation and in industry, particularly in Asia Pacific and Middle East

Note: bcm = billion cubic metres; Int. bunkers = international bunkers; Other = other energy sector and agriculture.

Demand in emerging market and developing economies in Asia increases by 340 bcm between 2024 and 2035, in line with historical trends. Around 35% is more demand from the power sector and another 35% from industry. This is accompanied by investment in new infrastructure: the region adds 270 GW of new gas-fired power generation capacity to 2035, a 70% increase on current levels. Natural gas demand in China rises by 200 bcm to 630 bcm between 2024 and 2035, which is more than the growth in demand from all other emerging market and developing economies in Asia combined. Natural gas demand in India nearly doubles to 2035 to reach 140 bcm, led by growth in its city-gas distribution sector.

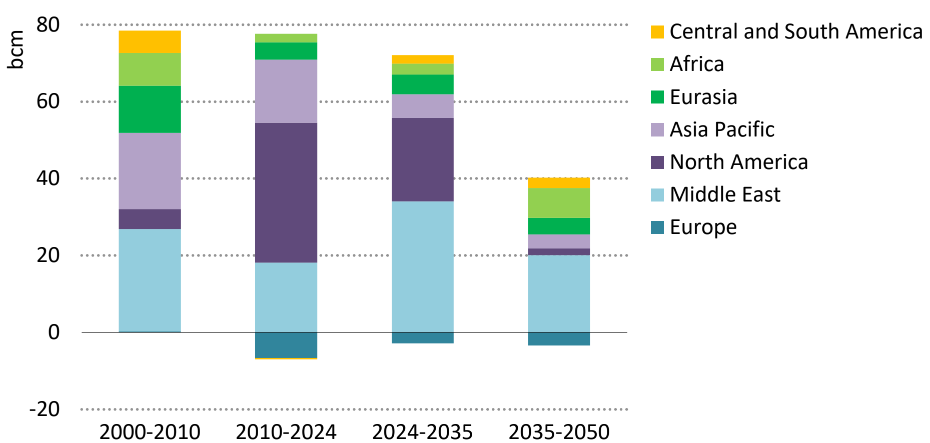
The Middle East is a major source of natural gas demand growth. Its use of gas expands by 240 bcm between 2024 and 2035. It is broad-based: the power and industry sectors together account for two-thirds of the increase, but more gas is also consumed in the oil and gas sector, for example in LNG liquefaction.

Demand in advanced economies increases by 50 bcm between 2024 and 2035 in the CPS. In the United States, demand increases by around 10% to more than 1 000 bcm in 2035, led by a 50 bcm increase in the use of gas for electricity generation and an additional 15 bcm to run LNG liquefaction terminals. Natural gas demand in the European Union falls by just over 10% to less than 300 bcm in 2035 as current policy measures to reduce reliance on gas imports and increase the share of renewables take effect. In Japan, demand rises marginally from 90 bcm in 2024 to 95 bcm by 2035. In Korea, demand stays flat at 60 bcm.

Supply

Meeting the rise in natural gas demand in the CPS requires an acceleration in investment in a wide range of supply sources. The Middle East sees the largest expansion in supply of any region in the CPS, and its share of global production rises from 17% in 2024 to 22% in 2035 (Figure 3.37). Qatar leads the way within the region, increasing output from 170 bcm in 2024 to over 300 bcm in 2035, and most of this additional output is used to boost its LNG exports. Saudi Arabia ramps up production of non-associated gas, increasing output by more than 75 bcm between 2024 and 2035 to meet growing electricity demand and to substitute for oil in the power system. Its Jafurah field, the region's largest unconventional, non-associated gas field, began production in 2024 and output is projected to exceed 20 bcm within five years. At peak production, it will provide nearly 15% of Saudi Arabia's total gas output.

Figure 3.37 ▷ Average annual change in natural gas production in the CPS to 2050

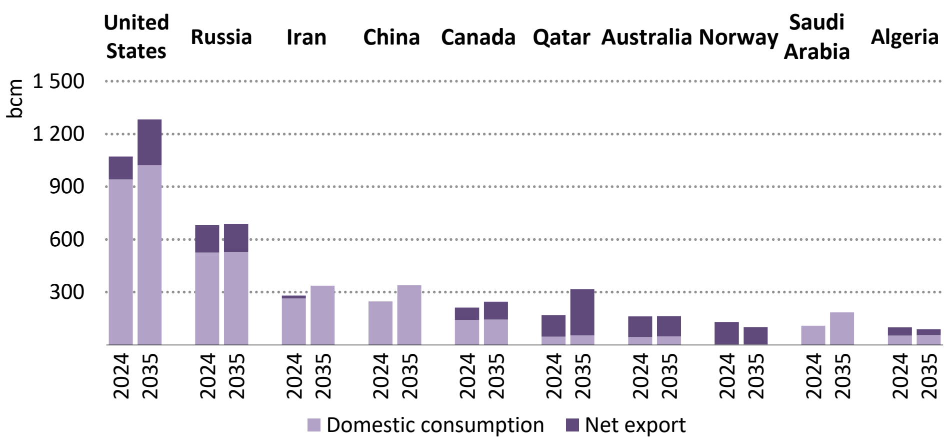


Natural gas supply growth is dominated by the Middle East after 2025

Note: bcm = billion cubic metres.

Today the United States is the world's largest gas producer, accounting for over one-quarter of global supply, 1 070 bcm, and it increases production in the CPS by 210 bcm to 2035 (Figure 3.38). The shale revolution shows some signs of maturation, and the average annual increase in shale gas production in the CPS to 2035 is around one-half of the level seen over the previous decade. In 2024, the United States exported around 18% of its natural gas production; this rises to more than 25% in 2035. The benchmark Henry Hub price rises to around USD 4.5 per million British thermal units in 2035 to support the production of the new supplies needed to cover these larger volumes of export alongside rising domestic demand.

Figure 3.38 ▷ Natural gas by producing country in the CPS, 2024 and 2035



All major producers invest in new supply to meet rising domestic demand or to boost exports, with nearly 80% of the global increase in supply from today's top-ten producers

Note: bcm = billion cubic metres.

Natural gas production in Canada rises by 35 bcm to 250 bcm in 2035 in the CPS. Around two-thirds of this growth comes from its shale resource base, which, building on the commissioning of LNG Canada in 2025, is increasingly supporting the country's entrance to the club of LNG exporters.

Natural gas production in Russia stays flat around 680 bcm to 2035, as do its exports, at around 160 bcm, and it is assumed that domestic prices increase to compensate for falling export revenue. Gas fields in West Siberia get a second lease on life from the mid-2030s as the Power of Siberia II pipeline to China ramps up. This enables the legacy Yamburg and Urengoy fields to maintain output, with modest upside for the newer Bovanenkovo basin.

The prospects for natural gas production in Australia differ by region and total production is broadly flat to 2035 (at around 165 bcm). Structural supply deficits on its east coast make it difficult to meet domestic demand while maintaining LNG exports from Queensland. In the west, supply growth from the offshore Carnarvon and Browse basins, among others, helps offset declines elsewhere, helping maintain Australia's position as the dominant regional LNG supplier.

Gas production in Africa rises in aggregate by 30 bcm to 2035, with increases in countries in sub-Saharan Africa more than offsetting declines in North Africa. In North Africa, Algeria and Libya have opened new exploration acreage in a bid to reinvigorate foreign inward investment, and in the CPS, this partially offsets declining production in existing fields. In Nigeria, efforts to boost the upstream sector lead to a near 15 bcm increase in natural gas production to 2035, and expansion of the LNG liquefaction plant on Bonny Island is set to further strengthen its position as an LNG exporter. Mozambique is also poised to increase production to support LNG exports, as the 18 bcm Mozambique LNG project is assumed to start around 2030. Other new gas producers also emerge in Africa, notably Senegal, where production increases to around 15 bcm by 2035.

In Argentina, production is set to increase by 60% to 2035, bringing the total to around 75 bcm, led by increases in the Vaca Muerta formation, which has large volumes of associated gas. There is also a small increase in gas production in Brazil, but production falls in most other countries in Central and South America. Overall, the region sees a net increase of 25 bcm in natural gas production between 2024 and 2035.

Trade

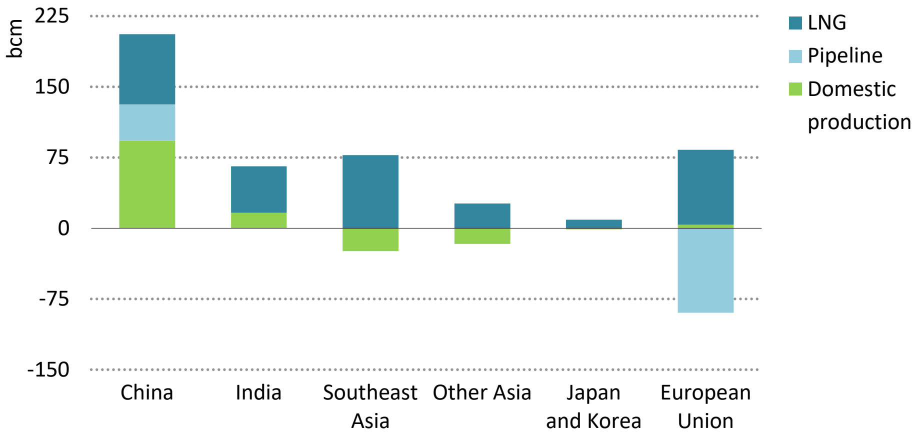
Around 1 100 bcm of natural gas was traded over long distances in 2024, 45% by long-distance pipeline and 55% as LNG. A large new wave of LNG capacity is set to come online over the period to 2030: this new capacity is fully utilised in the CPS, mainly through increased exports to emerging market and developing economies in Asia. Total LNG trade expands from 560 bcm in 2024 to 880 bcm in 2035. Over this period, LNG imports by Europe grow by 80 bcm, while imports by countries in Asia rise by 240 bcm; more than 70% of all LNG exports are shipped to Asia in 2035 (Figure 3.39).

China imported more than 100 bcm of LNG in 2024 – the largest amount of any country – and another 80 bcm of natural gas by pipeline. Its LNG imports have fallen to date in 2025 as a result of high LNG prices, robust domestic production and increased pipeline imports from Russia. In the CPS, its LNG imports rise by 75 bcm to 2035, while pipeline gas imports increase by 40 bcm, with roughly 65% of the increase from Russia and the rest from Central Asia.

Southeast Asia imported around 35 bcm of LNG in 2024. Rapidly rising demand and declining domestic gas production increase this to 80 bcm by 2035 in the CPS, and an additional 50 bcm per year of regasification capacity is built to accommodate this growth. In 2035, India imports 50 bcm of LNG, up from 35 bcm today. Other emerging markets in Asia, particularly Pakistan and Bangladesh, import around 75 bcm of LNG in 2035, a 60% increase on 2024 levels.

Japan and Korea – long-time leaders and first movers in the LNG industry – remain fully dependent on LNG to meet gas demand. Their combined imports rise by around 10 bcm to 2035 in the CPS.

Figure 3.39 ⊳ Change in natural gas supply balance in selected regions in the CPS, 2024-2035



LNG imports surge in Asia as domestic production fails to match growth in demand

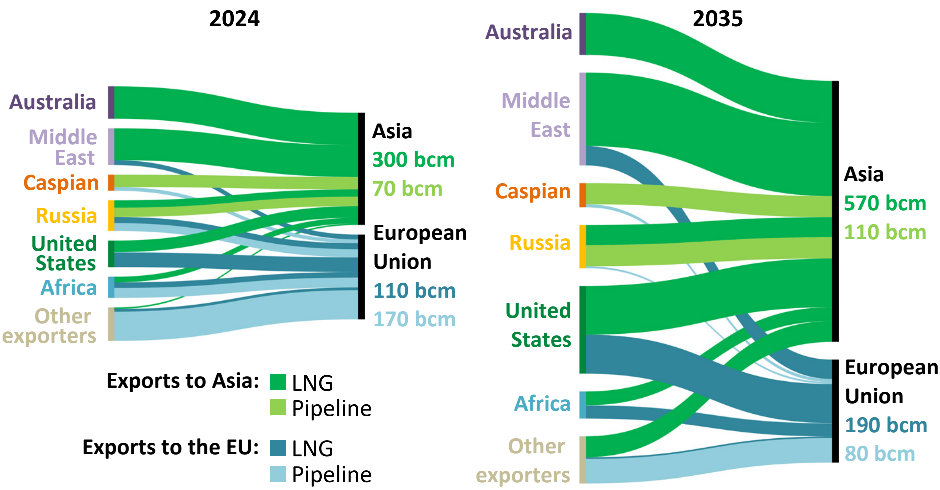
Note: LNG = liquefied natural gas.

The United States is the world's largest LNG exporter. It delivered 120 bcm in 2024 to more than 45 countries, with its flexible, destination-free contracts allowing cargoes to be redirected quickly in response to market shifts. Its export capacity doubles by 2030, and it maintains its current role as the largest LNG exporter through to 2050 in the CPS. It exports more than 250 bcm of LNG in 2035, half of which goes to Asia, up from 30% in 2024 (Figure 3.40).

The Middle East, led by Qatar, doubles its LNG exports in the CPS to 260 bcm in 2035, with the Ruwais LNG complex in the United Arab Emirates adding more than 10 bcm of new capacity by 2028.

Russia doubles gas exports to China from 40 bcm in 2024 to 80 bcm in 2035. The Power of Siberia I pipeline is currently operating at full capacity, and the Power of Siberia II pipeline, with nameplate capacity of 50 bcm, is assumed to ramp up from the mid-2030s. Russia also increases exports to the Caspian region. Russia's annual LNG exports remain around the current level of 50 bcm in 2035. Despite finding some alternative export outlets for its gas since its invasion of Ukraine closed off many of its previous ones, Russia's net income from natural gas exports remains below 2021 levels out to 2050 in the CPS.

Figure 3.40 ⊳ Natural gas exports to the European Union and Asia in 2024 and in the CPS in 2035



Asia is the main destination for gas exports by 2035 as exports to the European Union fall marginally; the United States remains by far the largest single LNG exporter

Note: bcm = billion cubic metres.

3.5.3 Coal

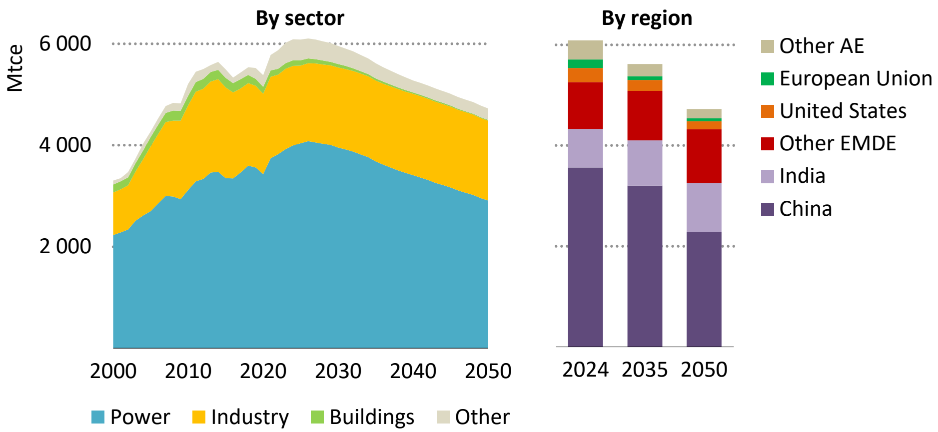
Demand

Since 2000, coal has been the fastest growing fossil fuel in the global energy mix. Global coal demand has nearly doubled since then, and reached the record level of 6 090 million tonnes of coal equivalent (Mtce) in 2024. Growth has been driven mainly by the use of coal to generate power in emerging market and developing economies, in particular China and India. However, in the CPS, global coal demand peaks before 2030 and then declines gradually: by 2035, demand is around 8% lower than 2024 levels, with a 315 Mtce reduction of coal use in power generation partially offset by a 30 Mtce increase in use in industry. By 2050, global coal use is around 20% lower than today (Figure 3.41).

The power sector currently accounts for around two-thirds of global coal demand. In the CPS, the increase in renewables electricity generation to 2035 corresponds to more than 85% of the increase in global electricity demand. As a result, renewables start to edge coal out in most regions apart from Southeast Asia. Meanwhile coal use in industry rises in several emerging market and developing economies. For example, coal demand for the industry sector in India increases by 60% to 2035 and in Indonesia by more than 45%. China sees a 16% reduction in coal use in industry to 2035, a drop of 150 Mtce, mainly in its iron and steel sub-sector.

Coal demand has fallen by around 40% since 2015 in advanced economies. It declines by a further 35% to 2035 as old coal-fired power plants are gradually retired: coal use in power falls by around 45% to 2035, and in industry it falls by around 5% from a low base.

Figure 3.41 ⊳ Coal demand by sector and region/country in the CPS to 2050



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Coal use peaks before 2030, mainly as demand declines in China and in advanced economies; only coal use in industry remains resilient to 2050

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

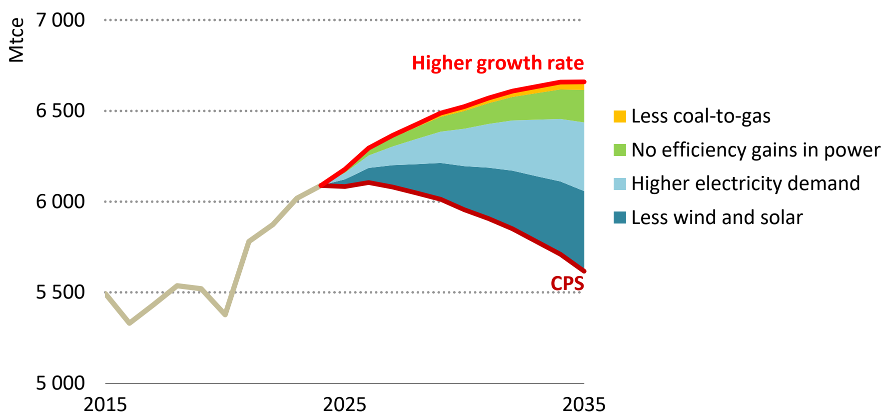
Box 3.5 ⊳ Could coal demand continue to increase?

A growth story for coal over the coming decades cannot entirely be ruled out but it would fly in the face of two crucial structural trends witnessed in recent years: the rise of renewable sources of power generation, and the shift in China away from an especially coal-intensive model of growth and infrastructure development. As such, sustained growth for coal demand appears highly unlikely. Nonetheless it is useful to explore the circumstances under which it could take place (Figure 3.42).

More than any other fuel, the dynamics in coal markets are determined by a handful of countries, mostly in Asia. By far, China is the most notable, followed by India, Indonesia and other countries in Southeast Asia. The average age of the coal-fired power plants in emerging market and developing economies in Asia is around 15 years, so many of them could in theory have a long operational future; however, continued growth in coal use would also imply the construction of substantial additional plants.

Continued growth in coal demand could take place if the expansion of wind and solar PV electricity generation ended. Electricity generation from wind and solar PV increases by around 1 000 TWh on average every year in the CPS between 2024 and 2035. Integration challenges as well as tariffs or other trade measures could hinder the level of expansion in some markets projected in the CPS. If the annual increase in global wind and solar PV generation was more in line with the 2024 level, 650 TWh, it would imply an additional 450 Mtce of coal demand in 2035 based on the current global power mix. Yet multiple factors push in the opposite direction, including the underlying economics and strong industrial interest in the manufacture and deployment of wind and solar PV, notably in China.

Figure 3.42 ⊳ Factors that could lead to continued coal growth above the levels of the CPS to 2035



Further increases in demand for coal could reflect a huge slowdown in clean technology deployment and a major reduction in efficiency gains

Note: Mtce = million tonnes of coal equivalent; CPS = Current Policies Scenario.

Electricity demand is another important variable: it increases by around 3% each year to 2035 in the CPS, which is similar to the average rate of growth in the last decade. But electricity demand increased by 4.2% in 2024. If the rate of demand growth were to be maintained through to 2035, it would imply an additional 380 Mtce of coal, assuming no changes in the power generation mix.

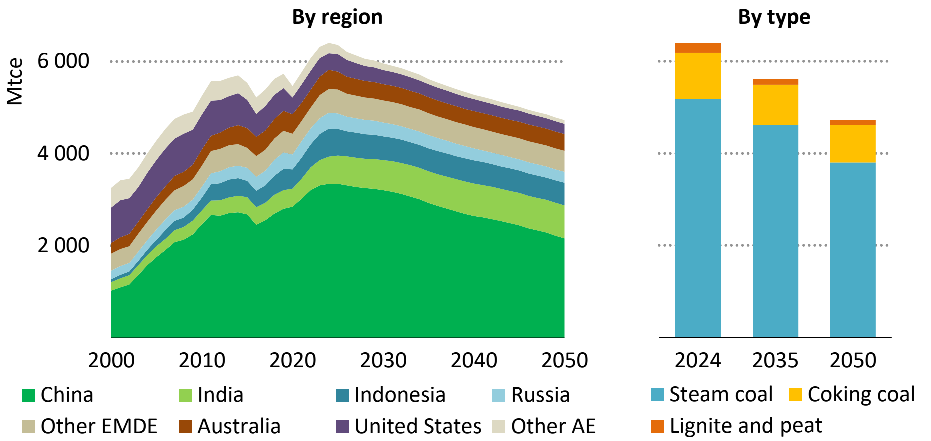
Coal demand could also be affected at the margin by slower increases in power sector efficiency. The CPS includes a slight increase in efficiency as older, less efficient plants are retired, or by reducing coal-to-gas switching in some markets, but neither of these factors are game-changers on their own.

In practice, the considerations that seem most likely to affect the pace at which the world moves away from coal concern the social consequences of change. As countries that have been down this route will attest, coal transitions are challenging (IEA, 2022). The implications of declining production on coal-dependent communities and regions can be substantial, and could prove to be more important than the economics of power generation in determining the rate of change. In the CPS, the decline of coal demand is relatively gradual, and would only continue an existing trend. China, for example, has already seen a huge reduction in its coal workforce as the sector modernised over the last ten years. In some circumstances, however, a prolonged role for coal could be driven by social or other political considerations.

Supply

Coal production in China expanded by around 2 300 Mtce between 2000 and 2024, which represents nearly three-quarters of the growth in global coal production over the period. In the CPS, production in China declines by 10% from close to 3 350 Mtce in 2024 to just over 2 900 Mtce in 2035 (Figure 3.43).

Figure 3.43 ⊳ Coal production by region/country and type in the CPS to 2050



Coal production falls gradually in most major producers; declines are steeper for steam coal, lignite and peat than for coking coal

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

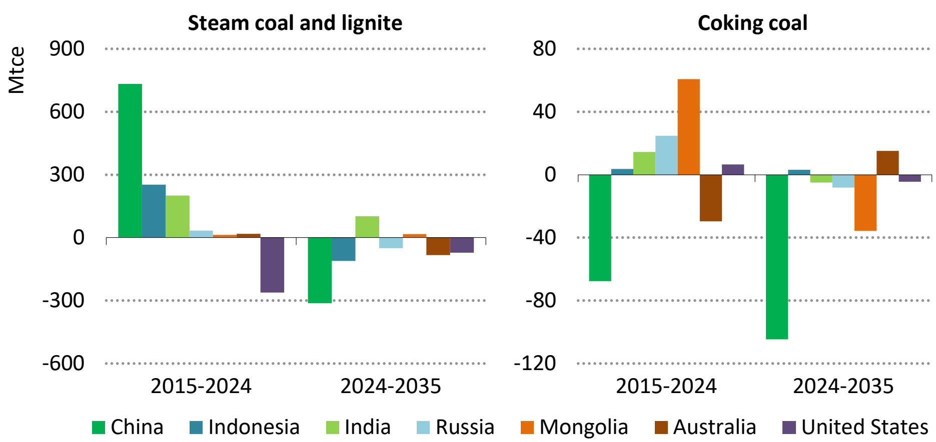
In India, reflecting strong domestic demand and supportive policies, coal production reached almost 600 Mtce in 2024, an increase of nearly 100 Mtce since 2022. In the CPS, India sees the largest increase in coal production, adding 100 Mtce to its annual output by 2035.

Most other emerging market and developing economies reduce coal output, though a few countries in Africa and Asia that currently produce small amounts of coal see modest increases in production to 2035 in the CPS. In South Africa, steam coal production falls by around 20%, mainly as a result of lower demand; export-oriented steam coal producers, such as Colombia, see larger reductions.

Coal production in advanced economies, totalling 1 000 Mtce in 2024, has fallen by roughly 400 Mtce since 2015. This downward trajectory continues in the CPS, albeit at a slower pace, with production falling by around 250 Mtce to 2035.

The production outlook varies by coal type (Figure 3.44). Steam coal is mostly used for power generation and accounts for around 80% of world production today, and its production falls by just over 10% to 2035. Coking coal is mostly used in iron and steel production, and its production expands in several countries. A key exception is China, where it falls by more than 20% to 2035 in the CPS. Lignite and peat production have the steepest falls, a drop of around 45% to 2035, mostly due to mine closures in Europe.

Figure 3.44 ▷ Change in coal production by type in selected countries in the CPS to 2035



India is one of the few countries to continue to significantly ramp up coal production

Note: Mtce = million tonnes of coal equivalent.

Indonesia – the world's largest steam coal exporter – sees a production drop of about 20% from 2024 to 2035 in the CPS, despite growth of nearly 45% in domestic coal demand. Australia – the world's largest coking coal exporter – sees a 15% drop in production to 2035, and a fall of 45% in domestic demand, mainly for steam coal used in power generation. Russia and Mongolia also see declines in production as China, their main export destination, reduces its imports.

Stated Policies Scenario

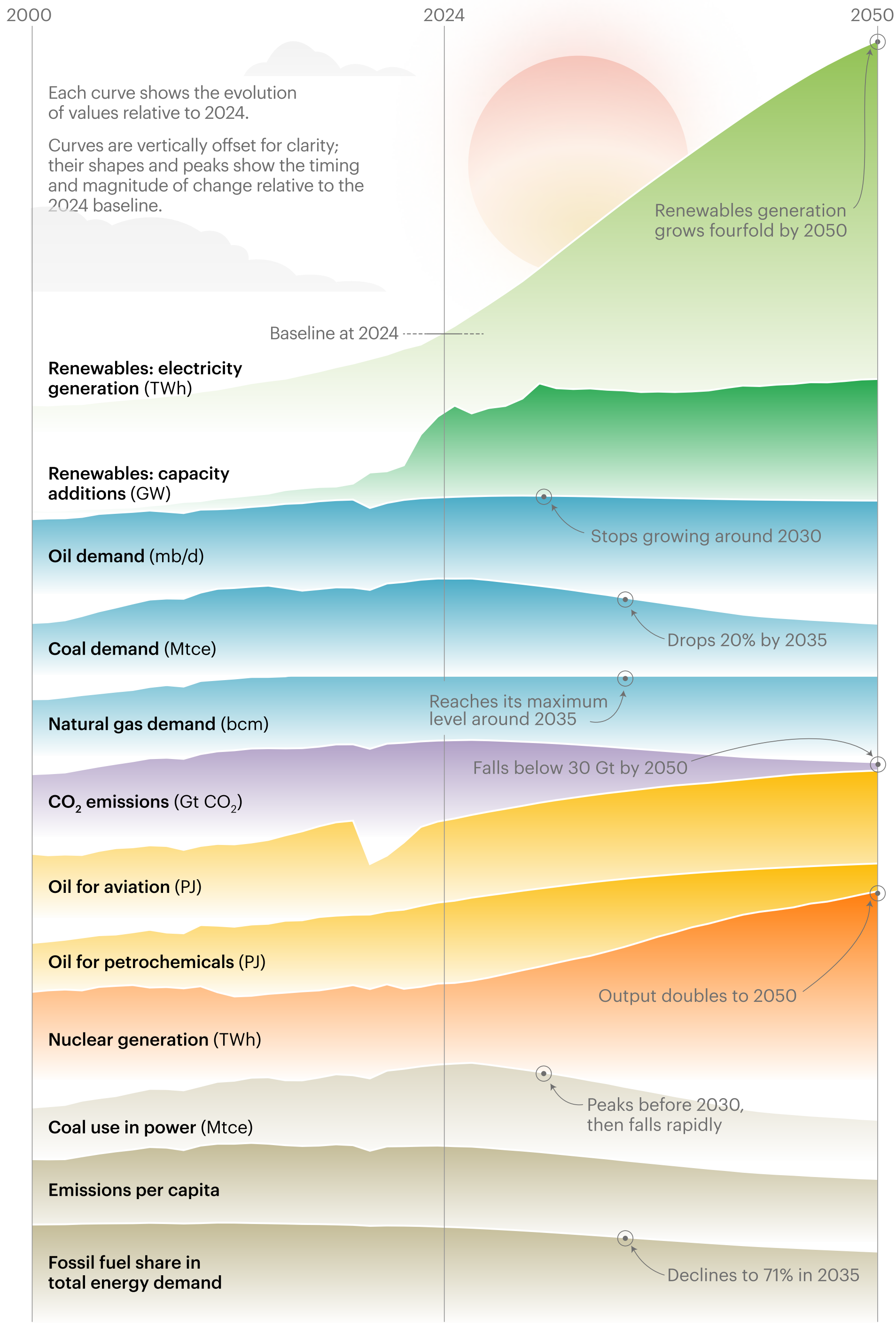
Stepping up the pace of change?

SUMMARY

- The Stated Policies Scenario (STEPS) is an exploratory scenario, designed to reflect the prevailing direction of travel for the energy system based on a detailed reading of country-specific energy, climate and related industrial policies that have been adopted or put forward, even if not yet codified in law. It reflects the state of technology and market conditions but does not include aspirational goals.
- Total final consumption grows 1% annually to 2035 in the STEPS, with India and other emerging market and developing economies leading demand growth. It increases more slowly than in the past decade as efficiency gains accelerate to 2.2% per year, driven by the increasing electrification of end-uses.
- Oil demand peaks at 102 million barrels per day (mb/d) around 2030 before gradually declining. Global electric car sales share rises from over 20% today to over 50% by 2035, despite lower electric vehicle (EV) sales in the United States in this *Outlook*. In 2035, over 840 million EVs displace 10 mb/d of oil, mainly in Asia and Europe. Oil use for petrochemicals and aviation continues to increase to 2035 and 2050. Natural gas demand increases nearly 1% annually to 2035, supported by abundant supply and major liquefied natural gas (LNG) expansions in the United States and Qatar, then levels off. Coal demand peaks before 2030 as declines in China outweigh increases in India and Southeast Asia.
- From the 2030s, renewables in aggregate meet all additional global energy demand as they provide increasing amounts of generation in a rapidly expanding power sector. The renewables share in electricity generation rises from one-third today to over half by 2035 and two-thirds by 2050, led by solar and wind power with support from batteries. Grid upgrades and dispatchable sources are critical to maintain security. Nuclear output grows 40% to 2035, maintaining a 9% share of electricity generation.
- The world moves firmly into the Age of Electricity in the STEPS, with electricity use rising four-times faster than overall energy demand to 2035. In advanced economies, EVs and data centres push up electricity demand. In emerging market and developing economies, rising incomes boost demand for appliances and air conditioners.
- Dynamism in the electricity sector is not matched by the rise of low-emissions fuels: liquid biofuels and biogases do well in some markets, but new fuels generally struggle to gain market share and remain heavily dependent on policy support to compete.
- Energy-sector CO_2 emissions peak near term at just over 38 gigatonne (Gt), falling to 35 Gt by the mid-2030s and below 30 Gt by 2050 – a level last seen in 2005 – driven mainly by reduced coal use in China's power sector. Emissions from end-use sectors flatten but do not decline significantly. Europe sees one of the largest percentage drops. By 2100, the global temperature is projected to rise by 2.5 °C.

Peaks and valleys of the Stated Policies Scenario

Where the energy system reaches new highs and where it falls away



4.1 Introduction

The Stated Policies Scenario (STEPS) has a long pedigree in the International Energy Agency (IEA) family of scenarios. It was introduced in 2019 with this name, but it has much in common with the previous New Policies Scenario that dates back to the 2010 edition of the *World Energy Outlook (WEO)*. The intention of this scenario is to reflect the prevailing direction of travel for the energy system based on a detailed reading of the latest policy settings in countries around the world. It takes into account specific energy, climate and related industrial policies that have been adopted or put forward, as well as policy intentions not yet codified into law but supported by markets, infrastructure and financial conditions. (See Chapter 2 for full scenario descriptions and Annex B for underlying assumptions).

Like the Current Policies Scenario detailed in Chapter 3, the STEPS is an exploratory scenario in that it does not target a predetermined outcome. Instead, it sets the starting conditions and sees where they lead. As such, it does not assume that aspirational goals, such as those included in some Nationally Determined Contributions, are achieved. It is grounded in what policies are actually in place or planned across different sectors of the energy economy.

This does not make the STEPS a forecast – as we have said on many occasions, the IEA does not have a long-term forecast. Policies and circumstances will undoubtedly change, and we do not seek to anticipate or predict those changes. The aim of this scenario, and of the *Outlook* as a whole, is simply to provide a coherent, rigorous, data-driven framework for assessing how the energy sector might evolve, to better inform the important decisions that are being taken today.

The methodology for the STEPS has been consistent over time, but the modelling approaches have evolved across successive iterations of the scenario. Among other things, there has been a concerted effort to develop insights into energy supply chains, including those for critical minerals. Work on electricity has been underpinned by granular hourly modelling of the operation of power systems, and by detailed consideration of new sources of demand such as data centres and artificial intelligence (AI). New geospatial analysis is now a regular feature of this IEA modelling and analysis.

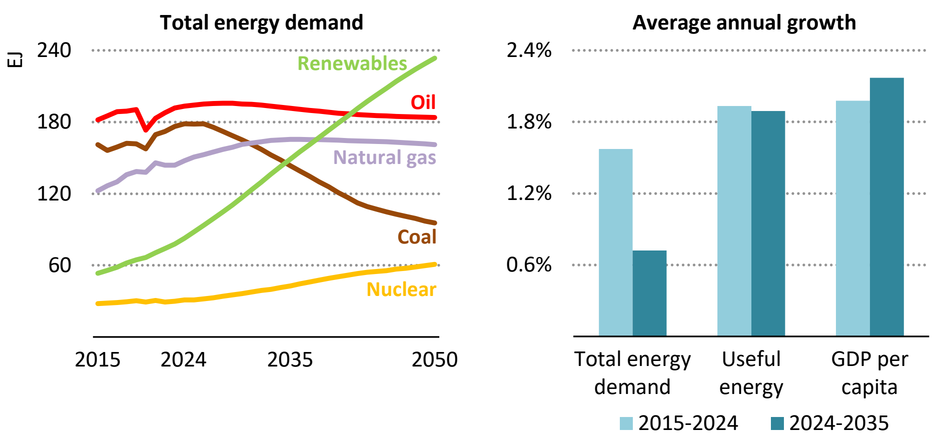
This chapter presents the new projections for the STEPS to 2050, starting with an overview of the broad energy demand outlook and the implications for emissions. It then goes into more detail on end-use sectors, examining among other things the future of the global vehicle fleet, the rapid growth in demand for cooling, and the ways in which some important trends are affecting the outlook for industry. The power sector section looks in detail at the onset of the Age of Electricity, which is characterised by strong demand growth across multiple sectors and continued structural changes in generation, and includes an exploration of its implications for grid infrastructure. The outlook for fuels is covered in the concluding sections, including oil, natural gas and coal as well as low-emissions fuels. Among other elements, it examines the drivers of demand and supply, and the prospective major expansion of trade in liquefied natural gas (LNG).

4.2 Overview

4.2.1 Total energy demand

Total energy demand increases from 654 exajoules (EJ) today to over 705 EJ in 2035, an increase that is roughly equivalent to the current energy demand in the European Union. Global gross domestic product (GDP) is assumed to rise at around 3% a year to 2035, in line with its rate of growth over the past decade, while total energy demand growth halves from an annual average of 1.6% over the past decade to 0.7% over the period to 2035. This continued decoupling of GDP and energy use reflects a rise in energy intensity improvements from an average of 1.4% per year over the past decade to 2.2% per year through to 2035. These improvements, which are chiefly driven by end-use electrification and efficiency gains from the uptake of renewables, mean that the energy ultimately available to end-users, i.e. useful energy, net of all conversion losses across the system, rises at virtually the same rate over the next decade as the last one (Figure 4.1). Growth in both total energy demand and in useful energy is fastest in emerging market and developing economies other than China, which enables economic development and welfare gains.

Figure 4.1 ▷ Total energy demand by fuel, 2015-2050, and growth of selected indicators, 2015-2024, and in the STEPS to 2035



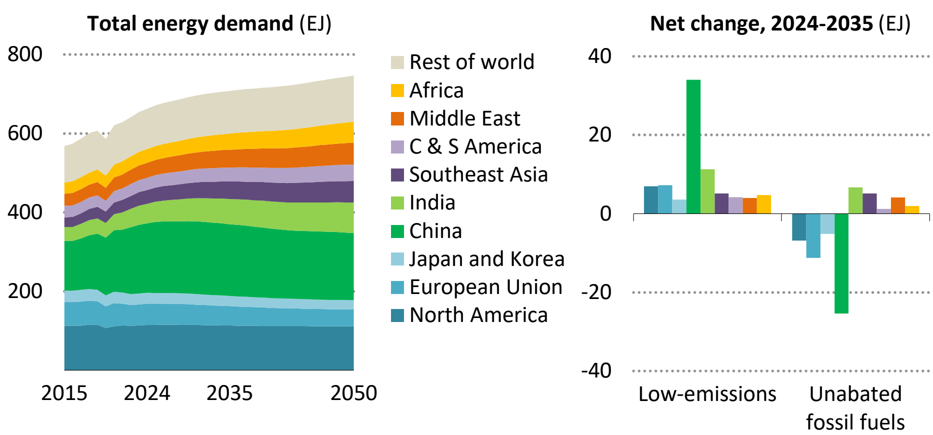
Fossil fuels reach high points in the next decade before being overtaken by renewables as total demand growth slows, but the energy available to end-users does not

Note: EJ = exajoule.

The fossil fuel shares in total energy demand decline from 79% today to 71% in 2035. Coal demand initially remains broadly stable at its current level of 6 090 million tonnes of coal equivalent (Mtce), but it peaks before 2030 and then declines to under 4 900 Mtce in 2035 as it is edged out of the power sector. Oil demand rises slowly to around 102 million barrels per day (mb/d) by 2030 before beginning a slow decline in subsequent years, with reductions in oil demand for road transport broadly offset by increased oil use for petrochemicals. Natural gas demand rises by 1% per year to 2035, driven mainly by growth in industry and power, and then remains stable. Demand for renewables increases by an average of 5.5% per year to 2035: most of the additional demand comes from the power sector, but the direct use of renewables also increases, particularly in industry and biofuels in transport. Renewable power capacity expands 2.6-times from 2022 to 2030, and 3.7-times by 2035. Nuclear capacity increases by 3% on average to 2035.

Today, around one-third of global energy demand is in advanced economies and two-thirds is in emerging market and developing economies. Between now and 2035, energy demand growth comes primarily from emerging market and developing economies, led by India, Southeast Asia, Middle East, China and Africa. While most of the growth in demand for oil and natural gas comes from emerging market and developing economies, demand for low-emissions sources increase in all regions (Figure 4.2).

Figure 4.2 ▷ Total energy demand by region, 2015-2050, and change by type and region in the STEPS, 2024-2035



IEA. CC BY 4.0.

Emerging market and developing economies drive growth in total energy demand; advanced economies and China see stronger shifts towards low-emissions sources

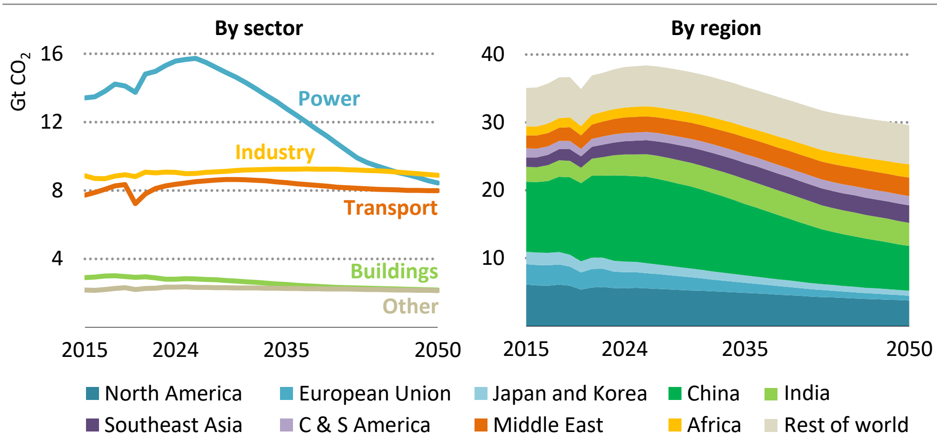
Note: EJ = exajoule; C & S = Central and South America.

Total energy demand is 4% higher by 2035 in the STEPS in this *Outlook* than in the version in the *World Energy Outlook-2024* (*WEO-2024)*. The differences are largely due to upward revisions in coal demand (10% or 440 Mtce higher in 2035 in this *Outlook*, mainly for use in power generation in China and United States), and in natural gas demand (8% or 350 billion cubic metres [bcm]) higher in 2035 in this *Outlook* mainly for use in power generation in the United States. The changes in China are driven by major regulatory changes for renewables that moderate their near-term growth, together with an expectation of more rapid growth in electricity output. In the United States, both regulatory shifts and higher expectations for data centre demand drive the changes to the outlook. Demand for nuclear power has also been revised upward (4% higher in 2035 in this *Outlook)*, which reflects an expanded pipeline of projects and increased policy momentum, particularly in some European countries. Demand for renewables has been revised downward in this STEPS (3% lower in 2035) primarily due to policy and regulatory changes in the United States.

4.2.2 CO_2 emissions

Global energy-related carbon dioxide (CO_2) emissions totalled 38 gigatonnes (Gt) in 2024. In the STEPS, they peak in the next few years and fall to around 35 Gt by 2035, a level last seen in 2015. By 2050, global CO_2 emissions are below 30 Gt, a level last seen in 2005. The reduction in emissions is primarily driven by changes in power generation (Figure 4.3), where the share of fossil fuels drops from around 60% today to less than 40% in 2035 and about 20% in 2050. Increased demand for renewables and further electrification of end-uses are the leading sources of emissions reductions through to 2035 and then to 2050. Although global energy-related emissions have yet to peak, CO_2 emissions per capita did so in 2013, and they continue to decline through to 2035 and beyond.

Figure 4.3 ⊳ CO_2 emissions by sector and region in the STEPS, 2015-2050



Changes in the power generation mix drive an overall reduction in energy-related CO_2 emissions, with reduced coal use as the main driver, especially in China

Note: Gt CO_2 = gigatonnes of carbon dioxide; C & S America = Central and South America.

Coal is the largest source of CO_2 emissions today, making up over 40% of the global total. Reductions in coal use bring about a 3.1 Gt decrease in CO_2 emissions to 2035, more than the overall net reduction by 2035. In parallel, emissions from oil use decline by 660 million tonnes (Mt), while natural gas emissions rise by 860 Mt. Natural gas accounted for almost half of the growth in CO_2 emissions over the last decade; it is also responsible for an increasing share of CO_2 emissions in the coming years as coal-to-gas switching continues in the power sector and as demand for gas rises in industry.

Underlying the global trend, regions see various trajectories. The European Union sees one of the largest percentage reductions: its CO_2 emissions in 2035 fall to 40% below today's levels (60% below 1990 levels). Emissions in China peak before 2030 and undergo the largest absolute reduction, falling 2.1 Gt to 2035. By contrast, emissions in India and Southeast Asia increase by around 20% (530 Mt and 440 Mt respectively). On average, per capita emissions in advanced economies are currently double those in emerging market and developing economies: the differential narrows in the STEPS, but they remain 75% higher in 2035.

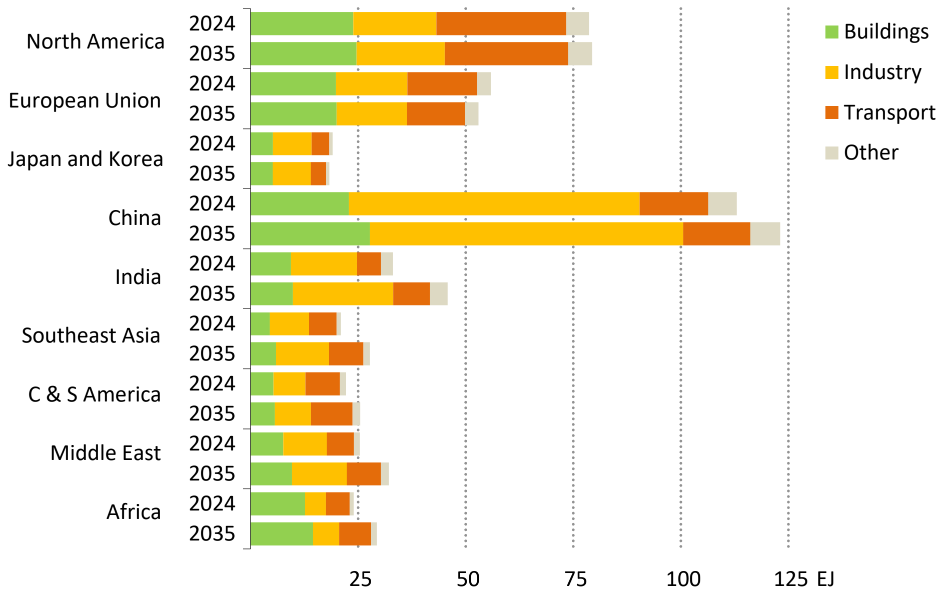
Energy-related methane emissions fall from around 145 Mt today to 115 Mt in 2035, reflecting concerted efforts in some countries to reduce the emissions intensity of supply and to provide access to clean cooking, together with a 4% reduction in global fossil fuel use. Accounting for all greenhouse gases, the long-term global mean temperature rise increases from today's level of around 1.4 degree Celsius (°C) to 1.5 °C by 2030 and reach 2 °C before 2060. By 2100, the temperature rise is 2.5 °C. (See Chapter 5 for more detail).

4.3 Total final consumption

Global total final consumption – all energy consumed by end-users – was around 450 EJ in 2024, of which the industry sector accounted for 38%, and the transport and buildings sectors for 28% each. The balance between end-use sectors varies by region, in part due to differing levels of access to energy services (Figure 4.4). In the STEPS, total final consumption rises to over 500 EJ through to 2035, and the balance by sector in each region is broadly stable. In advanced economies, each main sector represents close to one-third of the total, with the share of industry being the smallest. In emerging market and developing economies, by contrast, industry continues to account for the largest portion of total final consumption up to 2035, with its share of the total being as much as 60% in China and nearly half in India today. In Africa, the buildings sector is responsible today for over half of total final consumption, reflecting the lack of access to efficient energy sources faced by many households (see Chapter 6).

Total final consumption per capita is quite stable until 2035 at a global level of around 56 gigajoules (GJ) per capita, though there are regional differences. While new energy uses including AI grow steadily, advanced economies see consumption per capita decline from 110 GJ per capita to around 105 GJ per capita in 2035, thanks to efficiency improvements, notably those that flow from increasing electrification of heating and mobility. Meanwhile, emerging market and developing economies see consumption per capita increase from 42 GJ per capita today to 45 GJ per capita by 2035, with increasing demand for energy services from households acquiring vehicles, air conditioners and other appliances tempered by the switch to more efficient energy sources.

Figure 4.4 ▷ Total final consumption by sector in selected regions in the STEPS, 2024 and 2035



Total final consumption remains relatively evenly split across the main end-use sectors in advanced economies, while it is dominated by industry in Asia and by buildings in Africa

Notes: EJ = exajoule; C & S = Central and South America. Other includes agriculture and non-energy use.

4.3.1 Transport

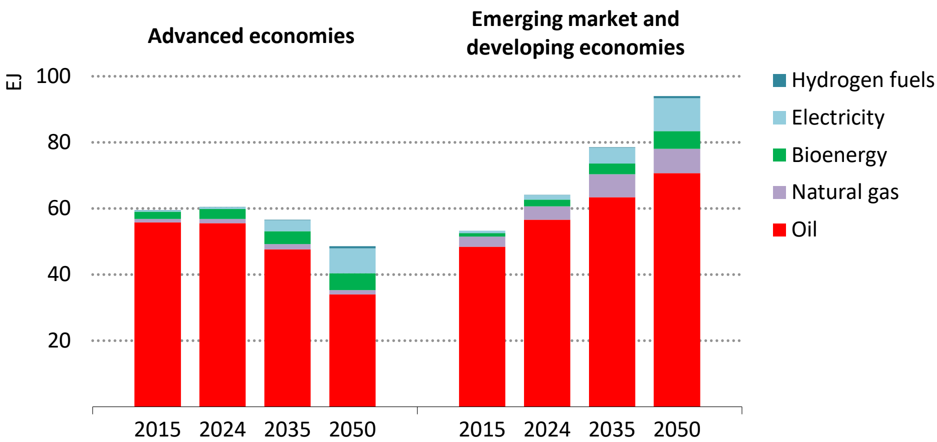
Oil continues to dominate energy use in the transport sector, but this is slowly changing. Its share of consumption in the transport sector was over 92% in 2015, but fell to 90% in 2024, reflecting the expanding use of electricity, bioenergy and natural gas.

Electrification plays an important part in reducing the dominance of oil in the STEPS (Figure 4.5). By 2035, electricity accounts for 6% of global transport energy demand, and some parts of world, e.g. Japan, United States, Canada, China and Europe as a whole, have already passed peak oil consumption in their transport sectors.

Natural gas also gains in importance in transport, particularly in shipping and long-haul trucking. In China, policy support and a favourable natural gas price environment encourage the adoption of LNG heavy-freight trucks. In India, natural gas car sales expand under similar conditions.

Bioenergy remains a key alternative to oil in transport. The rise of electric vehicles (EVs) limits the role it is likely to play in global road transport, but does not end it. Blending mandates continue to support bioenergy use in many regions, including Brazil, European Union, India, Indonesia and the United States. By 2035, bioenergy accounts for around 20-30% of transport energy use in Brazil and Indonesia, and close to 10% in the United States and the European Union.

Figure 4.5 ▷ Energy demand in transport by fuel and region in the STEPS, 2015-2050



Fossil fuel demand declines in advanced economies, while its rate of growth slows in emerging market and developing economies, levelling off relative to historical trends

Notes: EJ = exajoule. Hydrogen fuels include hydrogen and hydrogen-based fuels.

Trends in energy carriers vary across transport modes, with electrification leading in rail and road, while alternative fuels gain ground in shipping and aviation.

- **Road transport** still relies on oil, though electricity meets close to 7% of demand by 2035 in the STEPS, up from less than 1% today. Increasing electrification means that oil demand for road transport peaks in the coming years, even though passenger car activity rises by over 30% by 2035 as car ownership expands in emerging market and developing economies, and global freight activity increases by a third over the same period.

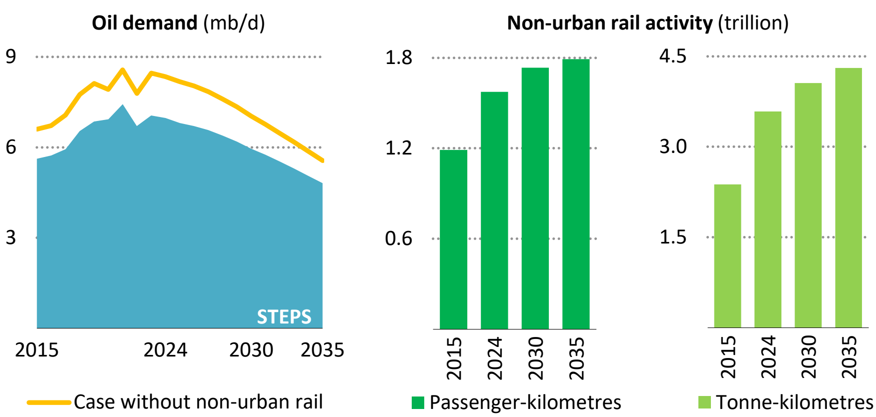
- **Rail** is currently the most electrified transport mode. It is also the most energy efficient mode for passenger transportation and the second most efficient mode for freight transportation (Box 4.1). Electricity and biofuels currently meet more than 50% of energy demand in rail transport, and this rises to 57% by 2035. As a result, oil demand falls slightly despite passenger and freight rail activity increasing by over 30% and 15% respectively. By 2050, the share of oil in rail transport declines from nearly 50% to 40%, while electricity and bioenergy together account for the remaining 60% of rail energy demand.

- **Shipping** remains heavily dependent on oil, which meets over 90% of its energy demand today. This share declines in the coming years, but remains over 80% in 2035. The fuel mix continues to diversify through to 2050, even as shipping activity rises around 45%. The share of oil in shipping falls to 70% by 2050, while the combined share of natural gas and bioenergy rises to over 25%, with methanol, hydrogen and ammonia together accounting for a further 3%. Today's policies support low-emissions fuels covering nearly 15% of shipping energy demand by 2050.
- **Aviation** remains the most oil-dependent mode over the outlook period, with oil accounting for over 95% of energy use in 2035 and 90% in 2050. The share of low-emissions fuels rises to nearly 5% in 2035 and 10% in 2050, the lowest across all transport modes, despite sustainable aviation fuel mandates in the European Union and United Kingdom. By 2050, oil use in aviation exceeds 10 mb/d, more than double the combined oil use of shipping and rail.

Box 4.1 ▹ How rail development is reducing oil demand in China

The rail network in China is highly electrified, with over 70% of non-urban rail activity powered by electricity. Therefore, shifting activity to rail from road and aviation transport helps reduce oil demand. In China, on average, non-urban passenger rail is around 80-times less oil intensive per passenger-kilometre than aviation. The equivalent figures for passenger cars are nearly 100-times less oil intensive and 10-times for buses. Freight rail is around 30-times less oil intensive than road freight.

Figure 4.6 ▹ Oil demand for transport in China with and without non-urban rail expansion, and non-urban rail activity in the STEPS, 2015-2035



Expansion of non-urban rail transport in China has reduced oil demand, avoiding nearly 1.5 mb/d in 2024 – more than the oil saved by EVs worldwide

Note: mb/d = million barrels per day; STEPS = Stated Policies Scenario.

China leads the world in non-urban passenger rail and freight rail activity, accounting for nearly 40% and 30% of global demand respectively. Its high-speed rail (HSR)[1] lines have doubled since 2015 to over 40 000 kilometres (km) today – almost three-times more than the length of HSR lines in the rest of the world combined. Europe has the second-largest HSR network, which is one-quarter the size of China's; Japan and Korea have the next largest (UIC, 2025). By 2035, China's HSR network stretches to around 45 000 km in the STEPS.

In a counterfactual case where non-urban rail activity in China remains at its 2000 level, oil demand would be nearly 1.5 mb/d higher in 2024 than it is – a level of avoided demand larger than the global oil savings from EVs today (Figure 4.6). Between 2015 and 2024, non-urban rail in China has cumulatively avoided almost 12 mb/d of oil demand and over 1.6 Gt CO_2 – equivalent to its annual emissions from transport, buildings and light industry combined in 2024.

4

How does the future vehicle fleet evolve?

In 2024, global electric car[2] sales rose by around 25% year-on-year to over 17 million, accounting for one-in-five cars sold worldwide. Sales are expected to reach over 20 million in 2025, and to account for over one-in-four cars sold worldwide. China alone is on track to see the sale of over 14 million electric cars in 2025 – more than the entire world total of electric car sales two years ago. Electric car sales in the European Union fell in 2024 following subsidy withdrawals in Germany, but the first-half of 2025 shows a nearly 22% year-on-year increase, driven by the introduction of around ten new battery electric models priced below EUR 25 000 and stricter CO_2 emissions standards. In the United States, electric car sales rose 10% in 2024, though growth slowed to 4% in the first-half of 2025. EV adoption continues to rise in emerging market and developing economies, particularly in Viet Nam, Mexico, Indonesia, Thailand and Brazil. For instance, the EV market share in Viet Nam exceeds 40%.

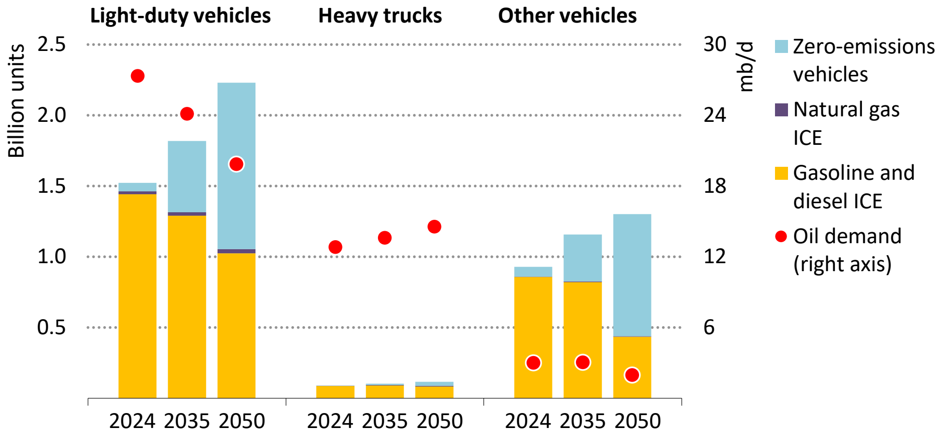
In the STEPS, EVs account for around 50% of sales of all vehicle types by 2035, resulting in over 10 mb/d of oil savings. Efficiency improvements in conventional gasoline and diesel vehicles reduce oil demand further by around 3.5 mb/d. Additional savings are from the use of bioenergy and natural gas as vehicle fuel, which avoid around 0.6 mb/d and 0.8 mb/d respectively by 2035.

Battery prices fell by around 75% between 2015 and 2024, making EVs more cost competitive with conventional cars in several key markets (IEA, 2025a). In addition, more affordable electric car models are entering the market, particularly in the European Union. Public charging infrastructure has expanded too, with more than 1.3 million new charging points added in 2024, bringing the global total to more than 5 million.

[1] Electricity-powered high-speed rail with maximum speed of at least 250 kilometres per hour.

[2] Electric cars include both battery electric and plug-in hybrid powertrains.

Figure 4.7 ⊳ **Global road vehicle fleet by powertrain and vehicle type in the STEPS, 2024-2050**



The global EV fleet expands more than sixfold by 2035, which avoids oil demand of over 10 mb/d that year

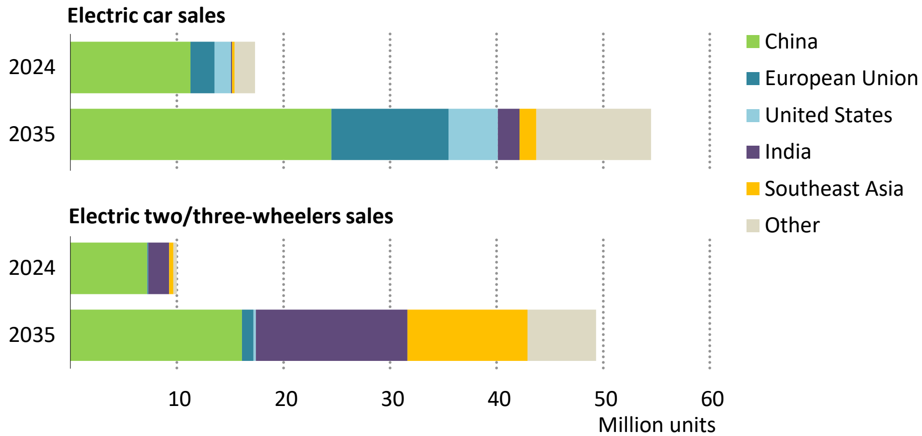
Notes: mb/d = million barrels per day; ICE = internal combustion engine. Light-duty vehicles include passenger cars and light commercial vehicles. Heavy trucks include both medium- and heavy-freight trucks. Other vehicles include buses and two/three-wheelers. Gasoline and diesel ICE vehicles are fuelled by gasoline, diesel, biofuels or synthetic fuels, and include hybrid internal combustion vehicles. Zero-emissions vehicles include both electric and fuel cell vehicles.

These technology trends, supported by fuel economy standards and zero emissions vehicle mandates, are increasing the uptake of EVs (Figure 4.7). In the STEPS, the peak year for internal combustion engine (ICE) car sales was in 2017, even though the global car fleet goes from 1.4 billion today to over 1.6 billion by 2035. By 2050, half of the global light-duty vehicle fleet is electric. Sales of electric two/three-wheelers and buses rise to 80% and 45% respectively of total sales by 2050. Electric two/three-wheelers are the most affordable entry point to electric mobility and require less power to operate: they are especially popular in China, India and Southeast Asia (Figure 4.8). Electric urban buses help to improve air quality and are being widely adopted: in 2024, nearly all new city buses in China and almost half in the European Union were electric.

Electrification is also reaching vehicle types that traditionally have been challenging to progress beyond oil use. In the STEPS by 2050, nearly 25% of the global heavy truck[3] fleet is electrified, a total of around 25 million vehicles. This growth is led by China, European Union, Japan, Korea and United Kingdom. In China, electric heavy trucks are already becoming cost competitive thanks to low electricity prices and policy support.

[3] Heavy trucks include both medium freight trucks (gross weight 3.5 to 15 tonnes) and heavy-freight trucks (gross weight >15 tonnes).

Figure 4.8 ▷ EV sales by vehicle type in selected regions in the STEPS, 2024 and 2035



China and European Union lead in the tripling of global electric car sales by 2035, while electric two/three-wheelers see a sixfold sales increase in developing economies

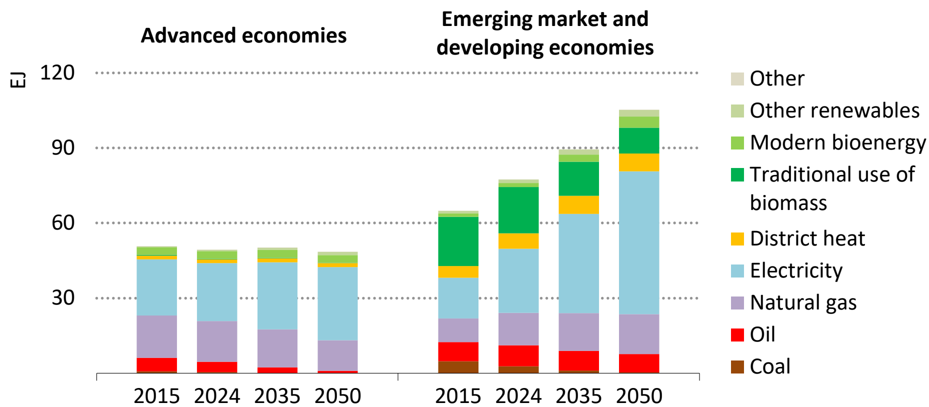
Sources: Historical numbers for electric car sales are based on ACEA (2025); European Commission (2025); EV Volumes (2025); Marklines (2025).

EV sales expansion has major implications for battery demand. By 2035, global EV sales battery demand rises to over 5 terawatt-hours (TWh), five-times the level of demand in 2024. Announced battery production capacity appears sufficient to meet this rapidly growing demand. China dominates both battery demand and manufacturing capacity. Battery demand for electric cars alone in China is already larger than the total battery demand of advanced economies, including battery storage, yet the share of advanced economies in total EV battery demand increases slightly in the long run in the STEPS.

4.3.2 Buildings

Global energy demand in the buildings sector rises in the STEPS at an average of 0.9% per year to 2035, a slower rate than the past decade annual average of about 1.0%. Annual coal and oil demand in buildings declined in the last decade, and it falls by a further 9% per year for coal and 2% per year for oil through to 2035 (Figure 4.9). Natural gas use increased at about the same rate as total energy demand in buildings over the last decade: in the STEPS, it increases at a slower rate in the short term, flattens out at around 870 bcm at the end of the decade, then shifts to a structural decline to 2050. This decline in natural gas demand is primarily in advanced economies, where heating demand is curbed by the electrification of space heating and efficiency improvements. In emerging market and developing economies, natural gas use continues to grow, particularly for cooking and water heating in countries such as Brazil, India and Indonesia, where economic growth boosts incomes and policies aim to expand gas distribution networks. By 2035, more than 700 million people gain access to clean cooking technologies, increasing the global access rate to over 80%. As a result, the traditional use of biomass declines by over a quarter by 2035.

Figure 4.9 ⊳ Energy demand in buildings by region and fuel in the STEPS, 2015-2050



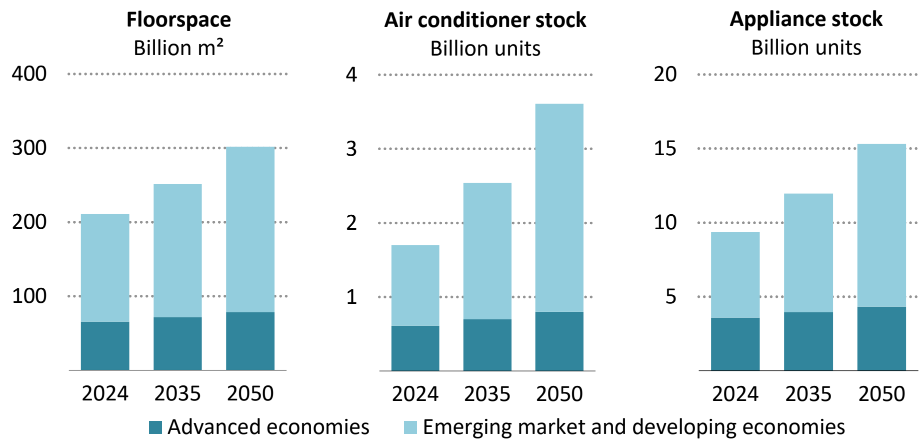
Electricity use in buildings increases significantly in all economies; fossil fuel use declines in advanced economies

Notes: EJ = exajoule; Other = non-renewable waste and hydrogen; Other renewables = solar thermal and geothermal. Buildings sector includes energy consumption for data centres and desalination.

Electricity use expands more than three-times faster than total building sector energy consumption. Electricity demand growth in buildings increases from an annual average of 2.6% over the past decade to 2.8% per year to 2035. Demand growth is particularly strong in emerging market and developing economies, where it rises by over 4% each year, reflecting *inter alia* a 25% increase in residential floorspace and a 70% increase in air conditioner ownership. Emerging market and developing economies account for 90% of the global ownership expansion of air conditioners, and their space cooling demand increases by more than 1 100 TWh in the period to 2035 in the STEPS, which is equivalent to current electricity use in the Middle East (Figure 4.10). In advanced economies, electricity demand grows on average by 1.3% per year to 2035, driven by the electrification of space heating, growth in appliance ownership, demand for information technology services, and the development of AI. Data centres account for half of buildings sector electricity demand growth to 2035 in advanced economies: in the United States, where data centre expansion is primarily concentrated, that share rises to 70%.

Global heat pump sales rose by 27% from 2020 to 2024. After a sharp increase in 2022, global sales declined in 2023 before stabilising in 2024. This was despite a drop in European sales in 2024, where the market contracted for two consecutive years following an unprecedented boom in sales during the 2022 energy crisis and its immediate aftermath. There are now signs of renewed growth: we estimate that global sales increased by about 5% in the first-half of 2025 compared with the same period in 2024.

Figure 4.10 ▻ Key residential energy demand drivers by economic grouping in the STEPS, 2024-2035



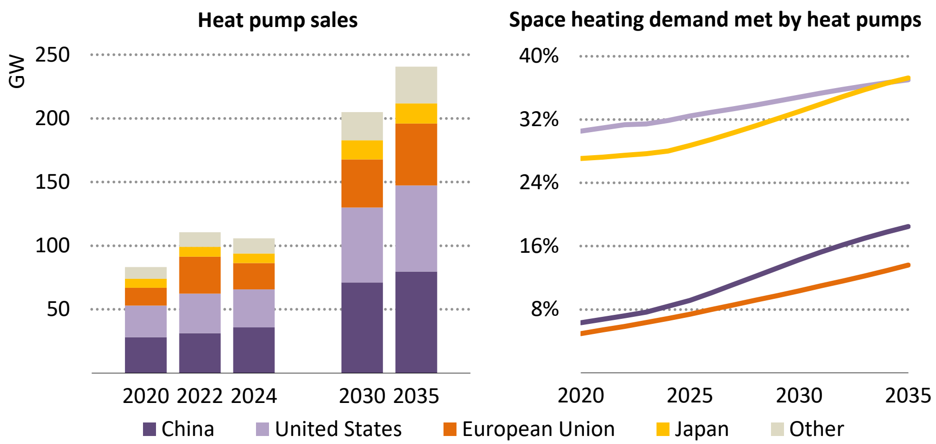
Over the next ten years, residential floorspace expands by 20% and the number of air conditioners units by 50%, mostly in emerging market and developing economies

Notes: m^2 = square metre. Air conditioners of varied sizes are converted to an equivalent number of room air conditioning units. Appliances include among others washing machines, dishwashers, dryers, refrigerators, televisions and computers.

In the STEPS, heat pump sales are supported both by their economic competitiveness and by continued regulatory support and financial incentives. In the United States and China, air-to-air units account for most heat pump sales and represent a cost competitive option for both space cooling and heating. In the Nordic countries, heat pumps are the most common choice for households, often thanks to low electricity prices. Elsewhere, continued regulatory support and financial incentives will be important, notably in the parts of the European Union with low cooling needs for air-to-water heat pumps. Although Japan is already a mature market for heat pumps, their use expands as more building owners opt to use a reverse cycle heat pump as their primary heating/cooling equipment. Subsidies for domestic heat pump water heaters further support growth in the outlook.

By 2035 in the STEPS, heat pumps meet almost 40% of space heating demand in Japan and the United States, while the share of space heating provided by heat pumps doubles in the European Union and China (Figure 4.11). Globally, heat pumps displace around 40 bcm of gas in 2035 relative to today, and reduce the energy intensity of heating by up to 8% in major heating markets. Despite the positive outlook in the STEPS, heat pump sales remain sensitive to consumer confidence and policy stability, as well as economic factors such as the electricity to natural gas price ratio. Failure to provide stable supportive frameworks would hinder the uptake of heat pump technologies.

Figure 4.11 ▷ Global heat pump sales and contribution to space heating demand in selected regions in the STEPS, 2020-2035



IEA. CC BY 4.0.

Heat pump sales double by 2030 with strong growth in four major markets, and meet an increasing share of space heating demand

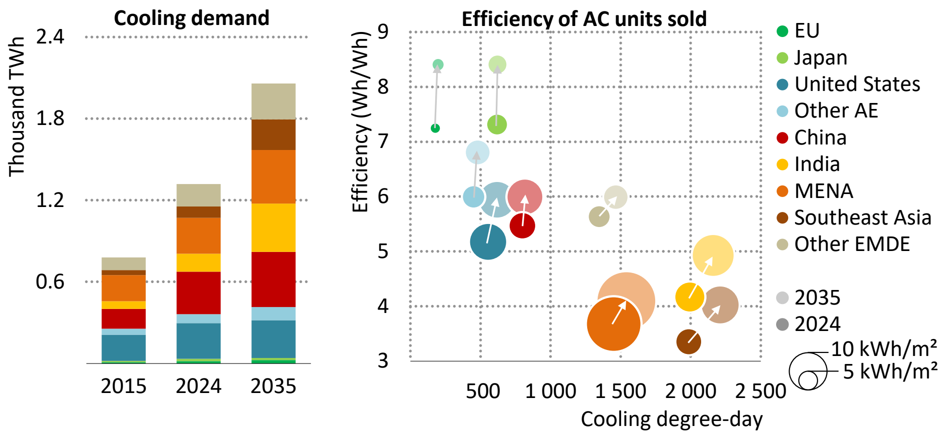
Note: GW = gigawatt.

Meeting mounting cooling needs with more efficient air conditioners

Space cooling has been one of the fastest growing energy end-uses in the buildings sector over the past decade, increasing by around 4% per year, second only to data centres. With rising incomes, population growth and a warming climate, this trend continues in the STEPS, resulting in an increase of 740 TWh in residential cooling demand by 2035 (Figure 4.12). The global distribution of cooling demand shifts significantly towards emerging market and developing economies, which account for 80% of residential cooling demand in 2035. Demand per capita increases by just over 10% in advanced economies, compared to almost 60% in emerging market and developing economies. This is primarily due to climatic differences, higher current levels of air conditioner ownership in advanced economies, and the higher efficiency of cooling systems sold in advanced economies reflective of stronger minimum energy performance standards (MEPS) for air conditioners.

Over the past two decades, MEPS for air conditioners have been instituted in nearly all major cooling markets. However, the stringency of the standards varies significantly across markets. In general, the countries with the highest projected growth in cooling demand are also the ones where the least-efficient air conditioners are being sold today. If all countries with established MEPS for air conditioners were to raise their standards to match those in Japan, global cooling demand would be 25% lower in 2035 than the 2 100 TWh projected in the STEPS.

Figure 4.12 ⊳ Residential cooling demand and air conditioner efficiency by region in the STEPS to 2035



Global space cooling demand swells 60% by 2035, driven by regions with high cooling needs and less efficient air conditioners

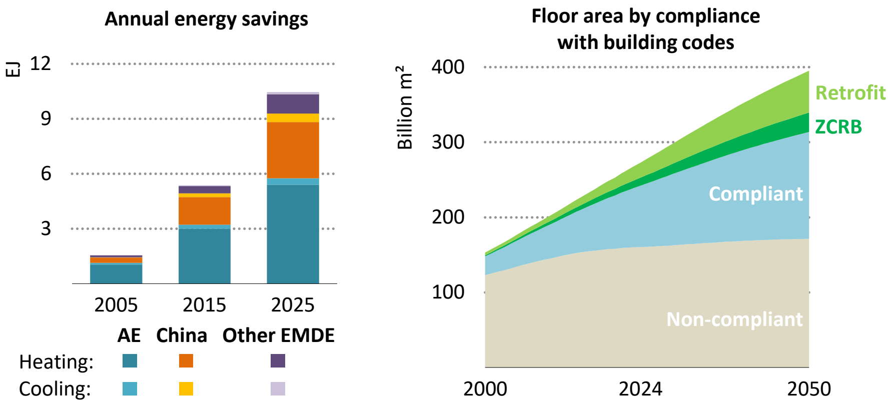
Notes: AC = air conditioning; TWh = terawatt-hours; Wh = watt-hour; EU = European Union; AE = advanced economies; MENA = Middle East and North Africa; EMDE = emerging market and developing economies. Bubble size reflects the average cooling consumption per square metre in the region. Air conditioner efficiencies reflect operation under local climate conditions.

Box 4.2 ⊳ Floorspace doubles but building codes restrain demand growth

Floorspace in buildings worldwide has increased from 150 billion square metres (m^2) in 2000 to 270 billion m^2 in 2024. Continuing urbanisation and economic development mean that it is set to reach 300 billion m^2 by 2030. The number of countries with mandatory energy-related building energy codes was 25 in 2000 and extended to 85 in 2025. Current energy-related building codes save around 10 EJ annually compared to a baseline without codes, primarily by reducing heating demand in advanced economies and China (Figure 4.13).

In some emerging market and developing economies where cooling needs are significant, the estimated energy savings linked to building codes are limited by enforcement and compliance challenges. In Central and South American countries with mandatory building codes, for example, less than half of all new construction meets energy performance standards. An assessment of compliance and enforcement policies in 29 emerging market and developing economies shows that only 11 countries have implemented the steps necessary to enforce building codes (World Bank, 2025). Reflecting these shortcomings, the stock of non-compliant floorspace stays steady between 2024 and 2050 in the STEPS, even though building codes having been established in all of the largest construction markets. In the coming decades, building codes nevertheless play a growing role to restrain additional energy demand for cooling.

Figure 4.13 ▹ Achieved energy savings from building codes and floor area by building code compliance in the STEPS to 2050



Building codes save the equivalent of China's space heating demand each year, yet the stock of non-compliant floorspace stays steady due to enforcement challenges

Note: EJ = exajoule; AE = advanced economies; EMDE = emerging market and developing economies; ZCRB = zero-carbon ready building.

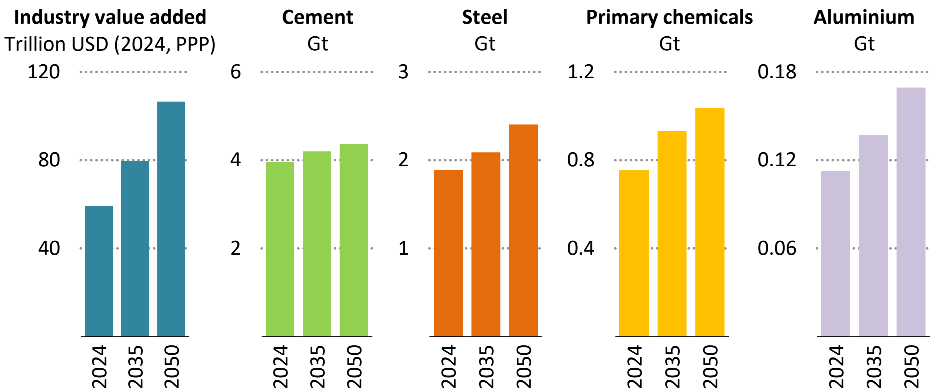
4.3.3 Industry

In the STEPS, energy demand in the industry sector increases by an average 1.2% per year to 2035 as a shift takes place from relatively energy-intensive industries[4] to higher value-added manufacturing. This rate marks a slowdown compared with the last decade, during which energy demand in industry was up by an average of 1.5% per year and contributed 40% to the overall increase in global total final consumption.

Today, non-energy-intensive industries account for less than a third of industrial energy demand and generate around two-thirds of industrial value added. In the STEPS, those industries increase production rapidly and are responsible for over half of energy demand growth to 2035. Energy-intensive industries experience less rapid increases. Steel and cement production rise by 1% and 0.6% respectively per year to 2035 (Figure 4.14), reflecting weaker domestic demand in China and advanced economies, while primary chemicals production, e.g. ammonia, methanol and high-value chemicals, and aluminium production both increase by around 2% per year as they substitute for other materials and respond to new demands, including those arising from the production of solar photovoltaic (PV) panels and EVs.

[4] Energy-intensive industries include iron and steel, non-metallic minerals, chemicals, non-ferrous metals, and paper, pulp and printing.

Figure 4.14 ⊳ Industry value added and production by sub-sector in the STEPS, 2024-2050



Chemicals and aluminium production are the main drivers of energy-intensive industry growth, while light industries see the fastest growth and boost industry value added

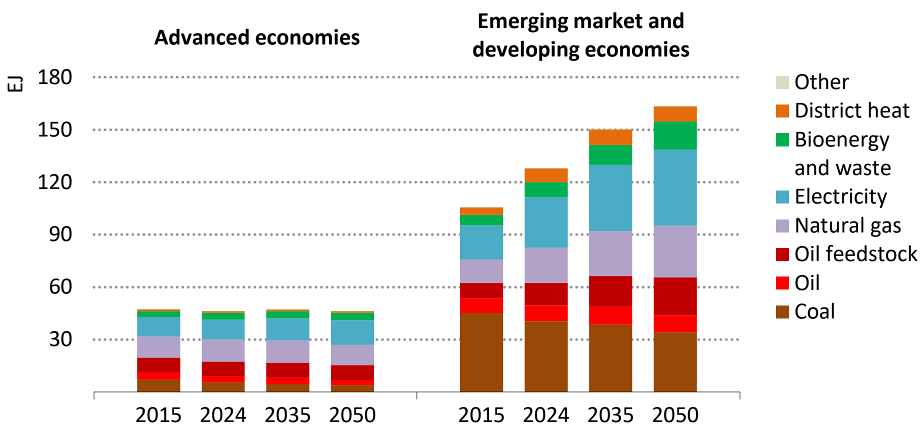
Note: PPP = purchasing power parity; Gt = gigatonnes.

Growth in industrial production is largely concentrated in emerging market and developing economies, where energy consumption in industry is almost three-times higher than in advanced economies. In large part, this reflects China's role as a global industrial centre, robust manufacturing industries in India and Southeast Asia, and the petrochemical industry in the Middle East. By 2035, almost all energy consumption growth takes place in emerging market and developing economies, with China accounting for around one-quarter of the total (Figure 4.15). In advanced economies, despite economic recovery and policy measures that support domestic production, energy consumption in industry does not increase significantly, with efficiency gains almost outweighing limited expansion of growth in industrial production.

Coal demand in industry falls 6%, primarily due to slow growth and substitutions in coal-intensive sub-sectors, mainly steel and cement. Scrap use for steel production increases with policy support, and new plants capitalise on higher scrap availability. New plants to produce iron often use natural gas instead of coal-fired blast furnaces, which cuts their share in iron production from 90% today to 84% in 2035 in the STEPS. The share of energy-intensive clinker used for the production of cement falls from 0.72 today to 0.71 in 2035 as clinker is partially substituted by other materials. Meanwhile, cement production shifts from China to other emerging market and developing economies where the average share of coal in the production process is around 40%, well below the 70% share in China.

Industry sector energy demand for all fuels except coal expands until 2035. Non-energy-intensive industries and chemicals drive growth in electricity demand, which rises at an annual average of 2.1% to 2035, outpacing the growth in demand for other fuels. Natural gas demand increases by an average 1.4% per year to almost 1 100 bcm by 2035, continuing its trend both in markets with domestic resources, e.g. Middle East and United States, and in importing regions such as China, India and Southeast Asia. Despite increases in the United States, natural gas demand in industry peaks in advanced economies by 2030, mostly due to the expanding electrification of industry in the European Union as part of measures like the Clean Industrial Deal. Oil demand in industry rises by around 1.6% per year to 24 mb/d by 2035, with almost 90% of the increase reflecting increased demand for plastics, even though the recycling collection rate is up from 19% in 2024 to 24% in 2035.

Figure 4.15 ▷ Energy demand in industry by economic grouping and fuel in the STEPS, 2015-2050



Emerging market and developing economies drive industrial energy demand growth; electrification in industry increases in virtually all economies

Notes: EJ = exajoule. Other includes geothermal, solar thermal, hydrogen and hydrogen-based fuels. 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 total final consumption, not the hydrogen output.

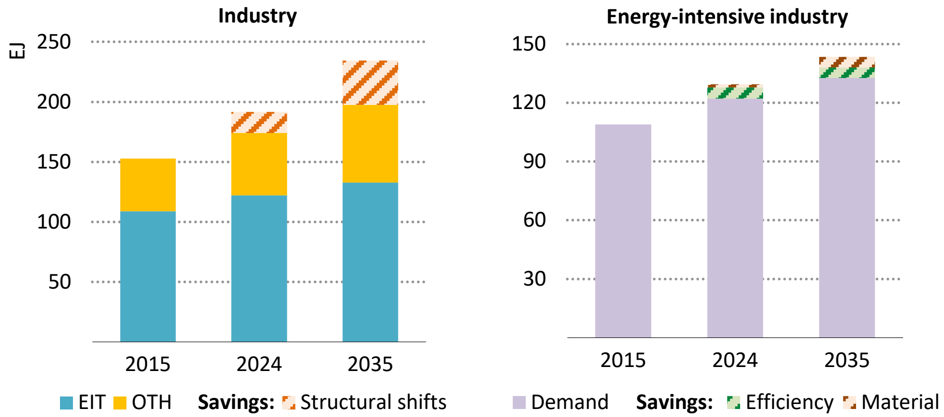
Structural shifts, improved material use and technical energy efficiency temper energy demand growth in industry

Although demand for industrial products continues to increase, the associated energy demand grows more slowly in the STEPS than it has over the last decade. Industrial intensity – measured as the energy per unit of value added by industry – improves at a rate of 1.6% per year until 2035, faster than the average rate of 1.1% since 2015 and notably faster than the rate since 2021 of 0.8%. Three key factors are at play.

- **Structural shifts** occur from energy-intensive to non-energy-intensive industries, which need less energy to add value to the economy. One unit of energy consumed by non-energy-intensive industries adds an average of almost ten-times as much monetary value as one consumed by energy-intensive industries. This structural shift has been underway since 2014, led by China (see Chapter 3, Box 3.1). If the global proportion of energy-intensive industries in industrial value added and their structure remained static from today to 2035, energy demand in industry would be about 37 EJ (19%) higher than in the STEPS (Figure 4.16).

- **Technical efficiency** improvements are driven both by policies – such as MEPS for motors, energy audits and funding support – and by cost-effective technological improvements. Over-capacity in some sectors and regions drives competition and stimulates improvements, while new plant additions are more efficient than existing facilities. Taken together, technical efficiency measures avoid about 5 EJ of energy demand in industry in 2035.
- **More efficient use of input materials** reduces energy-intensive industry demand. In steel, electric arc furnaces use up to ten-times less energy than production in the blast furnaces that currently dominate production (IEA, 2020), with the exact savings dependent on the share of recycled scrap used. Clinker substitution cuts thermal energy demand in the production of cement, reducing energy demand per tonne by a factor of eight compared to conventional production. Improvements in material efficiency accelerate compared to historic rates, supported by policies in China and India for steel scrap use, targets for plastic recycling, and the availability of more materials reaching the end of their lifetime and being available for recycling. In the absence of these improvements, energy demand in 2035 would be around 5 EJ higher than in the STEPS.

Figure 4.16 ▷ Avoided energy demand from efficiency improvements in industry in the STEPS to 2035



Structural shifts reduce energy demand by 19%; improved technical efficiency and material savings temper growth in energy-intensive industry more than in the past

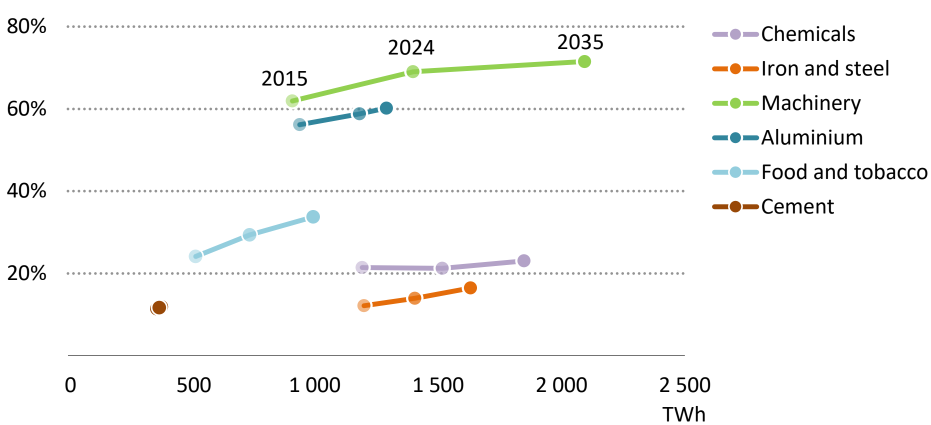
Notes: EIT = energy-intensive industry; OTH = other industry. Savings in 2024 and 2035 are calculated using the baselines of 2015 and 2024 respectively. Savings from structural shifts assume no change in the distribution of value added between energy-intensive and other industry. Material savings come from lower clinker ratios, increased scrap use and plastics recycling.

What is driving the Age of Electricity in the industry sector?

As in other end-use sectors, electricity demand growth in the industry sector is contributing to the Age of Electricity. The industry sector adds around 260 TWh per year to its current demand for electricity through to 2035, which is roughly as much as electricity demand today in Spain. Some of this growth in demand, nearly 15%, reflects the use of new electric technologies in industry, but most of it, around 85%, stems from activity growth and structural shifts to non-energy-intensive industries. These industries use a higher share of mechanical energy and require thermal energy at lower temperatures, making them easier to electrify, and they account for three-quarters, 2 100 TWh, of industry electricity demand growth by 2035.

In the machinery sub-sector, much of the increase in electricity demand reflects higher production rather than more electrification. Machinery has the highest share of electrification and the highest demand growth of all industry sub-sectors, with electricity demand increasing 50% by 2035 while the share of electrification only increases by two percentage points (Figure 4.17). However, there is scope for further electrification even in the machinery sub-sector: while its electrification rates are already over 70% in China, Japan and Korea, they are lower elsewhere, including in Europe at 55% and the United States at 60%.

Figure 4.17 ▷ Electricity demand and share of electrification for selected industrial sub-sectors in the STEPS, 2015-2035



Electricity demand growth is driven by activity growth in most sub-sectors, and by structural shifts towards non-energy-intensive sectors amenable to electrification

Measures to improve the use of materials tend to replace thermal energy demand with electrical alternatives, e.g. mechanical recycling for plastics instead of steam crackers; arc furnaces for steel scrap instead of blast furnaces, which have significant impact in some regions. In India, electricity use in the chemicals sub-sector more than doubles by 2035, while its total energy demand increases by less than 50%. In China, the share of electricity in the steel sub-sector increases by five percentage points. As conventional energy-intensive routes remain dominant, the global effect of these shifts is limited, but it increases the share of electricity in steel production by three percentage points by 2035 in the STEPS.

Policies to support industry electrification also have an impact, such as the EU Clean Industrial Deal (see Chapter 8, Section 8.4), carbon contracts-for-difference in various countries, and support for industrial heat pumps in China. The share of electricity in non-energy-intensive industries increases by four percentage points in the European Union and seven percentage points in China by 2035. However, electricity demand growth has implications for infrastructure, with factories requiring new grid access or increased connection capacity, and for the provision of flexibility to unlock the opportunities from electrification.

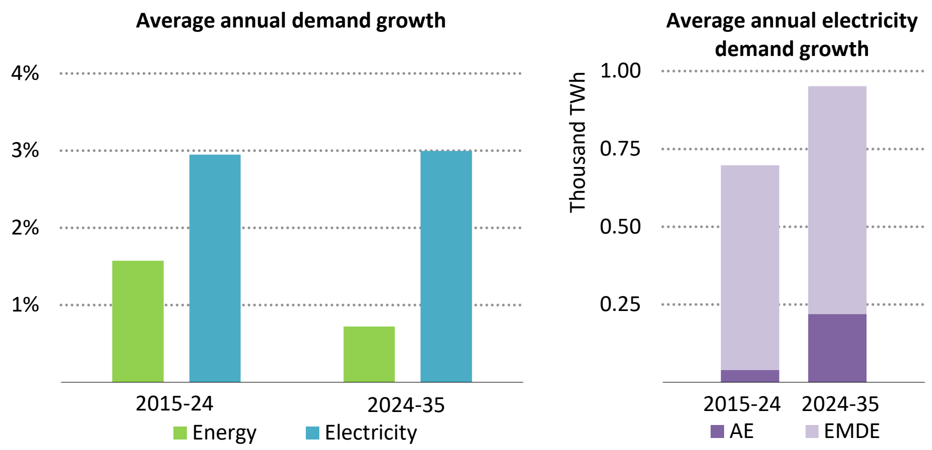
4

4.4 Electricity

4.4.1 Demand

Global electricity demand increased by close to 3% annually in recent years, and this rose to over 4% in 2024. China has been the dominant driver of growth in electricity demand, accounting for nearly two-thirds of the increase since 2015. Other regions, including India, the Middle East, and parts of Southeast Asia, have seen demand rise sharply, reflecting both rising economic activity and structural shifts towards increased electrification.

Figure 4.18 ▷ Global energy and electricity demand growth rates and electricity demand growth by region in the STEPS, 2024-2035



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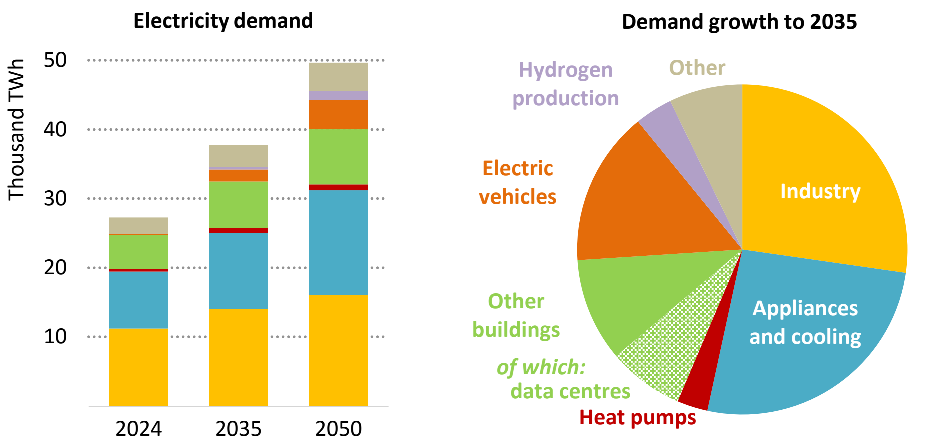
Electricity demand growth is outpacing overall energy demand growth and is rising fastest in emerging market and developing economies

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

The annual growth in electricity demand of close to 3% per year over the last decade is nearly twice the rate of growth for total energy demand (Figure 4.18). Between 2024 and 2035, global demand for electricity is projected to increase at over four-times the rate of total energy demand in the STEPS. In some advanced economies, such as the European Union and Japan, electricity demand has declined in recent years, though this trend is expected to reverse in the *Outlook* period.

Emerging market and developing economies account for around three-quarters of the additional global electricity demand by 2035 in the STEPS. China alone is responsible for 40% of this growth, maintaining its position as the world's largest electricity consumer. India also sees demand rise rapidly, with electricity demand reaching around 5 000 TWh by 2050 on the back of sustained growth of over 4% per year between 2024 and 2050 in the STEPS.

Figure 4.19 ▷ Electricity demand by end-use, 2024-2050, and demand growth by end-use in the STEPS to 2035



Electricity demand increases by nearly 1 000 TWh each year, mostly driven by industry, appliances, cooling and EVs

Notes: TWh = terawatt-hours. Other buildings include electric space and water heating excluding heat pumps, lighting, cooking, desalination and data centres. Other includes agriculture, non-road transport and other energy sector excluding hydrogen production.

One of the main reasons behind the strong rise in electricity demand in emerging market and developing economies is their relatively low level of electricity consumption per capita. Today, electricity demand per capita averages around 2 600 kilowatt-hours (kWh) per year in emerging market and developing economies, which is approximately three-times less than the average in advanced economies. However, this gap is gradually narrowing: by 2035, electricity demand per capita in emerging market and developing economies is projected to be 2.5-times lower than in advanced economies. This narrowing of the gap reflects a number of changes in emerging market and developing economies, including rising income levels, more access to electricity, increasing use of electric appliances, and the continuing electrification of the industry and transport sectors.

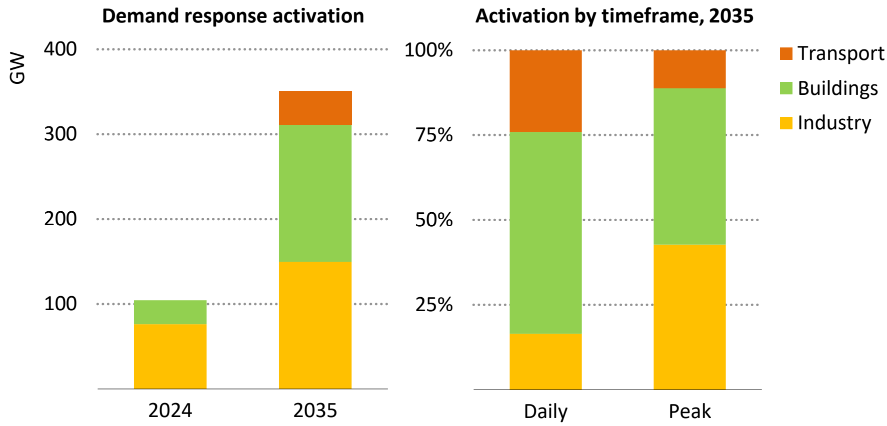
Global electricity demand increases by nearly 1 000 TWh per year through to 2035 – equivalent to adding the electricity demand of all advanced economies combined over the next decade (Figure 4.19). This surge reflects rising demand for appliances and cooling systems, rising levels of production in the electrified industrial sector, and the accelerating pace of electrification in the transport sector. Industrial electricity use remains a major driver, accounting for roughly 30% of the growth, closely followed by rising demand from appliances and cooling. In addition, the scaling-up of hydrogen production via electrolysis adds around 400 TWh to the total by 2035, equal to around 1.5% of current global electricity demand. This scaling-up is driven by various policy instruments: such as grants and quotas in the European Union; auctions in India, Japan and Korea; tax incentives as in Brazil; or contracts-for-differences as in Germany and Japan.

Box 4.3 ▻ Demand response: unlocking flexibility in the Age of Electricity

Electricity demand growth around the world in part is driven by the increasing use of technologies that can consume electricity flexibly, such as EVs and smart air conditioners. With the right regulatory and technical frameworks in place, these assets can provide demand response – the capacity to shift or reduce electricity use during peak periods – and offer valuable flexibility, serving as a fast and cost-effective buffer when supply is tight. Today, we estimate that around 100 gigawatts (GW) of demand response exists globally, primarily in the industrial sector and in countries like the United States with established programmes. Demand response is expanding rapidly in other countries and regions such as the United Kingdom and the European Union where regulation supports participation by the buildings and transport sectors, notably via aggregators and dynamic retail tariffs. In the STEPS, demand response activation, i.e. demand response capacity that is actually used, grows more than threefold by 2035, driven by higher participation from the buildings and transport sectors through smart air conditioners, heat pumps and EVs (Figure 4.20). Data centres can also provide flexibility through thermal storage, workload shifting or backup power, but high capital costs, regulatory constraints, and the need to maintain high information technology reliability limit how much their power use can be adjusted without risking service disruption.

The nature of demand response is also set to evolve. It is mainly activated today during peak demand periods, triggered dynamically by system operators. By 2035, in the STEPS, flexibility is mobilised daily in response to predictable price signals to shift consumption away from evening peaks to cheaper, low-demand periods earlier in the day (Figure 4.20). With the adoption of time-of-use tariffs and smart equipment, this form of routine flexibility, especially from heating, cooling and transport, accounts for most of the energy shifted across the year in the STEPS. However, targeted response remains critical: at peak times, industrial demand response continues to deliver a significant share of the flexible capacity. Together, these layers of flexibility strengthen system resilience and can reduce the need for peaking capacity, as discussed in Chapter 5.

Figure 4.20 ⊳ Demand response activation by sector and contribution to daily and peak activation in the STEPS, 2024 and 2035



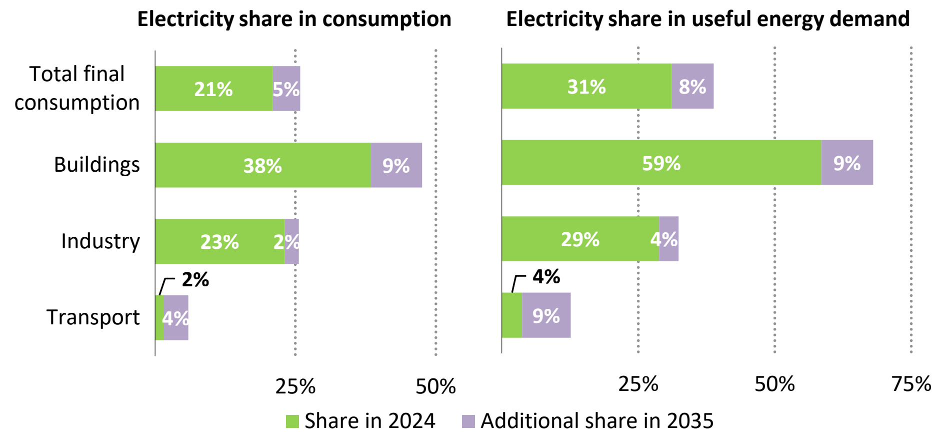
Demand response increases more than threefold by 2035, and all sectors support both daily load shifting and peak management

The drivers of electricity demand vary substantially across countries and regions. In advanced economies, EV adoption is the largest contributor, responsible for over 30% of additional electricity demand by 2035 in the STEPS. Demand from data centres – driven by increases in digitalisation and AI – is the second-largest by 2035, followed by electricity-intensive industries, appliances and air conditioning. In contrast, the buildings sector leads demand growth to 2035 in emerging market and developing economies. Rising levels of ownership of household appliances and increasing demand for cooling are major contributors, together with electrification in industry, notably in China, India and Southeast Asia.

In the STEPS, electricity accounts for over one-quarter of total final consumption by 2035, up from 21% in 2024. Electric technologies are much more efficient than others, for example, electric cars are two-to-four-times more efficient than fossil fuel alternatives, and heat pumps are around three-to-five-times more efficient. This means that contribution of electricity to useful energy delivered to end-users is more substantial than its share of total final consumption would suggest, and in fact it provides approximately 40% of useful energy to end-users by 2035 (Figure 4.21).

Some applications remain difficult or costly to electrify with current mature technologies. In energy-intensive industries, almost two-thirds of all energy use is to produce high-temperature heat above 400 °C, and production processes depend on specific materials, so tailored technologies need to be developed to electrify the processes involved either directly or through the use of electrolytic hydrogen (see Chapter 7, Box 7.5). In the transport sector, limitations in battery energy density make it difficult to electrify aviation and shipping, which together represent around 25% of non-electric transport energy demand in 2035.

Figure 4.21 ▹ Electricity in consumption and in useful energy demand by sector in the STEPS, 2024 and 2035



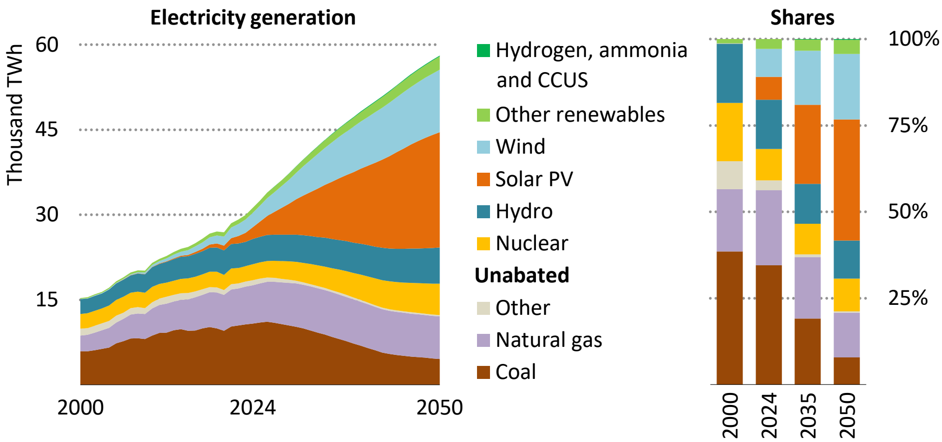
Electricity makes up over a quarter of total final consumption in 2035, but its share of the useful energy delivered to end-users nears 40% thanks to its higher efficiency

4.4.2 Electricity generation

The global electricity mix continues its structural transformation in the STEPS, albeit at a pace largely consistent with recent trends. In this scenario, policy targets are assumed to be extended and modestly scaled up beyond their current timelines, while carbon pricing sees significant but measured increases. Continued efforts to deploy energy storage, reform power markets and streamline permitting processes support steady growth in solar PV and wind power deployment in most regions. Over the past five years, annual capacity additions of solar PV and wind have increased by around 25% per year, and the markets for these technologies expand in the STEPS by another 25% to 2035, with annual capacity additions of around 820 GW. The expansion of solar PV and wind power in the STEPS is underpinned by the continued presence of supportive policy frameworks, improvements in power system operations, investment to modernise and expand grids, and more use of distributed energy resources to help reduce curtailment and enhance grid flexibility.

In the STEPS, global coal-fired power generation continues to expand in the near term, remaining the largest source of electricity until the early 2030s (Figure 4.22). It then begins a steady decline which reflects the commitment that more than 55 countries have made to phase out its unabated use. By 2035, coal-fired generation is around 20% below today's level, and is no longer the dominant source of electricity. By 2050, it falls to nearly 60% below its current level, though it remains a significant part of the mix in many emerging market and developing economies. Natural gas maintains a central role in the electricity generation mix: its use increases by over 15% to 2035 before gradually decreasing, and it continues to provide critical system flexibility and backup capacity. Oil-fired generation declines steadily as countries, including those in the Middle East, transition to alternative sources. Nuclear power experiences a notable resurgence, with output rising by nearly 40% by 2035 and by a further 40% by 2050, supported by policy commitments in more than 40 countries.

Figure 4.22 ▷ Global electricity generation by source in the STEPS to 2050



Expansion of solar PV, wind and nuclear curb coal-fired power and reshape the global electricity generation mix

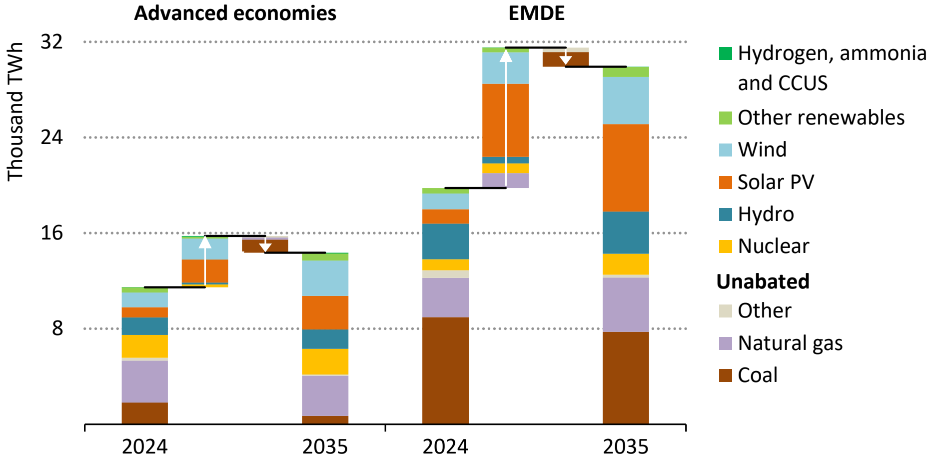
Note: TWh = terawatt-hours; CCUS = carbon capture, utilisation and storage. Other renewables include bioenergy and renewable waste, concentrating solar power, geothermal and marine. Other includes oil, non-renewable waste and other sources.

As a result of these trends, the global electricity generation mix undergoes a major transformation in the STEPS. The share of fossil fuels declines rapidly from 60% in 2024 to less than 40% by 2035 and just 20% by 2050, and the share of low-emissions sources rises sharply. Renewables, which currently account for about one-third of global electricity generation, expand to deliver over half by 2035 and more than two-thirds by 2050. Solar PV and wind are the main contributors, with their combined share of generation increasing from 15% today to 40% in 2035 and 55% in 2050. Nuclear power maintains a share of just under 10% throughout the period.

In advanced economies, low-emissions power generation rises 50% faster than electricity demand to 2035, with wind and solar PV outpacing total demand growth on their own

(Figure 4.23). While fossil fuel generation declines significantly – coal use falls 60% by 2035 and natural gas use by 5% – natural gas remains the single largest electricity source through to 2035. Nuclear energy meets almost 10% of demand growth to 2035, with its role expanding as a result of uprates at existing reactors, new construction and reactor restarts, particularly in the United States, France and Japan.

Figure 4.23 ▷ Electricity generation by economic grouping and source in the STEPS, 2024-2035



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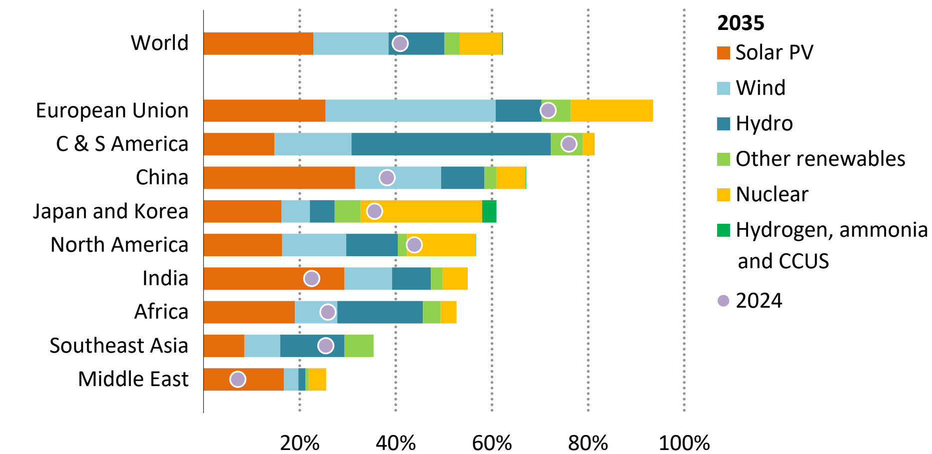
Solar PV and wind meet the bulk of electricity demand growth to 2035 in the STEPS; natural gas, nuclear and hydropower also contribute

Notes: EMDE = emerging market and developing economies; CCUS = carbon capture, utilisation and storage. Other renewables include bioenergy and renewable waste, concentrating solar power, geothermal and marine. Other includes oil, non-renewable waste and other sources.

In emerging market and developing economies, electricity demand increases by 50% through to 2035 in the STEPS, but low-emissions sources expand faster, increasing by over 10 500 TWh between 2024 and 2035. China alone accounts for two-thirds of this increase: the rapid growth in its low-emissions generation keeps pace with its rising electricity needs. Solar PV meets 60% of demand growth in emerging market and developing economies. Wind, hydropower and nuclear also contribute, with nuclear generation in emerging market and developing economies doubling by 2035. Gas-fired power also increases significantly, and coal remains the largest source of electricity across emerging market and developing economies in 2035, although it declines over the period.

In the STEPS, the global share of low-emissions electricity rises from 40% in 2024 to over 60% by 2035, driven by supportive policies, maturing supply chains and improving cost competitiveness (Box 4.4). By 2024, 143 countries had established targets to promote expansion of renewable electricity (REN21, 2025), which sets the background for policy support. Most regions see the share of low-emissions sources in electricity rise to over 50% by 2035, with notable exceptions in Southeast Asia and the Middle East, though both regions make substantial progress (Figure 4.24). The European Union sees large contributions from nuclear, wind and solar PV, while Central and South America benefits as the region with the world's highest share of hydropower. The most significant gains in low-emissions shares – over 25 percentage points – are in Australia, India, China, Africa, Japan and Korea.

Figure 4.24 ⊳ Share of low-emissions sources in electricity generation by region in the STEPS, 2024 and 2035



Low-emissions sources take a larger share of the electricity mix in all regions with renewables leading the way underpinned by low costs and widespread policy support

Notes: C & S America = Central and South America. CCUS = carbon capture, utilisation and storage. Other renewables include bioenergy and renewable waste, concentrating solar power, geothermal and marine.

Solar PV expands rapidly in most markets, supplying one-quarter or more of total electricity generation in Australia, China, India and the European Union in 2035, and making swift progress in Africa and the Middle East. Both onshore and offshore wind also expand rapidly, notably in Europe. Hydropower continues to play a central role in Central and South America, Africa and Southeast Asia, though the output from many individual projects is expected to decline as average temperatures increase. Geothermal energy remains a small part of the electricity mix to 2035, though innovation is expanding its potential (IEA, 2024). Meanwhile, low-emissions hydrogen and ammonia begin to gain traction in power generation in the form of hydrogen blended with natural gas and ammonia co-fired with coal particularly in Japan and Korea.

Nuclear power is experiencing a resurgence, with over 40 countries now pursuing policies to expand its role in the electricity generation mix. Investment is rising, 2025 is set to mark a record year for global nuclear power generation, and innovation in small modular reactors is generating renewed optimism. This momentum follows a challenging period marked by delays and cost over-runs in several high-profile projects in Europe and the United States. Globally, nuclear power output doubles to 2050 in the STEPS, maintaining a stable 9% share of electricity generation but falling well short of global initiatives to triple capacity. In the European Union, share of nuclear generation dropped from one-third in the late 1990s to 23% in 2024, and is projected to fall to 17% by 2035. The United States sees steady nuclear output to 2030, followed by strong growth that boosts its share from 18% today to over 20% in the long term. The nuclear share in the generation mix is also rising in Japan, Korea, India, Africa, Russia, Middle East and Brazil. In China, the nuclear share also edges up, outpacing soaring electricity demand, as the size of the nuclear fleet becomes the largest in the world in the early 2030s and it accounts of nearly half of global nuclear expansion to 2050.

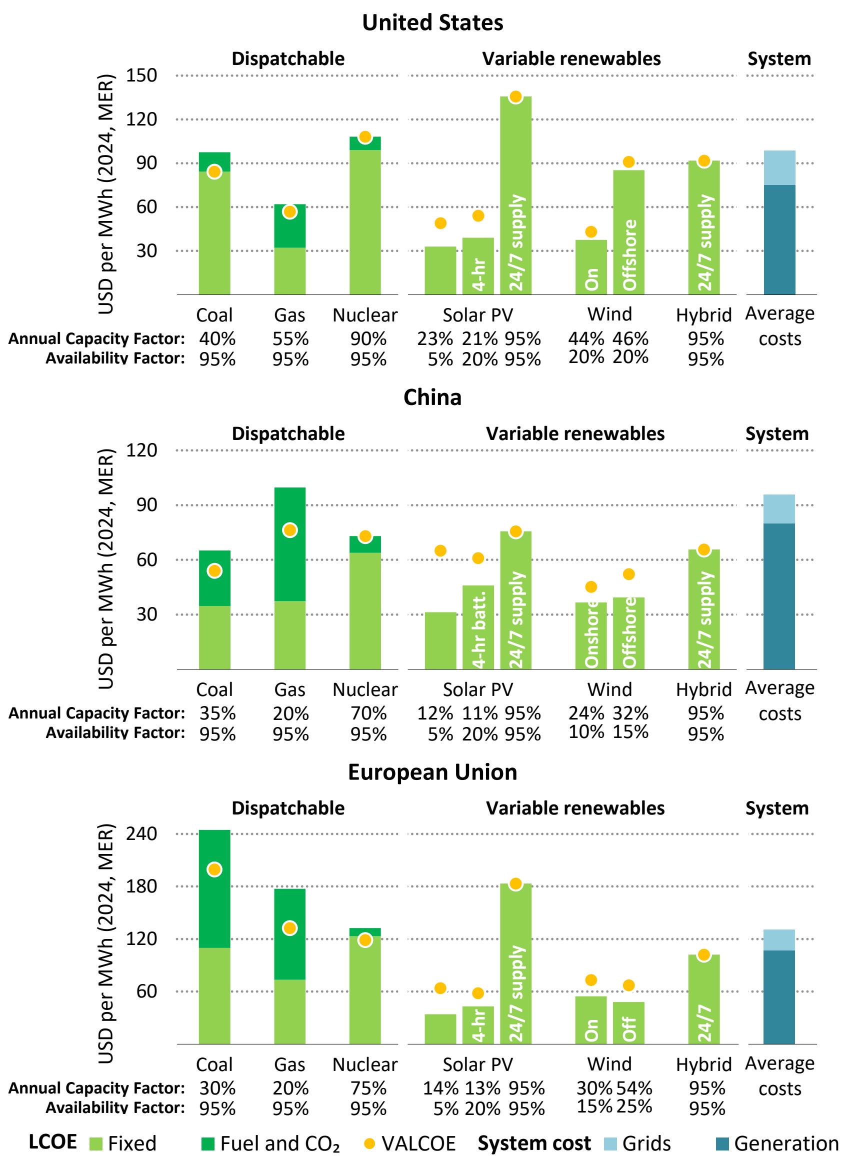
Box 4.4 ⊳ Competitiveness of solar PV, wind and battery storage

Since 2010, the levelised cost of electricity (LCOE) has declined by 90% for solar PV, 70% for wind generation and 90% for batteries, driven down by innovation, manufacturing gains and improved performance. Costs are projected to decline further by about 40% for solar PV, 30% for batteries and about 10% for onshore wind from 2024 to 2035.

In the STEPS, projected LCOEs for 2035 show that new solar PV, onshore and offshore wind have similar or lower average generation costs than new coal, gas and nuclear in the United States, European Union and China. However, assessing the competitiveness of power technologies requires looking beyond LCOE to the value these technologies provide to power systems. While LCOE captures all technology costs, i.e. construction, operation and maintenance, fuel and CO_2 emissions (where they have a price), it does not reflect when electricity is produced, its contribution to system adequacy and stability, or its ability to provide flexibility. The value-adjusted levelised cost of electricity (VALCOE), developed for and used in the IEA Global Energy and Climate Model accounts for these factors, offering a more complete metric, though it does not assign grid expansion costs to individual technologies and does not include emissions that are not priced in markets (IEA, 2025b). The VALCOE can also be compared to system average generation costs as an indicator of affordability (Figure 4.25).

The increasing competitiveness of solar PV and wind power has played an important part in their rapid expansion in many markets. A full assessment of their competitiveness depends on the value they bring to the system, which is influenced by weather variability and the cannibalisation effect. This effect, in which simultaneous output from many projects puts downward pressure on market prices and, in turn, their market value, is already evident in several markets with more and more hours of negative prices (IEA, 2025c). As a result, by 2035, pairing solar PV with four-hour battery storage, e.g. 20 megawatt (MW)/80 megawatt-hour (MWh) of battery storage paired with 100 MW of solar panels, becomes more competitive than standalone PV in major markets, as the added value of dispatchability outweighs the additional cost.

Figure 4.25 ▷ LCOE and VALCOE of power technologies in selected regions in the STEPS, 2035



Solar PV and wind are competitive with dispatchable sources in major markets in 2035

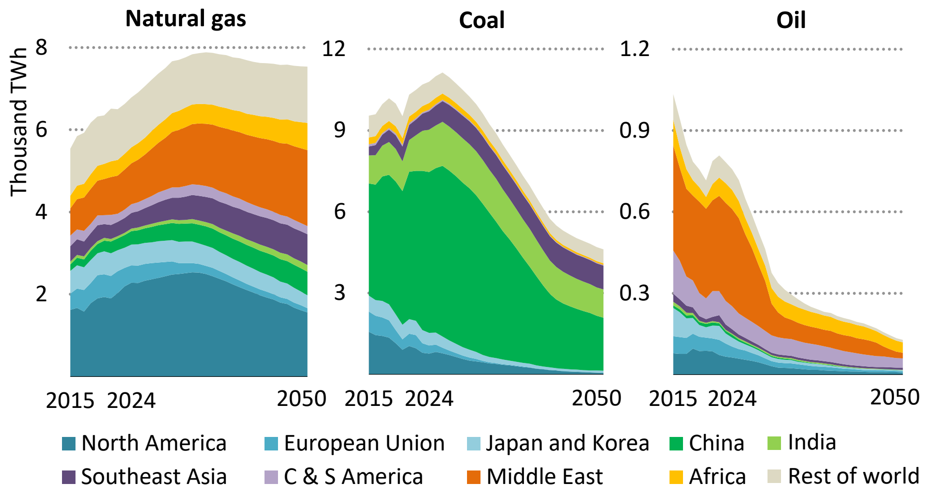
Notes: LCOE = levelised cost of electricity; VALCOE = value-adjusted levelised cost of electricity. MWh = megawatt-hour; MER = market exchange rate. 4-hr refers to battery storage duration. 24/7 refers to the ability to provide power in all hours of the day and all week. Availability factor is the share of nameplate capacity that can be reliably expected to generate electricity during times of peak demand.

It is technically feasible to combine solar PV, wind and battery storage to operate at an average capacity factor of 95% throughout the year, effectively providing power for 24 hours per day, seven days a week (24/7), comparable to what dispatchable sources of electricity can offer. Achieving this level of reliability from solar PV and wind installations requires system oversizing and storage to manage weather variability. For example, to be able to deliver 100 MW firm capacity, a project might include 600 MW of solar PV and 400 MW/1 600 MWh of battery storage behind the same inverter. Despite significant amounts of surplus electricity above 100 MW, (curtailed in this example, but potentially available for other uses if a grid connection is available), such a system could reach a value-adjusted levelised cost of electricity of around USD 75/MWh in China, USD 135/MWh in the United States and USD 180/MWh in the European Union, which is comparable to some dispatchable sources. Including onshore wind in hybrid projects could reduce these costs by 10–45%, making them competitive with coal, gas and nuclear, and similar to average generation costs in 2035. This level of availability and cost would make solar PV plus storage and hybrid projects attractive for the grid, or consumers that require 24/7 electricity, including industrial applications and data centres (IEA, 2025c).

Natural gas-fired power generation shows diverging regional trends (Figure 4.26). In the United States, gas use in the power sector continues to rise in the medium term before entering a gradual long-term decline, while the European Union sees significant reductions in gas-fired generation as it pursues ambitious renewable energy targets and seeks to reduce reliance on imported gas. In contrast, natural gas use continues to rise in emerging market and developing economies, with particularly strong growth in the Middle East, Southeast Asia and Africa, where its plays a key role to meet rising electricity demand.

Coal-fired power is approaching a turning point after decades of growth, with global trends increasingly shaped by developments in Asia. In China – the world's largest coal consumer – the rapid scaling-up of renewables and nuclear leads to coal generation reaching a peak by 2030. India is on a similar path, with rapid renewables deployment putting it on track to see coal use peak around the same time. However, coal-fired generation in Southeast Asia is projected to continue to rise through to 2040. Meanwhile, many other countries are actively phasing out unabated coal-fired power generation. The United Kingdom ended it in 2024. The European Union has made notable progress towards this goal, with Slovakia joining Belgium, Austria, Sweden and Portugal in achieving coal-free electricity generation, while Ireland targets a phase-out by the end of 2025. In Southeast Asia, the updated power plan in Viet Nam targets a full coal-phase out by 2050 through fuel switching to biomass or ammonia, while Indonesia has banned new coal plants not already planned and aims for a full phase-out by mid-century. Transition credit schemes are emerging as a financial tool to support efforts to shift from high-carbon sources, including coal, to low-carbon sources.

Figure 4.26 ▷ Electricity generation by fuel and region in the STEPS, 2015-2050



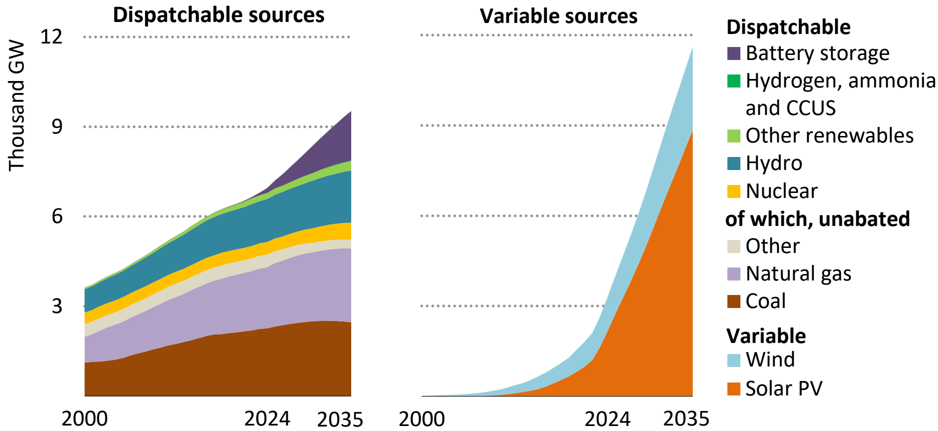
Natural gas remains a leading source of electricity generation; coal sees a steep decline, with over 55 countries aiming to phase it out; and oil continues to decline

Note: TWh = terawatt-hours; C & S America = Central and South America.

Oil use in the power sector is already at a relatively low level and is set to decline rapidly in the coming years in the STEPS, with particularly steep reductions in the Middle East as countries like Saudi Arabia pursue their 2030 energy transition goals. Across the Middle East and North Africa, this shift could free up significant volumes of oil and gas for export, with major implications for global markets and regional revenues. In Africa, however, oil remains an important source of electricity generation, especially for expanding access in remote and underserved communities. In most other regions, oil-fired generation is limited and typically confined to isolated areas where alternatives are not yet viable.

Dispatchable sources of electricity continue to play a vital role to ensure power system reliability and flexibility at a time when electricity demand is rising fast (Figure 4.27). Coal-fired power remains the largest dispatchable source worldwide until 2035, with capacity set to peak at around 2 500 GW in the early 2030s, driven by new construction in China, India and Southeast Asia. Natural gas-fired capacity also sees robust growth and overtakes coal, though supply constraints and long wait times for turbines are emerging in some fast-growing data centre markets. Among low-emissions options, hydropower remains the largest dispatchable source, followed by nuclear and bioenergy. Battery storage sees a major breakthrough in the STEPS, adding 1 700 GW to 2035, which comes close to matching the new capacity of all other dispatchable sources combined. It plays a critical role in providing short-term flexibility, while seasonal balancing continues to rely on hydropower and thermal generation (see Chapter 5).

Figure 4.27 ⊳ Global installed power capacity of variable and dispatchable electricity sources in the STEPS, 2000-2035



IEA. CC BY 4.0.

Nearly all forms of dispatchable power capacity continue to expand globally to 2035, including coal, natural gas and batteries, while variable sources of power skyrocket

Notes: GW = gigawatt; CCUS = carbon capture, utilisation and storage. Other renewables include bioenergy and renewable waste, concentrating solar power, geothermal and marine. Other includes oil, non-renewable waste and other sources.

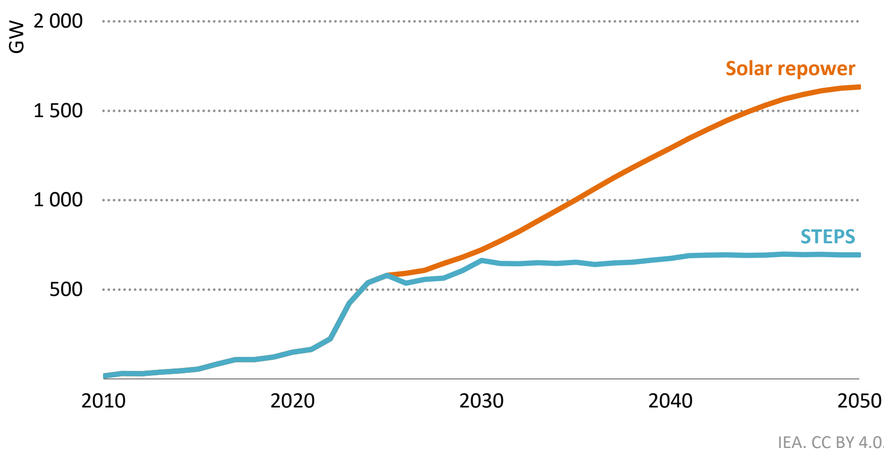
Renewables are set to expand significantly in the STEPS. Their installed capacity nearly triples by 2035, raising the renewables share of global electricity generation from one-third in 2024 to over half. Solar PV and wind continue to lead the way, with solar PV capacity projected to increase more than fourfold to 2035 with annual additions reaching around 650 GW. Accelerated repowering programmes for solar PV could enable energy outputs to increase still further (Box 4.5). Wind capacity increases two-and-a-half-times by 2035, with particularly robust growth in the European Union offshore wind sector and China onshore wind installations. There are also repowering opportunities for onshore wind, particularly in the United States and Europe which have numerous ageing installations: these could boost capacity and output at existing sites, though permitting and licensing processes may need to be streamlined.

Box 4.5 ⊳ Accelerated solar repowering could boost the market

Solar repowering refers to the process of replacing ageing or underperforming solar PV systems to increase electricity production, extend the system operational lifetime and improve the return on investment. There is mounting evidence that solar panels installed in the early 2010s, particularly in utility-scale projects, are now being replaced in many instances after just 10-15 years of operation because the technology is outdated or their performance has degraded. Today, solar panels are 40% more efficient than those from

2010, so replacing old panels while reusing existing infrastructure can increase energy output in a cost-effective way. Replacing solar panels once after 10 to 15 years instead of operating them for 20 to 30 years could reduce the overall LCOE by up to 20% under good conditions (Joel, Woodhouse and Bulović, 2019).

Figure 4.28 ▷ Global solar PV panel market in the STEPS and with accelerated repowering, 2010-2050



Shortening the replacement schedule for solar PV panels could drive further market growth, expanding it by up to 55% in 2035 without raising operational solar capacity

According to our analysis, an accelerated repowering schedule could lead to a substantial increase in the size of the solar PV panel market, benefiting from the current oversupply of solar products (Figure 4.28). Without increasing the total installed capacity in the projection period to 2050, an accelerated repowering schedule for solar PV power around the world could increase the solar PV panel market size by up to 60% in 2035 compared to the level in the STEPS, and double it by 2040, sustaining continued long-term market growth.

The accelerated repowering schedule would also raise the average performance of the solar PV fleet, due to faster stock turnover and uptake of higher efficiency panels. For example, a 2% absolute increase in the average efficiency of a panel would result in over 10% higher electricity output from each panel with the same rated capacity. By 2035, that would mean up to 15% higher electricity output from solar PV globally. Repowering solar projects could also increase the total capacity for a given amount of space, though this may require upgrades to inverters, cabling and grid agreements, or may be restricted by regulatory capacity limits. Repowering might also require existing contracts to be reviewed, which could risk the loss of preferential tariffs.

4.4.3 Electricity grids

Electricity grids are the backbone of modern power systems and will remain essential to ensure energy security, particularly in the emerging Age of Electricity. As electricity demand increases and energy transitions accelerate, grids must be modernised and expanded to connect new sources of generation such as wind and solar PV to demand centres in a timely and reliable manner. While distribution lines continue to make up over 90% of total grid length, transmission lines are a particular focus of attention because they need to be expanded to accommodate renewables, which are often located far from existing infrastructure. In the STEPS, global grid lengths increase by 30% between 2024 and 2035, reaching 110 million km, and by another 35% by 2050. Advanced economies see a 10% grid expansion by 2035, while emerging market and developing economies expand their grids by 40% over the same period. In parallel, ageing infrastructure must be replaced – nearly 20 million km by 2035 and another 30 million by 2050 – with advanced economies facing the most urgent needs due to the age of their existing assets (see Chapter 3).

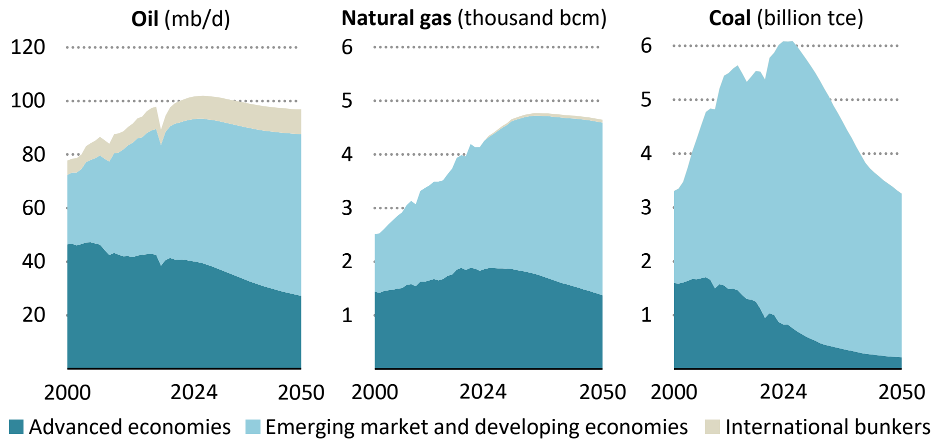
Achieving this transformation is not without challenges. Grids are becoming more complex, and long lead times for grid development, often over a decade for major transmission projects, are already causing delays, with swelling connection queues for renewables and long wait times for new grid connections (IEA, 2025d). More proactive planning processes, regulatory frameworks that support anticipatory investment, and an expansion of performance-based regulation could all help address the problems (IEA, 2023). Meanwhile supply chain constraints are tightening, especially for critical components like transformers, which have seen prices and delivery times nearly double in recent years (IEA, 2025d). These constraints also extend to raw materials. For example, grid expansion is a major driver of copper demand, and current project pipelines suggest a potential 30% shortfall in copper supply by 2035 (IEA, 2025e). Overcoming these hurdles is vital to ensure that electricity grids can support secure, affordable and sustainable electricity supply.

4.5 Fuels

The share of fossil fuels in global energy demand was around 87% in the 1970s and now is around 79%. In the STEPS, it drops to around 70% in 2035 and to less than 60% in 2050. Fossil fuel use in advanced economies has fallen by around 10% over the past decade, while it has increased by around 25% in emerging market and developing economies. In the STEPS, demand falls by around 15% in advanced economies to 2035 and increases by around 1% in emerging market and developing economies: the net effect is that global fossil fuel demand declines by more than 4% to 2035 (Figure 4.29).

Global oil demand reached 100 mb/d in 2024. In the STEPS, it increases to a peak level of 102 mb/d around 2030. It then gradually falls, and by 2035 it is back to around its 2024 level, with notable reductions in demand from passenger cars and the power sector, more than offset by increases from petrochemicals, aviation and other industrial activities. On the supply side, increases from the Middle East, Central and South America, and North America to 2035 are largely offset by declines in mature producers, including Europe, Russia and Mexico.

Figure 4.29 ⊳ Fossil fuel demand in the STEPS to 2050



Demand for coal peaks before 2030 and for oil around 2030. Natural gas reaches its maximum level around 2035 and then levels off.

Note: mb/d = million barrels per day; bcm = billion cubic metres; tce = tonne of coal equivalent.

Natural gas demand expands from 4 250 bcm today to 4 750 bcm in 2035 and it remains around this level thereafter in the STEPS. To 2035, declining demand in advanced economies is more than offset by increased demand in the industry and power sectors of emerging market and developing economies in Asia and the Middle East.

Coal demand rose to around 6 100 million tonnes of coal equivalent (Mtce) in 2024 – a record high. It remains around this level for a few years before starting to decline. By 2035, demand is around 20% lower than in 2024, a drop of 1 200 Mtce. Coal demand in China falls by more than 800 Mtce to 2035, which is around the total level of coal demand in advanced economies in 2024.

4.5.1 Oil

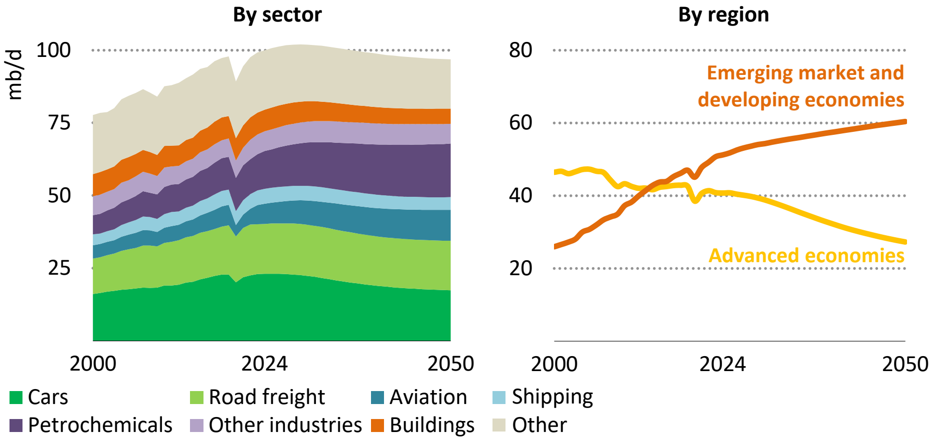
Demand

Oil demand rises from 100 mb/d in 2024, peaks around 2030, and then declines to 100 mb/d by 2035. It subsequently falls by around 0.2 mb/d each year on average from 2035 to 2050.

China was responsible for more than 75% of the increase in global oil demand between 2015 and 2024, and today it consumes around 16 mb/d. The electrification of road transport in China is the main reason for the global peak in oil demand in the STEPS: half of passenger car sales in China today are electric, and this share is 90% by 2035. As a result, oil demand in China peaks in the STEPS before 2030 and falls to around 15 mb/d by 2035.

Oil demand in India increases by 2 mb/d to 2035 – the largest increase in any country – and continues to rise through to 2050. The next largest increases to 2035 are in Africa (1.2 mb/d), and Southeast Asia (1 mb/d). In the Middle East, falling oil use in the power sector (1.4 mb/d) is more than offset by growth in petrochemical feedstock and road transport.

Figure 4.30 ▷ Global oil demand by end-use and region in the STEPS to 2050



Electrification of road transport is the primary cause of the peak in oil demand around 2030; oil use remains more resilient in petrochemical feedstock and aviation

Notes: mb/d = million barrels per day; Other industries = industry sector excluding petrochemicals; Other = other non-energy use, other energy sectors, power, agriculture, other transport. Excludes biofuels.

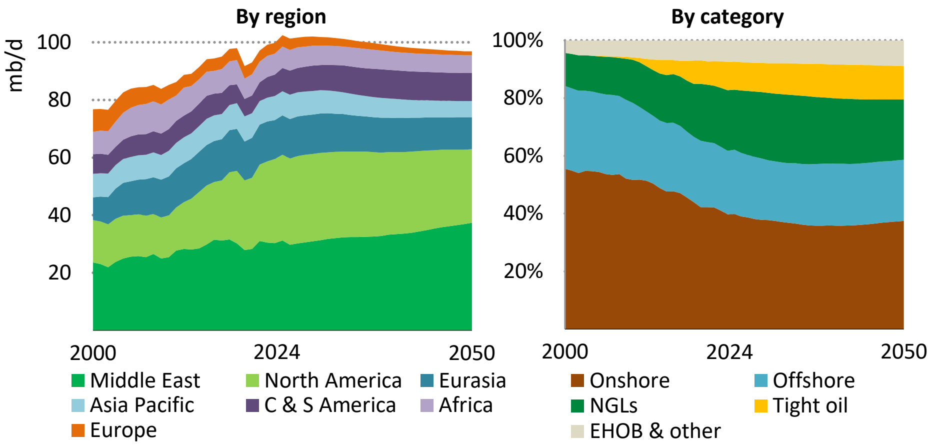
Oil demand in advanced economies fell by around 1.5 mb/d between 2015 and 2024, and it falls by a further 5.3 mb/d to 2035 in the STEPS. Declines in demand are slowest in North America, 6% to 2035, and fastest in the European Union at 30% (Figure 4.30).

The largest increases in demand for oil globally to 2035 are for its use as petrochemical feedstock (up by 3.3 mb/d to 2035), and in aviation (2.2 mb/d). The largest declines in oil demand reflect its displacement in cars (2.6 mb/d), and in the buildings sector (1.3 mb/d).

Supply

Oil supply peaks around 2030 in the STEPS and returns to 2024 levels in 2035. Increases in output by countries in the Middle East, Central and South America, and North America to 2035 are largely offset by declines in mature producers including Europe, Russia and Mexico (Figure 4.31). The share of OPEC+ in global oil supply remains around today’s level of 50% to 2035 in the STEPS before increasing to 53% in 2050 as a result of rising supply from the Middle East.

Figure 4.31 ⊳ Global oil supply by region and category in the STEPS to 2050



Middle East oil production supports robust supplies of NGLs, while the multidecadal contraction in the conventional crude oil share continues

Note: mb/d = million barrels per day; C & S America = Central and South America; NGLs = natural gas liquids; EHOB = extra-heavy oil and bitumen.

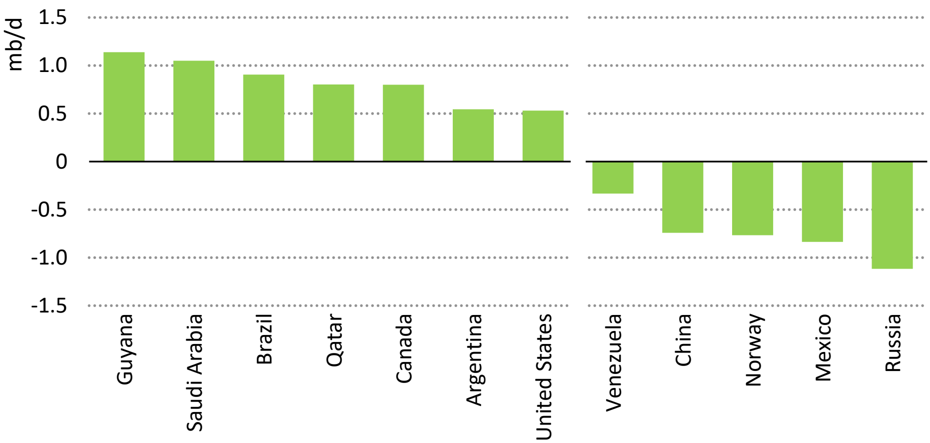
Middle East total oil supply increases by 2 mb/d to 2035, with the output of natural gas liquids (NGLs) increasing by over 2.5 mb/d over this period. Half of the increase in oil supply comes from Saudi Arabia, and it is derived from liquid-rich gas fields, including the unconventional Jafurah field, and its legacy onshore crude oil supergiant fields. Qatar increases production by close to 1 mb/d, most of which consists of NGLs from its supergiant North Field (Figure 4.32). The United Arab Emirates increases supply by around 0.5 mb/d to 2035 from 4 mb/d in 2024 following the expansion of its legacy fields and the capture of increasing amounts of NGLs from natural gas processing.

In Central and South America, the continued development of the Stabroek block in Guyana, the further expansion of the pre-salt ultra-deepwater fields in Brazil, and the ramp up of tight oil resources in Argentina, mean that their aggregate supply increases from 5 mb/d in 2024 to 7.5 mb/d to 2035. Suriname starts production from its offshore fields in the late 2020s, and production rises to 0.3 mb/d in 2035.

In the United States, oil supply in 2035 is 21.5 mb/d, slightly higher than in 2024 (21 mb/d). The United States remains the world's largest oil producer to 2050. Canada adds 0.8 mb/d to 2035, supported by pipeline expansions that facilitate debottlenecking and increased NGL volumes from shale plays.

Supply in Mexico fell marginally in 2024 to 2 mb/d. While new projects such as Trion, Polok-Chinwol and Zama are expected to start by 2030, overall production still declines by 0.8 mb/d to 2035. Supply in Venezuela drops by 0.3 mb/d to 2035 to 0.6 mb/d, its lowest-ever sustained level of output.

Figure 4.32 ⊳ Change in oil supply in selected producing countries between 2024 and 2035 in the STEPS



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Supply increases to 2035 come mainly from countries in the Americas and the Middle East, and falls from mature producers

Supply in Europe falls from 3.8 mb/d in 2024 by 1.4 mb/d to 2035. Despite the start-up of the Johan Castberg field in 2025, supply from Norway falls from 2 mb/d in 2024 by about 40% to 2035. Output in the United Kingdom falls by 35% as ageing fields face high decline rates.

Supply in Nigeria falls from 1.6 mb/d in 2024 by 0.3 mb/d to 2035. Supply in Algeria also contracts by 0.3 mb/d. Namibia and Uganda post the largest increases in Africa, 0.3 and 0.2 mb/d each, with Uganda expected to achieve its first oil in 2027 from projects in the Lake Albert Rift Basin.

Russian supply contracted by 0.3 mb/d in 2024 to close to 11 mb/d, lower than before its invasion of Ukraine. Sharp declines in oil revenues in 2024 created major profitability challenges that are undercutting on-going capital commitments; some large projects already face delays, e.g. the Vostok Oil project. Production falls by around 1 mb/d to 2035.

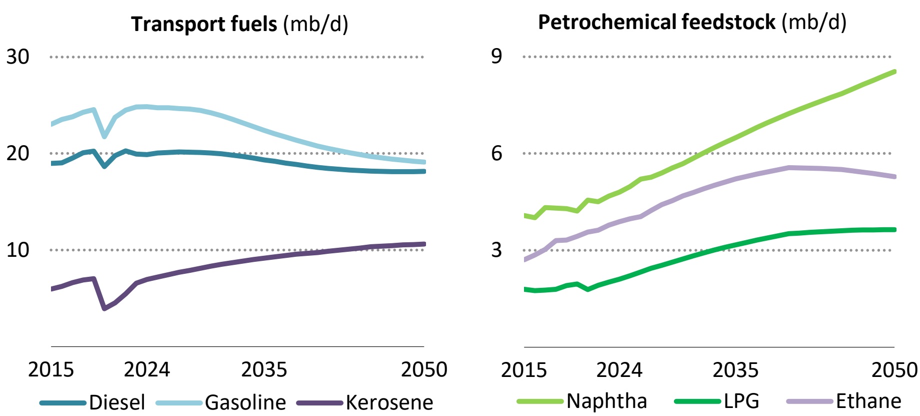
China is currently the world's fifth-largest oil producer at 5 mb/d, having increased supply by around 7% over the past decade. The resource base in China is maturing, and production falls by 0.7 mb/d to 2035 because the oil price in the STEPS is not sufficient to incentivise large-scale development of its tight oil resources.

Iran increased supply by more than 0.4 mb/d in 2024 to 4.7 mb/d, but output contracts marginally to 4.5 mb/d in 2035.

Refining

In the STEPS, demand for refined products peaks before 2030 at 86 mb/d, around 0.7 mb/d above 2024 levels, and demand in 2035 is 85 mb/d. By 2050, accelerating declines in gasoline and diesel consumption outweigh continued growth in refined petrochemical feedstock and jet fuel. This presents a major challenge for the refining industry, since it marks an end to the many years of steadily rising demand for road transport fuel that have been the bedrock of refinery profitability. Peak demand for vehicle gasoline and diesel is reached in the next few years. Demand for middle distillates is more robust with continued growth in demand for jet kerosene (Figure 4.33). Increases in fractionated NGLs supply and biofuels minimise the need for new refinery capacity to meet demand growth through to 2035. Of the 3.3 mb/d increase in petrochemical feedstock demand to 2035, more than half is met by non-refined fuels. After 2035, however, shrinking NGLs supply means demand will increasingly be met by refined products.

Figure 4.33 ▷ Demand for selected refined and fractionated products in the STEPS to 2050



As demand for road transport fuels contracts, aggregate demand for petrochemical feedstock expands

Notes: mb/d= million barrels per day; LPG = liquefied petroleum gas. Diesel, gasoline and kerosene include transport use only; naphtha, LPG and ethane include petrochemical use only.

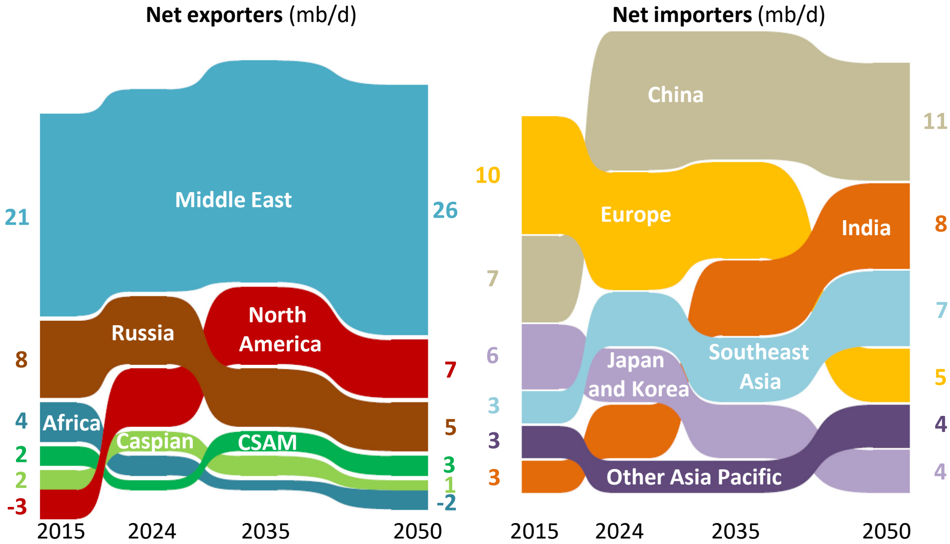
Despite weak demand growth for refined products in the STEPS, 6 mb/d of new refining capacity comes online in the period to 2035, which is largely offset by 5 mb/d of closures. This new capacity is located mainly in Asia, especially China and India, and to a lesser extent in the Middle East. The on-going shift towards large, integrated refining and petrochemical complexes continues, benefiting from economies of scale and lower operating costs. Refinery closures are largely concentrated in Europe and the United States, where ageing facilities face higher operating costs. In China, capacity remains flat through to 2035, with the commissioning of large, integrated refineries offset by the phasing out of smaller and ageing plants.

Trade

In the STEPS, trade flows increasingly shift towards emerging market and developing economies in Asia. Less than 60% of global net trade of oil was to these countries in 2024; this figure reaches 65% in 2035 and exceeds 75% in 2050.

China remains the largest net importer of oil to 2050, absorbing more than a quarter of global oil trade, but imports fall by 1 mb/d to 2035. India emerges as a strong demand hub, with a 50% increase in imports reaching around 7 mb/d in 2035. Southeast Asia imports rise by 1.5 mb/d between 2024 and 2035, while Japan and Korea imports fall by 0.6 mb/d.

Figure 4.34 ▷ Net oil trade for selected major exporters and importers in the STEPS to 2050



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New trade dynamics emerge as Eurasian supply loses ground, non-OPEC supply picks up, and Asian countries dominate the long-term demand

Note: mb/d = million barrels per day; CSAM = Central and South America.

The Middle East maintains its position as the dominant net exporter in the STEPS, exporting almost three-times more than the next largest exporter in 2035. Supply increases by 1.5 mb/d by 2035, and efforts to cut domestic demand for power generation avoid the use of about 1.5 mb/d of oil that is then freed for international trade. North American exports increase by more than 2 mb/d to 2035, although Mexico soon becomes a net importer. Africa also becomes a net oil importer in aggregate as increased production from new producers, including Uganda and Namibia, is more than offset by declining production from mature producers, mainly Algeria, Angola and Nigeria, and by increased demand. Russia and Caspian see a near-20% decline in export volumes to 2035 (Figure 4.34).

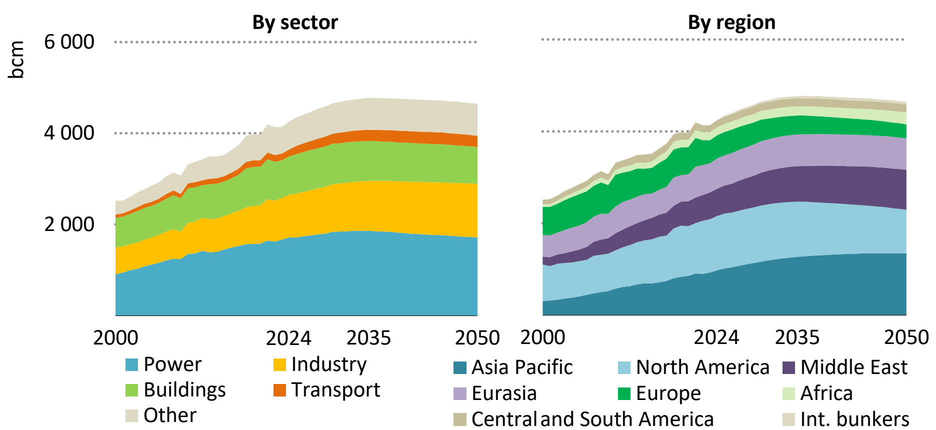
4.5.2 Natural gas

Demand

In the STEPS, natural gas demand grows at an average of 50 bcm per year between 2024 and 2035. Demand reaches just under 4 800 bcm in 2035 and then remains around this level through to 2050. Long-term natural gas demand growth is kept lower than in recent decades by the expanding deployment of renewables, efficiency gains and electrification of end-uses.

Demand for natural gas in advanced economies declines from 1 850 bcm in 2024 to 1 750 bcm in 2035. In the European Union, natural gas demand peaked in 2010, and it has fallen by around 20% since Russia's invasion of Ukraine at the start of 2022, to a level of around 330 bcm in 2024. Demand falls by a further 20% between 2024 and 2035, to 260 bcm, as stated policy measures take effect that reduce gas imports and lower the share of gas in the electricity generation mix. Gas demand in Japan peaked in the early 2010s and now stands at around 90 bcm: it falls by 3 bcm by 2035. US domestic gas demand was 940 bcm in 2024 and it levels off before 2035.

Figure 4.35 ▻ Global natural gas demand by sector and region in the STEPS to 2050



Natural gas demand growth levels off in the mid-2030s, with reductions in North America and Europe more than offsetting increases in Asia Pacific and Middle East

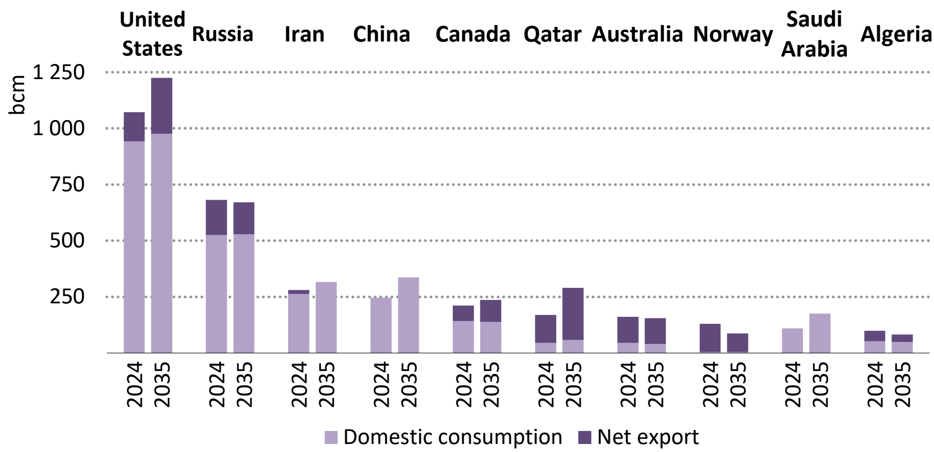
Note: bcm = billion cubic metres; Int. bunkers = international bunkers.

Demand for gas in emerging market and developing economies increases from 2 400 bcm in 2024 to 2 950 bcm in 2035 (Figure 4.35). Half of this growth comes from emerging market and developing economies in Asia, led by China with 160 bcm of growth, and most of the remainder from the Middle East. By 2035, the Middle East accounts for just under 20% of global gas use in the power sector, up from 15% today.

Supply

Growth in natural gas supply is led by the Middle East and the United States in the STEPS through to 2035, with their combined output increasing by close to 450 bcm (Figure 4.36). A number of gas producing countries, including Australia and Norway, see their output decline as fields mature in the period to 2035.

Figure 4.36 ⊳ Natural gas by producing country in the STEPS, 2024 and 2035



The Middle East and United States drive growth in global gas supply to 2035, and they add around 250 bcm to their combined export capacity

The United States maintains its position as the world's largest natural gas producing country. Production rises by 150 bcm to 2035 before declining to 2050. Domestic demand increases at a slower pace than supply to 2035 and then falls faster than supply to 2050, leaving room to develop additional export capacity: the share of US natural gas produced for export rises from 12% today to 20% in 2035 and 30% in 2050.

The Middle East sees the largest growth in supply in the STEPS to 2035, led by Qatar, Saudi Arabia and the United Arab Emirates. Qatar natural gas production increases by 70% between 2024 and 2035, with nearly all of the 120 bcm growth earmarked for export.

Natural gas production falls in Russia from 680 bcm in 2024 to 670 bcm in 2035, while net exports fall by 10% over the same period. Declining profits limit upstream investment and production declines at mature fields such as Urengoy and Yamburg.

Gas production in Europe falls by 20%, 50 bcm, to 2035, with the commissioning of new offshore developments in the Black Sea and eastern Mediterranean region more than offset by decreases in other fields, notably in Norway, where production decreases by more than 30% between 2024 and 2035.

Trade

Around 1 100 bcm of natural gas is traded over long distances each year, equivalent to a quarter of global gas demand. A little over half of this total is traded in the form of LNG.

A large wave of new LNG supply is expected to come online over the next several years. After taking into account anticipated declines in supply from existing LNG export projects, global available LNG export capacity is set to rise from 565 bcm in 2024 to 830 bcm in 2030 (Box 4.6). This is much higher than the growth in demand, implying significant slack in global gas markets and putting downward pressure on natural gas prices and narrowing the spreads between key regional gas price benchmarks. This leads to significant demand response in price sensitive regions such as India and Southeast Asia. Still, in 2030, around 65 bcm of available LNG capacity is surplus to requirements in the STEPS. Based on currently announced projects, some of which come online after 2030, this surplus is gradually worked off by 2035 and by 2040 around 65 bcm per year of new LNG export capacity is required.

Box 4.6 ▷ Assessing available LNG capacity

LNG liquefaction terminals often report their annual nameplate capacity, which is the maximum rated output of the plant. In practice, LNG terminals do not always run at 100% of nameplate capacity. This is because of maintenance work, unplanned outages or issues at upstream facilities, because of the time taken for newly commissioned terminals to ramp up to full capacity, and because of fluctuations in demand, for example, between seasons or as a result of a drop in market demand.

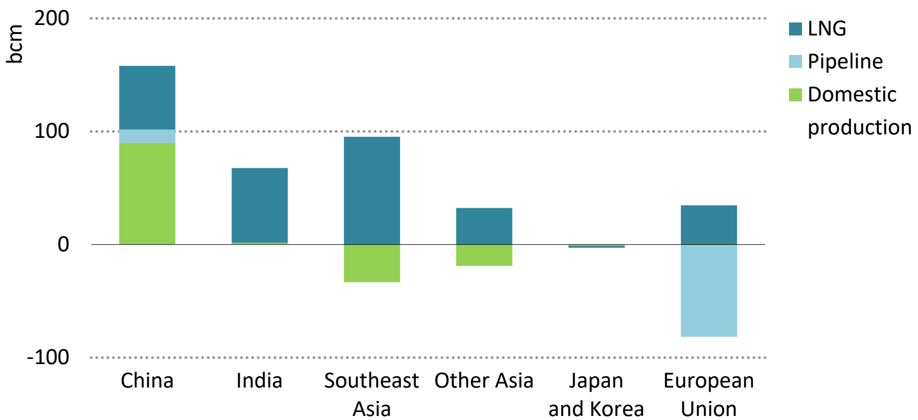
In 2024, global nameplate LNG capacity was 665 bcm on an annualised basis, while actual LNG demand totalled around 560 bcm, implying a global utilisation rate of nameplate LNG export capacity of 85%. Over the last decade, this utilisation rate has varied between 75% and 85%.

In our scenarios, we use a value of 85% to de-rate the nameplate capacity of existing LNG terminals in order to account for maintenance and unplanned outages, and we assume 95% utilisation rates for under construction LNG terminals once they become fully operational. These factors reduce the nameplate capacity of LNG terminals down to the available capacity.

Around 290 bcm of new nameplate LNG capacity is currently under construction and is set to come online by 2030, and around 10 bcm of capacity is likely to be shut down by 2030 as plants reach the end of their technical or economic lifetime. As a result, available LNG capacity expands by around 265 bcm between 2024 and 2030, compared with 200 bcm of growth in LNG demand over this period.

In 2035, more than 75% of total LNG exports flow to Asia in the STEPS, up from just under 70% in 2024. China has been the world’s most active LNG buyer in recent years, accounting for around 25% of new long-term LNG contracts signed since 2020. China increases its LNG imports by around 55 bcm to 2035, and an additional 20 bcm of pipeline gas is imported through expansion of the Power of Siberia I and Far East pipelines from Russia. Total imports in 2035 in China reach around 250 bcm, more than double the volumes of India, the next largest importing country. China becomes increasingly influential in balancing global gas markets through to 2035 as it actively manages its portfolio of pipeline, LNG, domestic production and storage assets, backed by a mix of long-term, short-term and flexible gas contracts.

Figure 4.37 ▷ Change in natural gas supply balance in selected regions in the STEPS, 2024-2035



LNG meets 285 bcm of the growth in natural gas demand in key importing regions

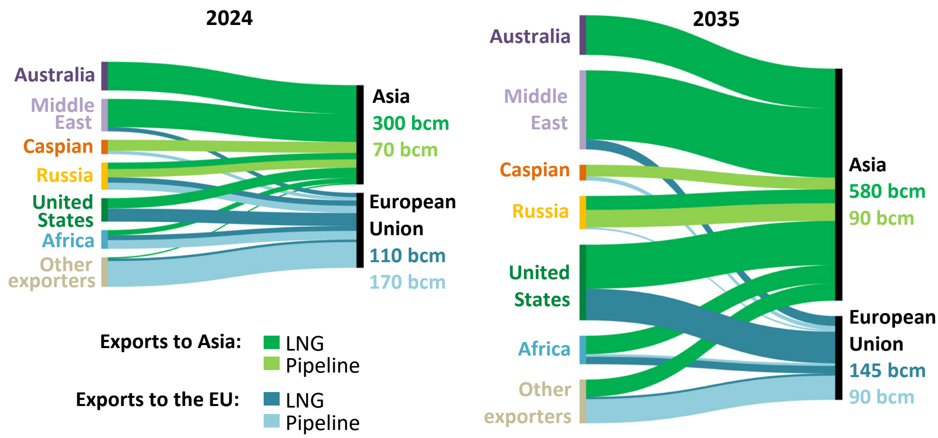
Note: bcm = billion cubic metres; LNG = liquefied natural gas.

In India, growth in natural gas demand to 2035 is largely met by LNG imports, which almost triple between 2024 and 2035. There are also large increases in LNG imports in other regions in Asia which need gas imports to compensate for declining domestic production and to meet additional demand growth. These include Southeast Asia, where LNG imports rise from 35 bcm today to 135 bcm in 2035, and other developing Asia, primarily Pakistan and Bangladesh, where LNG imports increase from 45 bcm to 80 bcm over the same period.

LNG imports to the European Union rise from 110 bcm in 2024 to 145 bcm in 2035 to compensate for declining domestic production and a drop in pipeline supply. Total imports fall by 65 bcm from 2024 levels, tracking the fall in overall European Union demand. In Japan and Korea, LNG imports stay flat at around 90 bcm and 60 bcm, respectively.

Today, the United States is the world's largest LNG exporter, and it leads the growth of new capacity, accounting for around 160 bcm of projects under construction, 50% of the global total. These projects bring its total nameplate LNG capacity to 300 bcm per year in 2030. Its LNG exports reach 240 bcm by 2035 and its pipeline exports to 80 bcm.

Figure 4.38 ⊳ Natural gas export to the European Union and Asia in 2024 and in the STEPS in 2035



65% of the growth in gas trade to 2035 is driven by United States and Middle East exports to Asia

Note: bcm = billion cubic metres; LNG = liquefied natural gas.

Around 20% of the increase in new LNG capacity to 2035 is from Qatar, which has approved three major LNG expansion projects since 2021, with the latest addition being its 22 bcm North Field West project, announced in 2024. Its LNG supply capacity is set to expand from around 100 bcm in 2024 to around 200 bcm in 2035. Its North Field West project, announced in 2024, could further add to its capacity. LNG export capacity in Australia stays flat, and it maintains its position as the third-largest LNG exporter throughout the outlook period. In Canada, the 19 bcm per year LNG Canada project began operation in 2025, while two smaller projects are scheduled to start before 2030. In Africa, around 40 bcm worth of new projects are under development, including the 18 bcm per year Mozambique LNG project that has seen multiple delays and is not expected to come online until around 2030. Taking into account capacity retirements, LNG exports from Africa reach around 75 bcm in 2035.

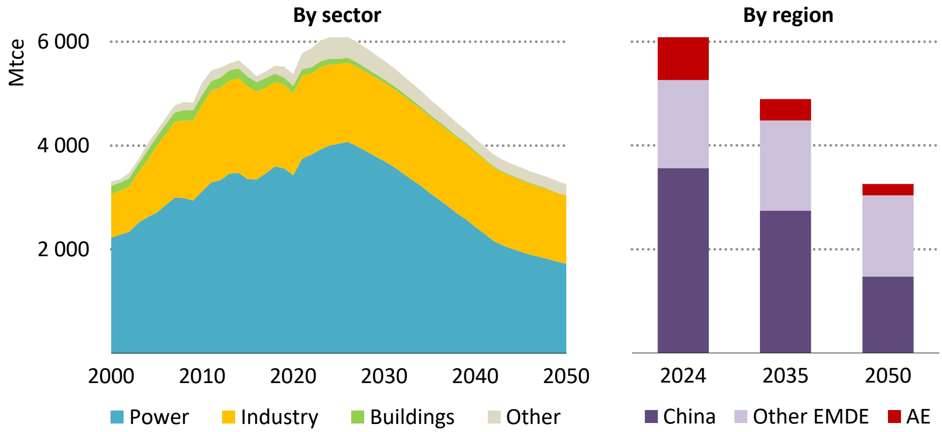
Russia does not manage to replace the gas export volumes lost to Europe. There is a small increase in its pipeline exports to Central Asia, but its overall exports fall by 7 bcm by 2035, with pipeline exports to China plateauing at a level of around 50 bcm per year, up from 30 bcm today. These exports to China are supported by an increase in annual deliveries from the Power of Siberia I pipeline and by the commissioning of the Far East pipeline. The flattening of demand for gas in China in the late 2030s means that there is no need for an additional large-scale pipeline from Russia to China. Russian LNG production peaks at close to 55 bcm around 2040, far below the government target level of more than 150 bcm by 2036.

4.5.3 Coal

Demand

Coal demand worldwide has risen by around 65 Mtce on average each year since 2015. It reached a record high in 2024, in part due to a surge in electricity demand driven by increased cooling needs in China, India and other emerging market and developing economies that experienced acute heat waves. There is limited further growth in coal demand in the STEPS: it soon peaks at around 6 100 Mtce, and demand in 2035 is 20% lower than in 2024 (Figure 4.39).

Figure 4.39 ⊳ Coal demand by sector and region in the STEPS to 2050



Coal demand falls by 20% to 2035 and 45% to 2050, mainly from declines in power; coal demand in industry is more resilient as there are few alternatives for steel production

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

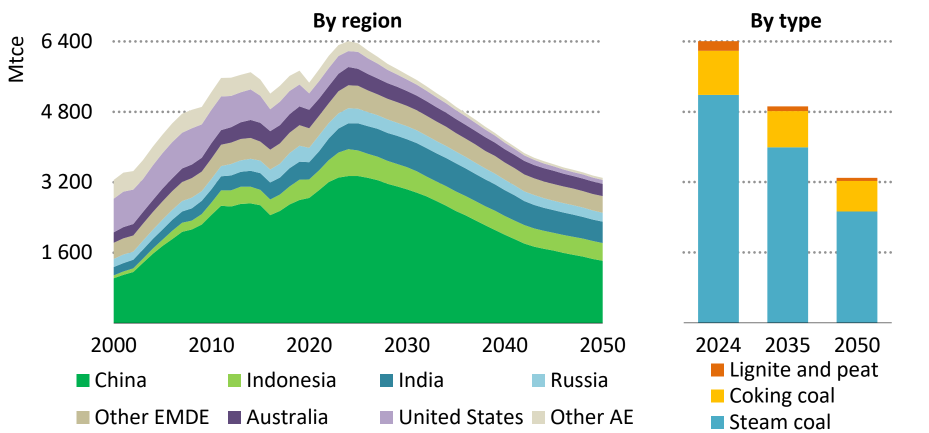
China is responsible for more than 3 550 Mtce of coal demand today. In the STEPS, its demand falls by around 25% to 2035: this reduction of more than 800 Mtce is broadly equivalent to all of the coal used in advanced economies in 2024. Coal use falls across all main sectors in China, with the power sector in the lead. India, Indonesia and other emerging market and developing economies in Southeast Asia see coal demand increase by 10-35% to 2035 as they tap all alternatives available to power their increasing electricity needs. Coal use plateaus in the Caspian region. In Africa, coal demand declines by around 20%, with demand in South Africa falling 30%, largely due to a 45% reduction of coal use in power.

Coal demand in advanced economies falls by 50% to 2035 in the STEPS, consolidating a trend that started over a decade ago. The largest absolute decline is in the United States, where coal demand drops by nearly 140 Mtce, equivalent to Japan's coal use in 2024. The industry sector also sees a reduction in coal use, but it is much more moderate.

Supply

China accounts for half of global coal supply today. In the STEPS, its production falls broadly in line with domestic demand, dropping by about 25% to 2035 and by 60% to 2050. China remains responsible for around half of global coal production to 2035, but its share falls to below 45% by 2050 (Figure 4.40).

Figure 4.40 ▷ Coal supply by region and type in the STEPS to 2050



China cuts its coal output by nearly 800 Mtce between 2024 and 2035, almost as much as total coal production from all advanced economies in 2024

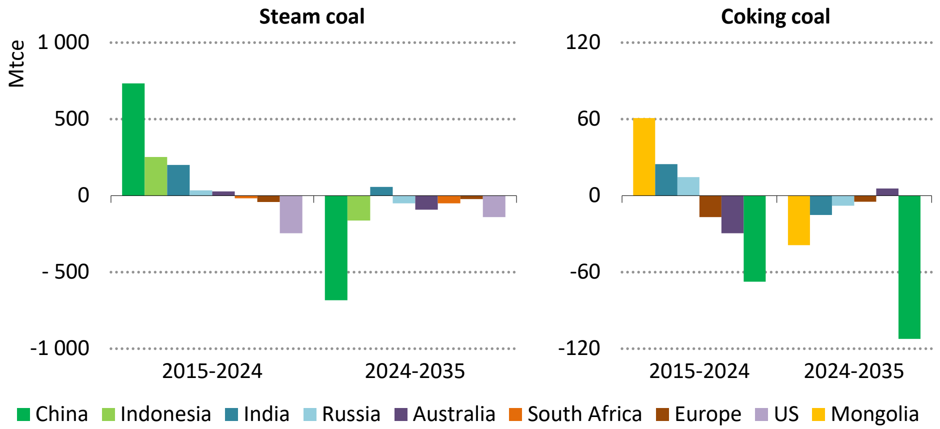
Note: Mtce = million tonnes of coal equivalent; EMDE = emerging market and developing economies; AE = advanced economies.

Around 80% of coal produced in 2024 was steam coal, mainly used for heat production or steam-raising in power plants (Figure 4.41). The global share of coal in electricity generation drops from 35% in 2024 to below 20% in 2035, mainly because the expansion of renewables generation exceeds the growth in electricity demand, and steam coal production drops by around 25% between 2024 and 2035, a reduction of nearly 1 200 Mtce.

Most of the remaining coal produced in 2024 was coking coal, which is mainly used in the iron and steel industries. Steel production rises by just over 10% between 2024 and 2035 in the STEPS. There are some alternatives to the use of coking coal to make steel from iron ore, including natural gas, biochar, hydrogen and direct electrification. These alternatives are used in around 10% of iron production today, and their use is expected to increase over the next ten years. As a result, coking coal production falls by nearly 20% to 2035.

Lignite and peat production, mostly used for power generation, falls by more than 50% to around 100 Mtce by 2035 in the STEPS. Two-thirds of this reduction occurs in Europe as demand from the power sector continues to fall and as several lignite mines reach the end of their lifetimes.

Figure 4.41 ⊳ Change in coal production in selected countries in the STEPS



IEA. CC BY 4.0.

Coal production declines in all major producing countries except India to 2035

Note: Mtce = million tonnes of coal equivalent; US = United States.

In India, coal production increases by around 50 Mtce to 2035 as it pursues its long-term strategy of reducing coal imports and enhancing energy security. This falls short of the increase of around 75 Mtce in its demand for coal over the period, but it helps to limit growth in coal imports. In 2024, Coal India Ltd obtained environmental clearance for the Gevra mine to expand production to 70 million tonnes per year, which would make it the largest coal mine in Asia. It also announced the launch of 36 new mines over the next five years.

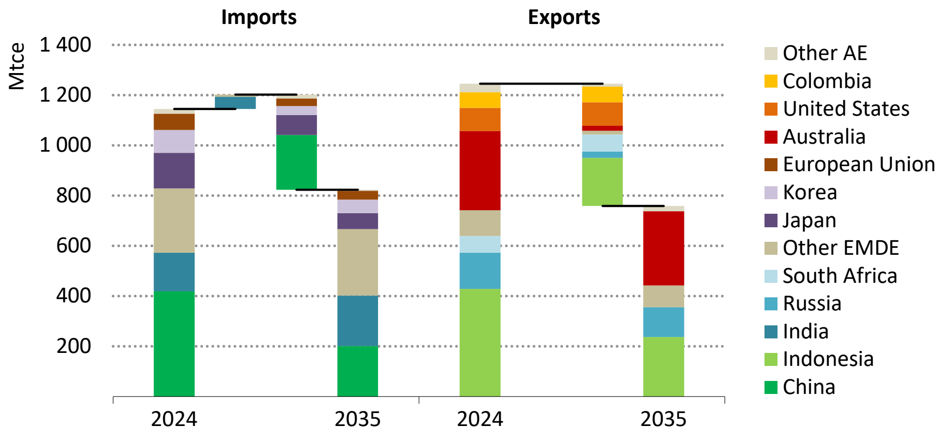
Countries that mostly produce steam coal for export see large production declines. For example, production in Indonesia falls by around 25% by 2035: domestic demand for coal increases, but it faces a shrinking export market as nearly 50% of Indonesian coal exports go to China today. Production in Colombia drops by around 70% by 2035 as exports fall by over 85%. Production in Russia decreases by over 20% to 2035 as both domestic demand and exports decline.

In advanced economies, coal production decreases by around 40% to 2035 (less than the 50% decline in demand over the same period). The decline is limited to just under 25% in Australia which is the world's largest coking coal exporter. Production in the European Union falls by 80 Mtce to 2035, and in the United States it decreases by nearly 160 Mtce, much less than the 330 Mtce reduction seen over the past ten years.

Trade

Around 1 200 Mtce of coal was traded worldwide in 2024 (Figure 4.42). China, India and Japan account for around 60% of imports today, while Indonesia, Australia and Russia account for close to 70% of exports.

Figure 4.42 ▹ Coal trade in the STEPS, 2024 and 2035



Coal trade declines by around 30% to 2035 and shifts even further to the Asia Pacific region, which is already responsible for close to 85% of coal trade flows

Notes: Mtce = million tonnes of coal equivalent; EMDE = emerging market and developing economies; AE = advanced economies. Differences in historical data between exports and imports are associated with coal in transit, losses and statistical differences.

In the STEPS, coal exports decline by more than 30% between 2024 and 2035, a larger drop than the overall reduction in coal demand over the period. Coal imports to China fall by around 220 Mtce: this 50% reduction outweighs the reductions in imports in all other countries combined. Coal trade within the Atlantic Basin also declines, with exports from the United States falling by around 35% to 2035, mainly as a result of lower overall demand in Europe. Coal imports increase by around 30% from 2024 levels in India. By 2035, India imports as much coal as China.

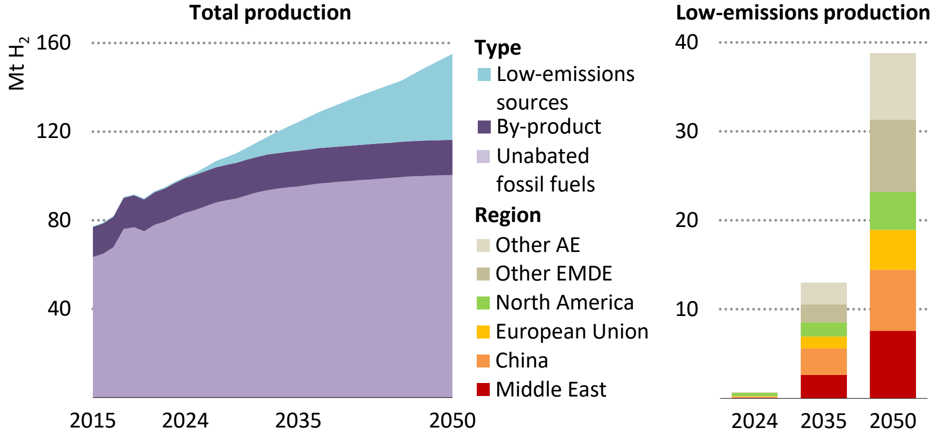
Steam coal exporters see more rapid declines than coking coal exporters. For example, steam coal exports to 2035 fall by over 85% in Colombia and around 45% in Indonesia, while coking coal exports from Mongolia fall by just over 25%. Australian exports of steam coal drop by nearly 20% while its coking coal exports increase by around 5%. Mozambique is one of the few countries to significantly increase coal exports, which rise to more than 15 Mtce by 2035 as new mine developments ramp up.

4.5.4 Low-emissions fuels

Low-emissions hydrogen

Global hydrogen production was nearly 100 million tonnes (Mt) in 2024, of which around 85% was produced from unabated fossil fuels, and around 15% was a by-product from processes in refining and the chemicals industry. Less than 1% was produced from low-emissions sources, mostly electrolysers running on low-emissions electricity and fossil fuels equipped with carbon capture, utilisation and storage (CCUS) (Figure 4.43). Around 80% of the 0.7 Mt of low-emissions hydrogen produced in 2024 was from existing fossil fuel facilities that have been retrofitted with CCUS, and 20% from electrolysis. Nearly all of the hydrogen produced today is used in oil refining and chemicals manufacturing.

Figure 4.43 ▷ Hydrogen production by type and low-emissions hydrogen production by region in the STEPS to 2050



Low-emissions hydrogen represents less than 1% of total hydrogen production today but accounts for the majority of growth from 2030 onwards

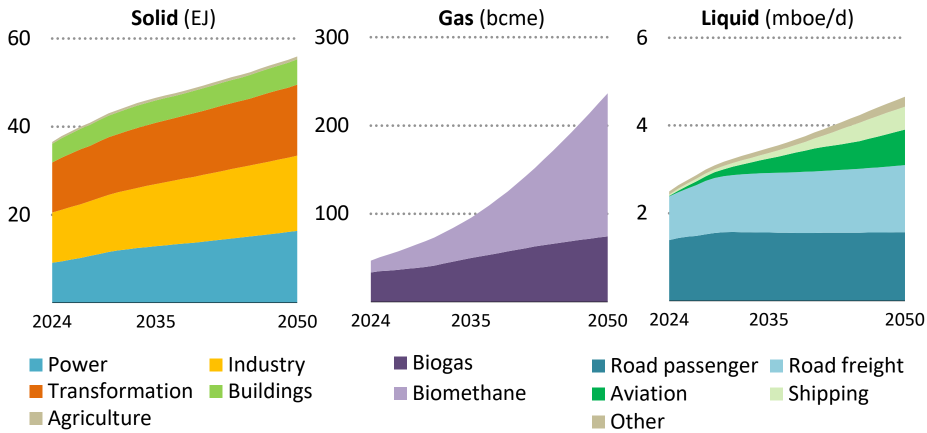
Note: Mt H_2 = million tonnes of hydrogen; EMDE = emerging market and developing economies; AE = advanced economies.

In the STEPS, total hydrogen production increases to around 125 Mt in 2035. Unabated fossil fuels remain the dominant production route, though its share drops from 85% in 2024 to around 75% in 2035. The installed capacity of electrolysers is up from 1.5 GW in 2024 to almost 100 GW in 2035. In total, 10 Mt of hydrogen in 2035 is produced from electrolysis powered by low-emissions electricity, mostly in China, Middle East and the European Union. Hydrogen production using fossil fuels with CCUS increases to 3 Mt in 2035, a fivefold increase from 2024, and takes place mainly in North America. Increases in low-emissions hydrogen help to meet new sources of demand growth rather than displacing production from fossil sources: the transport and power generation sectors together account for around half of low-emissions hydrogen use in 2035.

Modern bioenergy

Global bioenergy consumption increased marginally in 2024 to just over 60 EJ. The traditional use of solid biomass accounted for one-third and the remainder consisted of modern bioenergy, which includes modern solid bioenergy, liquid biofuels and biogas (Figure 4.44).

Figure 4.44 ⊳ Modern bioenergy demand by type and sector in the STEPS to 2050



Solid bioenergy remains the most used form of modern bioenergy, but biomethane is the fastest growing to 2050

Notes: EJ = exajoule; bcme = billion cubic metres of natural gas equivalent; mboe/d = million barrels of oil equivalent per day. Transformation is the energy consumed converting primary bioenergy into usable final forms.

Today, solid bioenergy accounts for 85% of modern bioenergy demand, and this share falls marginally to 75% by 2050 in the STEPS. Encompassing a range of feedstocks from forestry residues to municipal solid waste, it is mainly used in the power and industry sectors, where the presence of onsite process residues creates a natural use base. These sectors consume most of the increase in solid bioenergy production to 2035, with power generation in China and industry in India accounting between them for 30% of the overall increase.

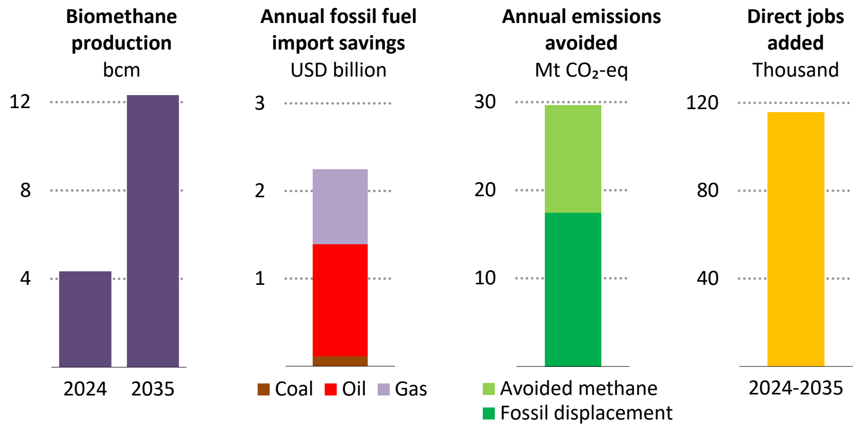
Liquid biofuels production rose to around 2.5 million barrels of oil equivalent per day (mboe/d) in 2024. Around 95% is consumed in road transport, with North America, and Central and South America the largest centres of demand. Demand in Brazil increases by around 0.2 mboe/d to 0.7 mboe/d by 2035 in the STEPS, supported by its Fuel of the Future law which sets new blending mandates for ethanol with gasoline and biodiesel with diesel. Despite this, liquid biofuels use in road transport remains broadly flat after 2030 as sales of EVs increase. However, total liquid biofuel use continues to rise, with around 0.3 mboe/d consumed in aviation and 0.15 mboe/d in shipping in 2035, both up from near negligible levels in 2024. The largest increases are in North America and Europe, reflecting measures such as the European Union ReFuelEU Aviation, FuelEU Maritime Regulations and Emissions Trading System, plus the extension of tax credits for liquid biofuels in the United States. Diversification of waste collection and feedstock pathways is essential as demand for feedstocks that meet sustainability criteria increases.

Biogas is the fastest growing form of bioenergy, reaching 95 billion cubic metres of natural gas equivalent (bcme) in 2035 in the STEPS.[5] A rising proportion of biogas is upgraded to biomethane, which sees production increase threefold to 2035 to 45 bcme, and twelve-fold to 2050 to 160 bcme. This is driven by supportive policies in several countries that reflect the attractiveness of biomethane as a drop-in substitute for natural gas and its energy security benefits (Box 4.7).

Box 4.7 ▹ Energy security benefits of biogas: focus on the European Union

Biogases, which include both biogas and biomethane, are homegrown resources and are consumed in the country in which they are produced. For countries dependent on imported gas, developing production of biogases can bring energy security benefits. Its development relies on policy support as production costs are currently double natural gas prices.

Figure 4.45 ▹ Impacts of biomethane production in the European Union in the STEPS, 2035



Expanding EU biomethane production decreases fuel import needs by more than USD 2 billion by 2035 while providing new jobs and reducing emissions

Note: bcm = billion cubic metres; Mt CO_2-eq = million tonnes of carbon-dioxide equivalent.

Recent global spatial analysis by the IEA of biogas potential concluded that nearly 1 trillion cubic metres of natural gas equivalent of biogas could be produced sustainably each year (IEA, 2025f). Only around 5% of the global potential for sustainable production of biogas and biomethane is currently being used. Though currently the European Union makes use of around 40% of its biogas potential – more than any other region or country

[5] One bcme is a measure of energy and equals 36 petajoules based on the lower heating value.

– and has set ambitious biomethane targets as part of its efforts to develop domestic energy sources and eliminate imports of Russian gas. In Denmark, biogas accounts for 40% of overall gas demand. Biogas production in France is growing rapidly. In the European Union, the annual savings in reduced fossil fuel imports from biomethane consumption rise to USD 2 billion by 2035 in the STEPS, and the increased use of biomethane also reduces emissions and creates jobs (Figure 4.45).

Implications of CPS and STEPS

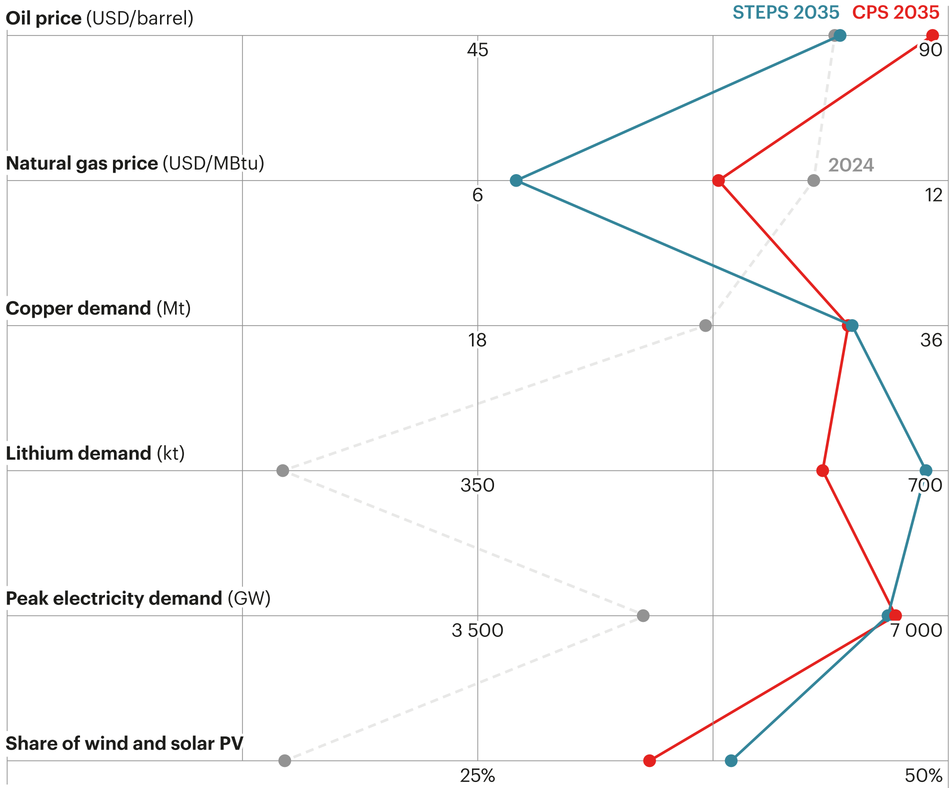
Between continuity and change

SUMMARY

- By 2035, energy demand in the Current Policies Scenario (CPS) is around 35 exajoules (EJ) higher than in the Stated Policies Scenario (STEPS), a difference roughly equivalent to the current annual energy demand of the Middle East. All the extra energy required in the CPS compared to the STEPS comes from oil, natural gas and coal.
- In the absence of renewed geopolitical disruptions, markets for oil and natural gas appear well supplied in the coming years. But production from existing oil fields declines at a rate of 8% per year, if no investment is made, so it does not take long for supply to tighten – especially with higher oil demand in the CPS. Around 20 million barrels per day (mb/d) of new supply from yet-to-be approved projects come through in the STEPS by 2035 to ensure a balance between supply and demand, and around 25 mb/d in the CPS.
- Emerging market and developing economies in Asia, including China, are the destination for nearly 60% of the oil and gas exported globally in 2035 in both scenarios, up from 45% today. The total fossil fuel import bill for these countries rises by 40% in the CPS over the next ten years, reaching USD 1.2 trillion by 2035. Although total energy investment is marginally lower in the CPS than in the STEPS, energy prices and overall energy bills are generally higher.
- Supplies of key critical minerals are catching up with demand growth to 2035 if anticipated projects come through on time, with the important exception of copper. But the high level of market concentration means that there is a risk of significant shortfalls if supply from the largest producing countries is disrupted for any reason.
- By 2035, electricity is responsible for around 25% of total final consumption in both scenarios, compared with 21% today. By then, around half of global economic output depends directly on electricity, and peaks in demand are rising, exacerbated by periods of extreme heat that push up cooling use. Both scenarios show a more complex electricity system in which the increasing use of electricity underlines the vital and growing importance of electricity security.
- A new IEA dataset shows that extreme weather events caused operational disruptions to critical energy infrastructure and power outages to 210 million households in 2023. Extreme temperatures driving up peak demand could lead to a loss of two-thirds of planning reserve margins in the worst affected regions, underlining the need for increased climate resilience planning and implementation.
- High levels of emissions point towards a temperature rise above pre-industrial levels of 2.9 °C in the CPS and 2.5 °C in the STEPS by 2100, well above the levels targeted in the Paris Agreement.

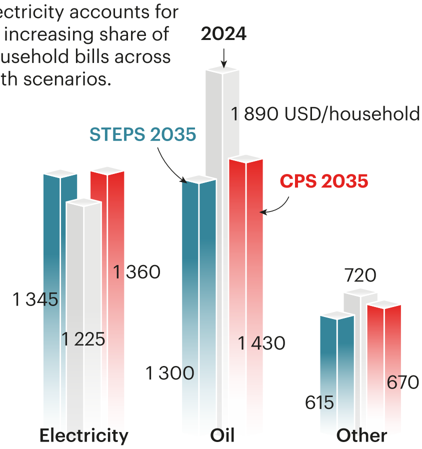
Energy security indicators

Energy security cannot be measured with a single indicator: multiple risks and opportunities coexist across both the STEPS and CPS.



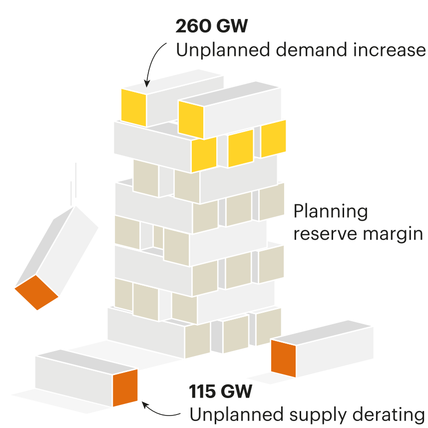
Energy bills in advanced economies

Electricity accounts for an increasing share of household bills across both scenarios.



Electricity security

Among other risks, extreme temperatures impact electricity demand and supply

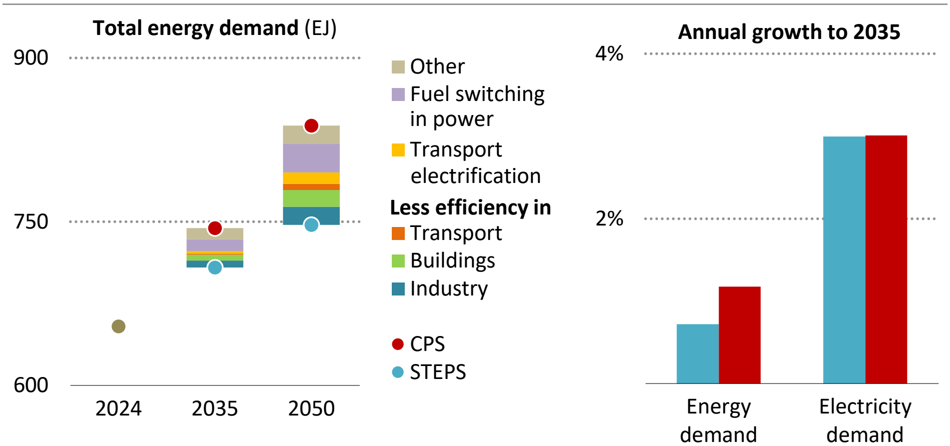


5.1 Overview

In some respects, the Stated Policies Scenario (STEPS) and the Current Policies Scenario (CPS) are similar. Both describe outlooks in which energy demand continues to grow, and in which there is continued investment in all fuels and all technologies. But there are important differences that lead to divergences over time that have an impact on energy security risks, emissions and the environment, and investment and affordability trends. In this chapter we consider each of these three key elements in turn.

The STEPS and CPS have the same levels of economic growth and similar energy service demand throughout the projection period to 2050. However, differences in the stringency of energy efficiency policies, in fuel mixes and in electrification result in variations in the outlook for total energy demand. In the CPS, total energy demand increases by around 1.2% per year to 2035. In the STEPS, it increases by around 0.7% per year. Demand grows more slowly in the STEPS for a range of reasons: there is less use of fossil fuels in the electricity sector, which lowers conversion losses; increased use of more efficient electric technologies, particularly in transport; and more rapid progress on efficiency improvements. By 2035, total energy demand is around 35 exajoules (EJ) higher in the CPS than in the STEPS, which is roughly equivalent to the current annual energy demand of the Middle East (Figure 5.1).

Figure 5.1 ⊳ Factors driving the difference in total energy demand, 2024-2050 and rate of demand growth by scenario, 2024-2035



CPS has a slower rate of energy intensity improvements, leading to a large and widening difference in global primary energy demand over time

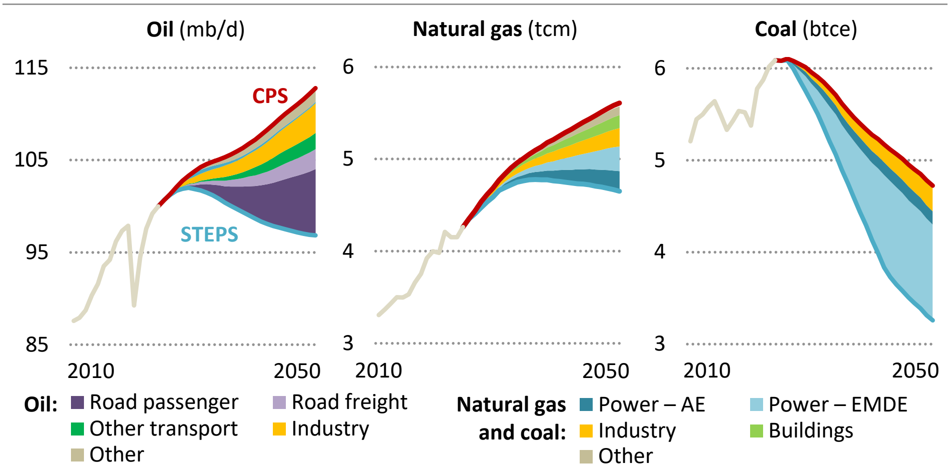
Note: EJ = exajoule; CPS = Current Policies Scenario; STEPS = Stated Policies Scenario.

More of the energy demand in the CPS is met by fossil fuels than in the STEPS. Today total demand for oil, natural gas and coal is around 520 EJ: by 2035, this rises to around 540 EJ in the CPS and falls to about 500 EJ in the STEPS. Global oil demand grows at a rate of around

0.4% per year to 2035 in the CPS, while the STEPS sees a peak around 2030 and a subsequent modest decline. This puts the oil demand trajectory firmly within the range of comparable scenarios produced by other organisations (Box 5.1). While the share of electric cars in total passenger car sales increases in both scenarios, it does so more slowly in the CPS, rising from around 20% today to reach around 40% worldwide by 2035, compared with over 50% in the STEPS. Slower sales of electric vehicles (EVs) explain around 40% of the difference in oil demand between the two scenarios by 2035.

Natural gas becomes the second most widely used fossil fuel in both scenarios, overtaking coal before 2035. Natural gas use in the electricity sector is around 15% higher in the CPS by 2035 than today, although its share in total electricity generation falls marginally. In the STEPS, faster efficiency improvements, higher levels of renewables deployment and output, and stronger end-use electrification together dampen natural gas demand growth in electricity generation and end-uses. Total gas demand growth averages 1% per year in the STEPS to 2035, compared to 1.3% over the past five years, and natural gas use in the electricity sector is around 10% higher by 2035 than today (Figure 5.2).

Figure 5.2 ▷ Fossil fuel demand in the STEPS and additional demand in the CPS by sector, 2010-2050



Oil demand is higher In the CPS as the uptake of EVs is slower; there is also higher demand for gas and coal notably in emerging market and developing economies

Notes: mb/d = million barrels per day; tcm = trillion cubic metres; btce = billion tonnes of coal equivalent; AE = advanced economies; EMDE = emerging market and developing economies. Other for oil includes power and buildings. Other for natural gas includes transport.

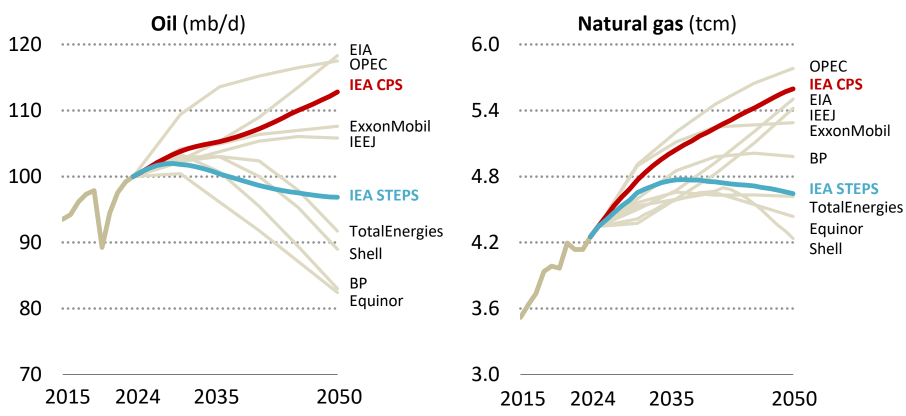
The CPS sees coal use plateau for the next few years before falling, albeit more gradually than in the STEPS. By 2050, coal use is almost 50% higher in the CPS than in the STEPS – a bigger difference in outcomes between the two scenarios than for any other fuel. Most of it stems from the prolonged use of coal in the electricity systems of emerging market and developing economies, notably China and India, but the United States also sees a less steep drop for coal use in power generation.

Box 5.1 ▷ *World Energy Outlook* projections for oil and natural gas compared with other assessments

In this *World Energy Outlook*, global oil demand in 2050 is 113 million barrels per day (mb/d) in the CPS and 97 mb/d in the STEPS, while natural gas demand reaches 5 600 billion cubic metres (bcm) in the CPS and almost 4 650 bcm in the STEPS. These levels fall within the range of comparable scenario projections recently published by governments, companies and other international organisations.

None of the scenarios used for comparative purposes is designed to meet specific goals, such as those of the Paris Agreement. However, each scenario is a product of varied methodologies, as well as differing assumptions about economic growth, global co-operation, commodity prices, technology costs, relative strength of existing and planned energy policies, competition between fuels and technologies in different sectors, and rates of innovation. As a result, the outlooks differ significantly (Figure 5.3).

Figure 5.3 ▷ Comparative scenarios of global oil and gas demand to 2050



IEA CPS is near the middle of a range of scenarios that project strong continued growth in oil and gas; the IEA STEPS sits with other outlooks that project declines to 2050

Notes: mb/d = million barrels per day; tcm = trillion cubic metres. IEA CPS = International Energy Agency Current Policies Scenario; IEA STEPS = International Energy Agency Stated Policies Scenario. Reference scenarios are shown for the US Energy Information Administration (EIA) (2025); ExxonMobil (2025); The Institute of Energy Economics, Japan (IEEJ) (2025); and the Organization of Petroleum Exporting Countries (OPEC) (2025). Other scenarios include: Current Trajectory scenario from BP (2025); Walls scenario from Equinor (2025); Surge scenario from Shell (2025); Trends scenario from TotalEnergies (2025). Values are adjusted to match IEA historical values, definitions and energy conversion factors.

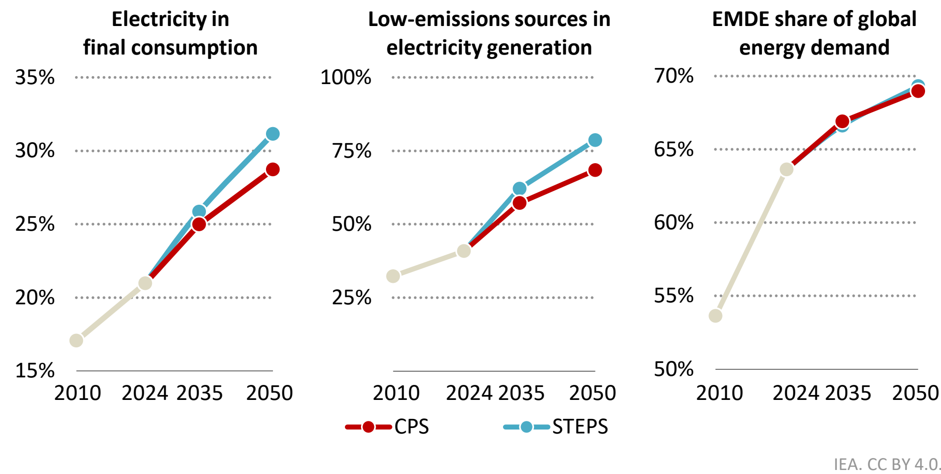
The range of assessments of future oil demand vary by around 35 mb/d in 2050. The CPS, the reference scenarios of the US Energy Information Administration (EIA), and the Organization of Petroleum Exporting Countries (OPEC) all show a rising trajectory for global oil demand, with both the EIA and OPEC projecting levels of oil demand around 120 mb/d in 2050. In contrast, oil demand remains relatively flat in both the STEPS and the reference scenarios developed by the Institute of Energy Economics in Japan (IEEJ), and by ExxonMobil. Other scenarios show sharper declines, with demand in 2050 ranging between 82 and 89 mb/d.

There is more divergence among the scenarios in natural gas demand. The susceptibility of natural gas to a wider range of outcomes than oil is due in part to its higher price sensitivity, which stems from fierce competition between natural gas and other fuels and technologies across sectors. It also reflects the way in which natural gas sits at the crossroads of energy transitions, with a role that is capable of changing substantially depending on geography, timeframe and sector. The CPS has a level of natural gas demand in 2050 that is close to the US EIA, OPEC and IEEJ reference scenarios; the STEPS sits slightly below the middle of the full range of scenarios and is one of several scenarios that project a peak and decline in natural gas demand by 2050.

Two other broad trends characterise both the STEPS and the CPS. First is the growing importance of emerging market and developing economies in global energy demand and energy markets, despite a continuing lack of access to modern energy services in numerous countries. Between 2014 and 2024, the share of emerging market and developing economies in global energy demand increased from around 55% to around 65%. Their share continues to rise in both scenarios, though it does so less rapidly than in the past decade because energy demand growth in China slows in the years ahead. Progress in closing the electricity and clean cooking access gaps slows in both scenarios as China, India and Indonesia near universal access, leaving countries with less fiscal room for manoeuvre and weaker policies with most of the work that still has to be done. (The implications of the CPS and STEPS for the energy access gaps are explored in Chapter 6.)

Second is the trend of expanded penetration of renewables in the electricity generation mix and a higher share of electricity in total final consumption. This is visible in both the STEPS and CPS, although the rate differs. The global share of renewables in electricity generation – around 30% today – reaches around 50% in the CPS in 2035 and around 55% in the STEPS, while the share of electricity in total final consumption – around 20% today – reaches around 25% in both the STEPS and CPS by 2035. In the CPS this stems from rising demand for electricity in industry and other uses; while a faster rate of increase in the STEPs reflects a more prominent role for new end-uses of electricity such as mobility and heat (Figure 5.4). The share of electricity in total final consumption stays more or less the same in both scenarios because a faster rate of energy efficiency improvements in the STEPS offsets increased use of electricity.

Figure 5.4 ⊳ Selected energy indicators by scenario to 2050



Both scenarios see low-emissions sources accounting for more power generation and emerging market and developing economies increasingly dominating energy demand

Note: EMDE = emerging market and developing economies; CPS = Current Policies Scenario; STEPS = Stated Policies Scenario.

5.2 Energy security

There is no single fuel, technology or trend that dominates the narrative in either scenario. In setting energy and economic policy frameworks, governments have to navigate a complex world in which multiple sources of energy with distinct characteristics co-exist, and to grapple with both traditional and emerging security issues.

Energy security has long been defined by the IEA as the uninterrupted availability of energy sources at affordable prices. This implies the need to consider a diverse set of vulnerability indicators across the energy system, including for example: the share of oil and gas transiting through maritime chokepoints such as the Strait of Hormuz; the increase in variable supply and peak demand for electricity; market balances and supply concentration of critical minerals; and energy security risks arising from extreme weather events that are exacerbated by continued high levels of energy-related emissions.

Today, tense geopolitical situations and the uncertainties about global trade have commodity markets on edge. However, a softening of market balances may be on the horizon for a range of commodities, including oil and natural gas, and potentially for some critical minerals such as nickel and cobalt. Since there is also currently a surplus of manufacturing capacity for technologies such as batteries and solar photovoltaics (PV), a period of downward pressure on prices looks likely for the remainder of the 2020s.

Nonetheless, there is no room for complacency. The IEA scenarios show how quickly supply buffers can be eroded and oil and gas investment levels rendered insufficient. Markets can quickly be thrown out of balance, for example, by higher than expected energy demand growth, disruption to supply or a lack of effective policies to manage energy security challenges. Diversity of supply remains a cornerstone of energy security, particularly since the production and supply of some key commodities and critical minerals is highly concentrated geographically. This is as relevant for electricity and associated energy technologies such as batteries or EVs as it is for oil and gas. Electricity is increasingly important to the functioning of modern economies, and electricity systems are becoming increasingly complex. Maintaining electricity security therefore is a key priority. We explore these issues in more detail below.

5.2.1 Fuel security

The continued centrality of oil and gas in both the STEPS and CPS demands vigilance on a range of risks, including those that bear on the adequacy of upstream investment to meet changes in demand, the availability of sufficient infrastructure such as liquefied natural gas (LNG) and refining capacity to meet market needs, and the need for diversification of supply in the face of high levels of market concentration.

Adequacy of upstream investment and resource development

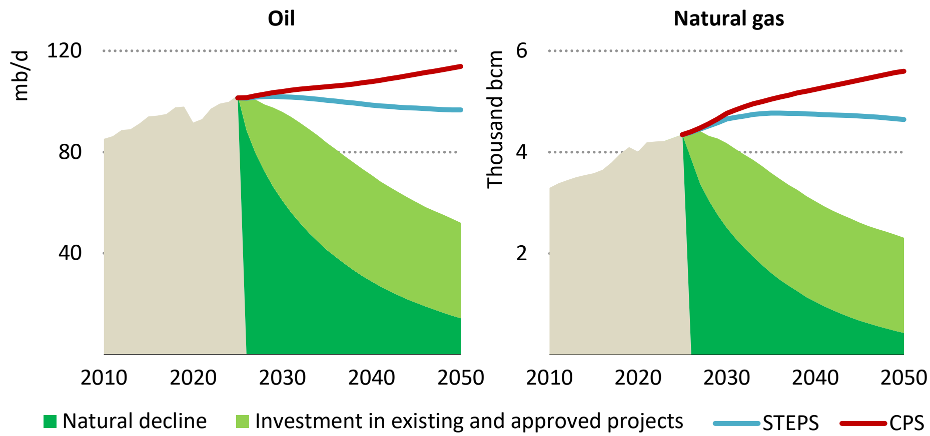
Declining output from existing fields is a key driver for new investment in oil and gas development. Around 90% of annual upstream oil and gas investment since 2019 has been to offset production declines rather than to meet demand growth. If no new fields were to start up and no capital expenditures were made on any current supply source, then oil production to 2035 would fall on average by around 8% per year, or around 5.5 mb/d on average, often referred to as the natural decline rate. This is equivalent to losing more than the annual output of Brazil and Norway each year (IEA, 2025a). Natural gas production would fall as well, decreasing by an average of 9%, or 270 bcm, each year, which is roughly equivalent to the current total natural gas production from Africa.

In reality, investment is set to continue in existing oil and gas fields, and approved projects currently under development are expected to ramp up. Yet this serves merely to reduce the projected rate of decline in conventional sources of oil and gas supply to around 4-5% per year on average. New, yet-to-approve conventional oil and gas projects are therefore needed. In the STEPS, nearly 20 mb/d of new conventional supply comes online by 2035 to ensure a smooth balance between supply and demand. In the CPS, this rises to around 25 mb/d. For natural gas, around 1 200 bcm of new conventional supply comes from new projects in the STEPS by 2035, and this rises to close to 1 500 bcm in the CPS (Figure 5.5).

Declines in existing sources of supply incorporate very sharp falls for tight oil and shale gas. Maintaining or increasing production in these fields could make a major contribution to filling the supply gap that emerges in the STEPS and CPS. However, there are limits to how responsive such fields can be, especially in the absence of higher commodity prices. (See

Chapter 3, Box 3.3). Spare crude oil production capacity could potentially be used to fill the gap. As of October 2025, global spare oil production capacity is around 3.5 mb/d (excluding Iran, Russia and Venezuela), 60% of which is in Saudi Arabia. However, this buffer could be quickly eroded; for example, crude oil production in Saudi Arabia increases by more than 0.5 mb/d to 2035 in the CPS.

Figure 5.5 ▷ Oil and natural gas supply by scenario to 2050



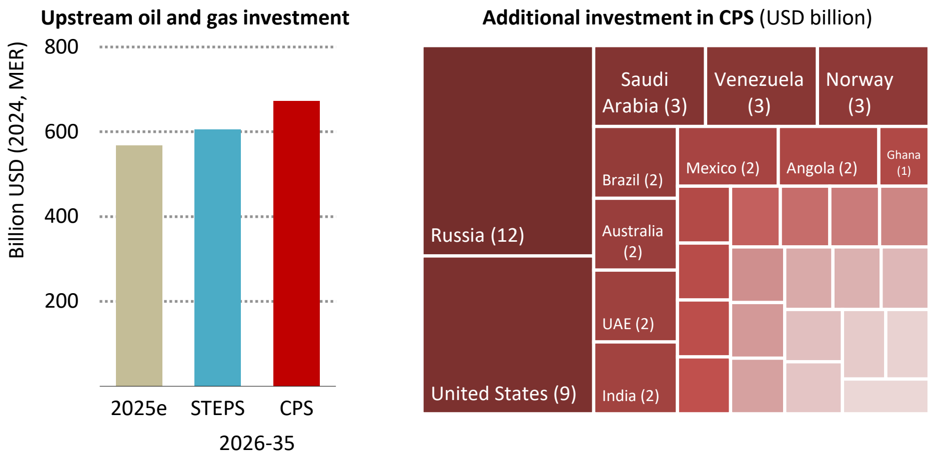
Most investment in both scenarios offsets decline in existing fields, though the CPS requires investment in higher cost supply to meet rising demand

Notes: mb/d = million barrels per day; bcm = billion cubic metres; STEPS = Stated Policies Scenario; CPS = Current Policies Scenario. Approved projects = conventional projects that received final investment decision before July 2025.

Whether the current investment levels in upstream, refining and transport assets for oil and gas are sufficient to meet demand in the scenarios is a key consideration. Macroeconomic uncertainties and a drop in oil prices in 2025 are set to reduce upstream oil and gas investment in 2025 by around 5% to a total of USD 570 billion – the first reduction since the Covid-19 pandemic. Today's level of total oil and gas investment is just under the average annual level in the STEPS to 2035. This is in part because of structural cost reductions per barrel of oil, which have been achieved in recent years thanks to increased capital discipline in the oil and gas sector, changes in the types of projects executed, and changes in the design of projects.

Upstream investment in oil and gas is about 10% higher in the CPS than in the STEPS, averaging an additional USD 65 billion to 2035 (Figure 5.6). This is more than the difference in oil and gas demand between the two scenarios (demand in the CPS is 5% higher than in the STEPS in 2035). This is because the additional resources that are developed above the level of the STEPS are, in aggregate, higher cost sources of supply: investment has to be increasingly directed to explore and develop new fields in frontier basins, and supporting infrastructure built from scratch. In the CPS, global oil prices are 10% higher than in the STEPS at around USD 90 per barrel in 2035, and natural gas prices in the European Union and East Asia are around 30-40% higher than in the STEPS. Natural gas prices in the STEPS during this period are close to the short-run marginal cost of delivering LNG, while in the CPS they reflect the long-run marginal cost of developing new supply. These higher prices unlock investment in higher cost sources of supply, but they also feed through to upstream cost inflation which makes all resource developments generally costlier to develop in the CPS than in the STEPS. Higher rates of depletion of existing resources to meet the increase in demand also contributes to price increases.

Figure 5.6 ⊳ Average annual investment in oil and natural gas supply by scenario to 2035



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An extra USD 65 billion of upstream oil and gas investment per year is needed in the CPS, 60% of which is invested in just ten countries

Note: MER = market exchange rate; STEPS = Stated Policies Scenario; CPS = Current Policies Scenario; 2025e = estimated values for 2025; UAE = United Arab Emirates.

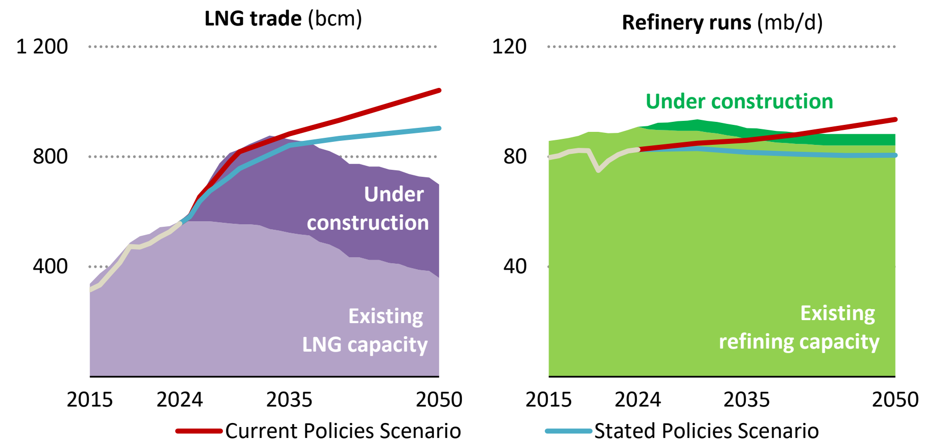
The CPS includes higher production from a range of major resource-holding countries to balance supply and demand, and OPEC+ oil production in 2050 is 15% higher, 8 mb/d, than at any point in the history of oil markets. This assumes that constraints on oil production and trade in countries currently subject to sanctions ease, but it is possible that sanctions will remain in place longer, and perhaps all the way though to 2050. In this case, the additional production would need to come from alternative suppliers, such as the United States, Canada, Brazil and large producers in the Middle East. This would require increased investment and would be likely to entail higher prices than those currently projected in the CPS.

Refining and LNG

Existing infrastructure is better equipped to meet the slower oil and gas demand growth in the STEPS than in the CPS. This is visible in the utilisation rates of midstream assets such as LNG terminals and oil refineries.

Available LNG liquefaction capacity, taking into account retirements and maintenance, expands by 265 bcm between 2024 and 2030. While this is enough to cover near-term demand growth in both scenarios, the CPS sees a supply gap opening in the early 2030s, several years earlier than in the STEPS. In 2050, the CPS requires 340 bcm of additional annual LNG export capacity above what is in place and under construction today (accounting for retirements); the STEPS needs an additional 200 bcm of annual export capacity.

Figure 5.7 ▹ Global LNG trade and oil refinery runs by scenario relative to existing and under construction capacity



LNG projects can meet STEPS demand until the late 2030s and CPS demand until the early 2030s; refining capacity is sufficient in the STEPS, but an additional 5 mb/d is needed in CPS

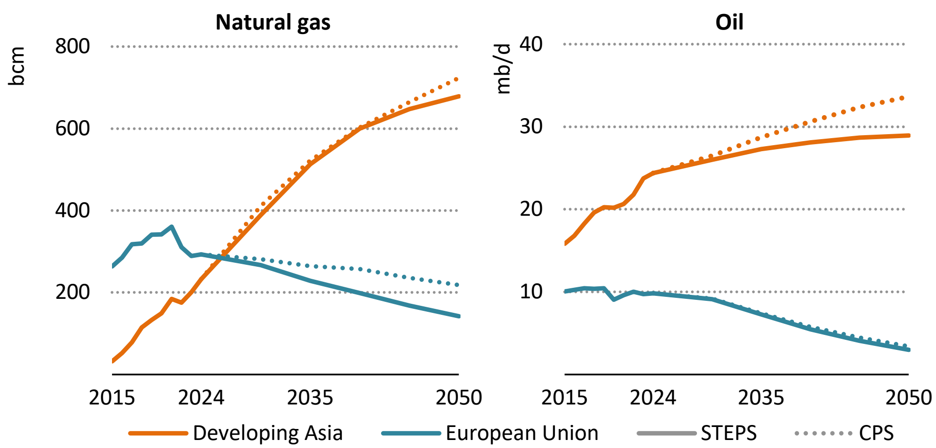
Note: bcm = billion cubic metres; mb/d = million barrels per day.

For oil refining, the degree of surplus or deficit in practice is dependent on market dynamics in individual countries, but on a global basis existing capacity is sufficient to meet demand through to 2050 in the STEPS, while in the CPS a supply gap opens in the early 2040s (Figure 5.7). In both scenarios, demand becomes more geared toward petrochemical feedstock; this favours refineries that are closely integrated with petrochemical plants, most of which are based in Asia and the Middle East.

Import dependence and diversification

Emerging market and developing economies in Asia, including China, are the destination for nearly 60% of the oil and gas exported globally in 2035 in both scenarios, up from 45% today. Natural gas imports in the region more than double in both scenarios to 2035 (Figure 5.8). Southeast Asia, currently a net exporting region for natural gas, shifts to a net importer over the course of the next decade: to 2035, its demand for gas rises by 30% while its gas production drops by 15%. Similar trends are projected for India, where natural gas import dependence rises from around 50% today to 70% in 2035. Additional imports also cover the full increase in oil demand growth in India to 2035.

Figure 5.8 ⊳ Natural gas and crude oil net imports in selected regions by scenario to 2050



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Oil and gas imports rise significantly in emerging market and developing economies in Asia to reach 60% of global oil and gas trade by 2035

Note: bcm = billion cubic metres; mb/d = million barrels per day; STEPS = Stated Policies Scenario; CPS = Current Policies Scenario.

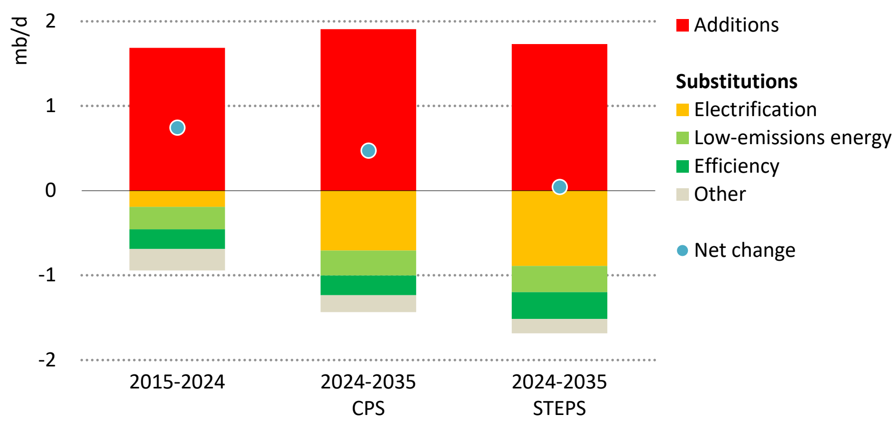
Total imports of oil and gas in the CPS are about 6% higher than in the STEPS in 2035, and 20% higher in 2050. In the CPS, emerging market and developing economies in Asia import 560 bcm of LNG in 2050, four-times more than today, and 160 bcm of long distance pipeline gas, more than double today's level; oil imports rise to 35 mb/d by 2050, which represents 95% of their aggregate oil demand. The total fossil fuel import bill for those economies in Asia increases from USD 900 billion today to USD 1.2 trillion by 2035 in the CPS: this is 25% higher than in the STEPS, where the bill is moderated by larger substitution effects (Box 5.2).

Box 5.2 ⊳ Forces driving oil substitution are stronger in the STEPS than in the CPS

All major sources of energy hit record high levels in 2024. Global energy demand rose 2%, spurred by a 1.5% increase in fossil fuel demand, while electricity generation from wind and solar increased by 17%. Both the CPS and the STEPS see demand for energy services increases continuing in future years. How this translates into overall energy demand for each energy source is subject to inter-fuel competition based on costs, technologies and policies that vary by scenario.

Oil demand growth in recent years illustrates some of the dynamics. Over the last decade, demand for energy services dominated by oil, such as mobility, rose by over 1.5 million barrels of oil equivalent per day (mboe/d) as a result of factors such as increased economic activity, rising levels of vehicle ownership and expanding population. However, there were also forces at work leading to a reduction in demand for oil through efficiency gains, for example from improvements in the fuel economy of conventional cars, or with direct substitution of oil by another energy source, as in EVs replacing internal combustion engine vehicles, or blending gasoline with ethanol, or using renewables or natural gas to replace oil use for power or in buildings and industry. Together such forces led to just under 1 mb/d of oil substitution on average between 2015 and 2024, meaning the net increase in oil demand, accounting for both additions and substitutions, was closer to 0.7 mb/d per year.

Figure 5.9 ⊳ Average annual change in oil demand due to additions and substitutions by scenario, 2015-2035



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Oil substitution is stronger than in the last decade in both scenarios, but oil demand stays flat in the STEPS reflecting gains from clean energy, efficiency and electrification

Note: mb/d = million barrels per day; STEPS = Stated Policies Scenario; CPS = Current Policies Scenario.

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Both scenarios illustrate how the dynamics might play out in the years ahead. In the CPS, growth in oil demand based on underlying activity levels is slightly stronger between 2024 and 2035 than in the previous decade, but the rate of oil substitution through efficiency, clean energy and electrification is also stronger: the annual net change in demand is just under 0.5 mb/d, which is roughly two-thirds of the increase seen in the previous decade. In the STEPS, underlying oil demand growth from increased economic activity is broadly in line with the rate of increase over the last decade, but more rapid uptake of EVs and larger efficiency gains than in the CPS is enough to keep oil demand in 2035 close to today's levels.

5.2.2 Electricity security

Electricity accounts for 21% of total final consumption, compared to nearly 40% for oil, but its importance is more significant than the numbers alone suggest. Electricity is crucial to maintain essential services such as communications and healthcare, and the digital services underpinning many sectors, including transport and logistics, retail trade and public services; households depend on it for everyday energy services; and it disproportionately powers high value-added sectors like financial services and advanced manufacturing. This means that the economic costs of electricity outages are very high. Examples such as 2025 outages in Chile in February and in April across the Iberian Peninsula affecting Portugal and Spain serve as reminders of how disruptions can cascade and affect millions (see Chapter 8). As the share of electricity in final consumption increases and power systems become more complex, electricity security is becoming more and more important. This section explores how different aspects of electricity security evolve in both scenarios.

Ensuring resource adequacy is essential to electricity security

Given that electricity demand and supply must match at all times, system operators need to ensure adequate resources to meet peak demand.[1] Generation capacity, transmission lines, storage technologies and flexible demand all have a part to play. The challenges that system operators face to meet increasing peak demand is becoming more complex as electrification, climate change and new consumption patterns shift demand profiles.

Both scenarios see similar levels of peak demand growth to 2035, implying similar challenges to ensure resource adequacy. However, the drivers of peak demand differ (Figure 5.10). By 2035, peak electricity demand rises across all regions in the STEPS, but the largest growth is concentrated in emerging market and developing economies: the sum of peak demands in different electricity systems worldwide is projected to increase by 40% from around 4 750 gigawatts (GW) in 2024. The adoption of EVs and electrification of space heating push peak demand higher in advanced economies, while expanding ownership of air conditioners

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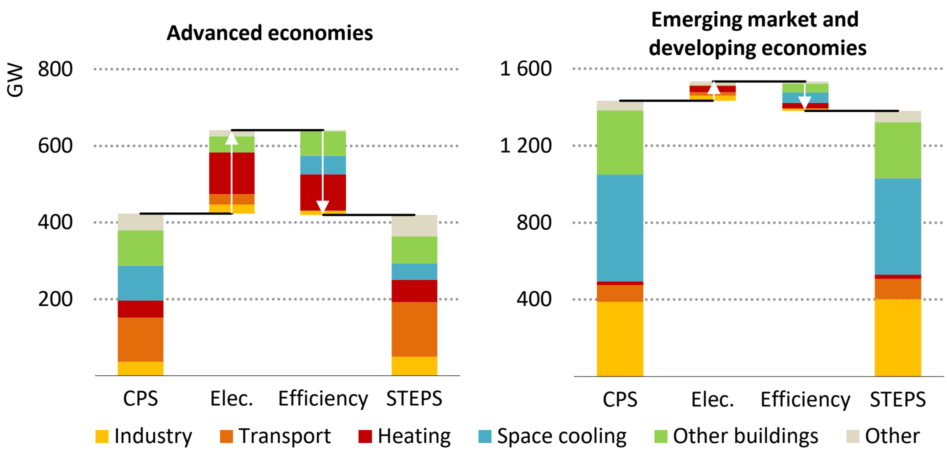
[1] Peak electricity demand refers to the highest level of electricity consumption during the year, before the activation of any demand response measures.

and appliances helps to drive up peak demand in emerging market and developing economies. In the CPS, slower rates of efficiency improvements in appliances such as air conditioning lead to growth in peak demand that is comparable to that in STEPS, despite overall lower levels of electrification.

Figure 5.10 ▷ Peak electricity demand growth by economic grouping and selected end-uses by scenario, 2024-2035



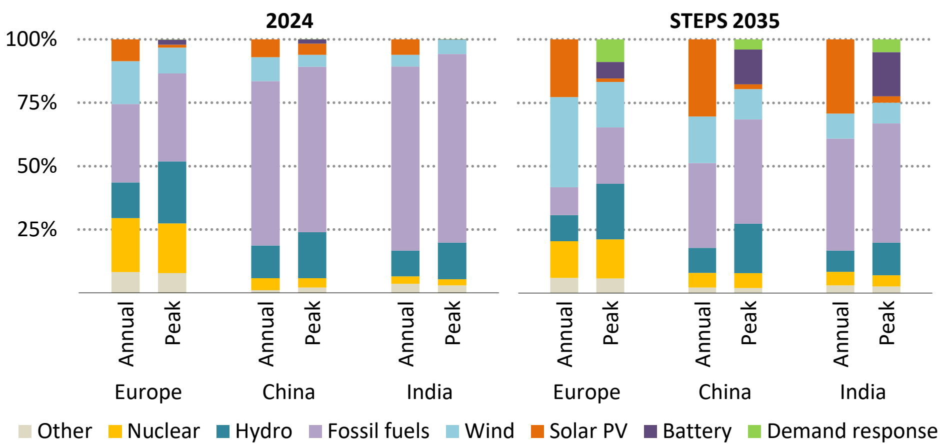
Peak demand increases by 1 800 GW by 2035, largely driven by cooling, with peak levels comparable in both scenarios, but lower efficiency offsets lower electrification in the CPS

Note: GW = gigawatt; Elec. = electrification; STEPS = Stated Policies Scenario; CPS = Current Policies Scenario.

Peak electricity demand is a key metric for assessing resource adequacy for electricity systems. Systems characterised by high shares of variable renewables must be designed to meet demand when low output coincides with periods of high demand, i.e. peak residual load. At these times, the supply mix differs significantly from the average mix across a year. Lower output from wind and solar PV is compensated for by operating dispatchable plants, such as natural gas, coal, hydro or nuclear plants, at close to their maximum available capacity, by discharging storage and by shifting load through demand response. Today most capacity adequacy in Europe is supplied from nuclear, hydro and fossil fuels; most in India and China from dispatchable fossil fuel plants, mainly powered by coal. While these sources remain critical, the picture changes noticeably in each of these by 2035 in the STEPS, with battery storage and demand response contributing around 20% of peak net demand (Figure 5.11).

While resource adequacy planning largely deals with times of low renewables output, hours with very high shares of variable renewable generation can also present operational challenges. For example, system operators must ensure the system has sufficient inertia to slow frequency deviations following sudden imbalances, allowing time for control and protection systems to respond and maintain grid stability. This can be achieved by keeping online a base level of synchronous generation from sources such as thermal or hydropower plants. System operators can also use synthetic inertia from battery storage or variable renewable generators with grid-forming inverters and deploy technologies like enhanced static synchronous compensators and synchronous condensers at strategic points in the grid.

Figure 5.11 ▹ Annual electricity supply mix and in peak residual load hours in Europe, China and India in 2024 and in the STEPS in 2035



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Dispatchable power sources remain important, batteries and demand response are set to become increasingly important providers of secure capacity in peak residual load hours

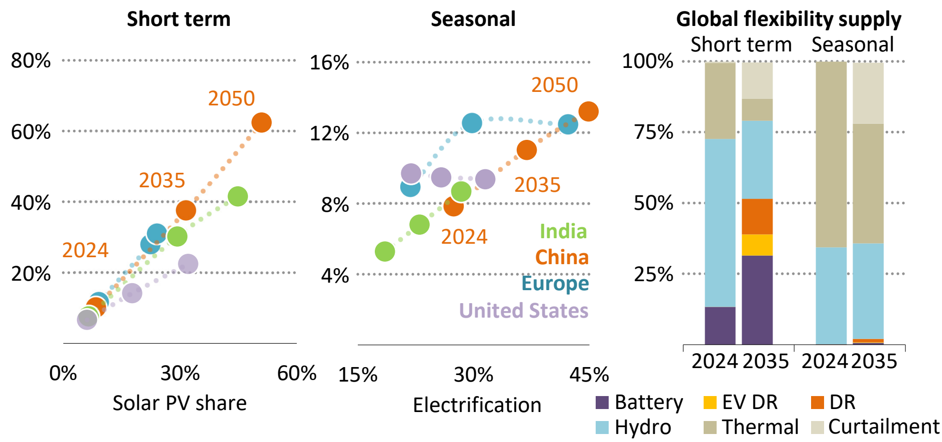
Notes: Other includes bioenergy, geothermal and other renewables. Hydro includes reservoir, run-of-river and pumped storage. Peak residual load is defined as the top 100 hours of the residual load, i.e. demand less generation by variable renewables, over a year.

Flexibility

In addition to having sufficient resources to meet peak demand, electricity systems must be flexible enough to manage variability in demand and supply, ensuring the instantaneous stability of the grid and maintaining balance every hour, in all seasons (Figure 5.12). As both variable renewable energy deployment and the electrification of end-uses increase, power system flexibility challenges evolve in scale and complexity.

Short-term flexibility addresses hour-to-hour variations in demand and supply. Today, typical requirements for short-term flexibility are equivalent to around 10% of average demand in many systems. By 2035, these requirements are projected to increase by two- to seven-times in the STEPS. India and China experience a particularly rapid rise in short-term needs due to their reliance on solar PV. Europe follows a similar trajectory as China, with short-term needs reaching around 30% of average demand once the share of solar PV exceeds 25% of generation. While Europe reaches this threshold by 2050, China overtakes it in 2035.

Figure 5.12 ⊳ Short-term and seasonal flexibility needs in selected countries, 2024-2050, and global flexibility supply in the STEPS, 2024 and 2035



Higher shares of variable renewables and evolving electricity demand patterns increase flexibility needs; batteries and demand response emerge as key flexibility sources

Notes: DR = demand response; EV DR = electric vehicle smart charging. Short-term and seasonal flexibility needs are measured relative to average electricity demand. Electrification represents the share of electricity in total final consumption. Thermal = fossil fuels, nuclear, bioenergy, hydrogen and ammonia. Curtailment refers to the curtailment of wind and solar PV generation.

Seasonal flexibility requirements are driven by longer term imbalances, e.g. weekly and monthly, caused by temperature-sensitive demand and weather-dependent generation. Such requirements vary significantly by region, reflecting differences in climate and power generation mix. In Europe, seasonal flexibility needs expand faster than overall electricity demand, driven by the electrification of heating. In India and China, rising cooling demand has a similar effect, leading their seasonal flexibility needs to also increase faster than overall demand to 2035. In the United States, seasonal flexibility needs increase in line with overall electricity demand, remaining relatively stable at around 10% of demand.

In most regions, short-term flexibility needs increase more in the STEPS than in the CPS. This is largely because the STEPS sees faster uptake of variable renewables in power generation than the CPS. However, lower appliance efficiencies in the CPS also amplify demand variability, somewhat offsetting the effect of having a smaller proportion of variable renewables in the generation mix.

Seasonal flexibility requirements evolve in a broadly similar manner in both scenarios. Power grids and interconnections help even out fluctuations in demand and supply by connecting generators dispersed over a wide area within and between countries and regions. Thus, they help reduce the demand for flexibility from other sources while at the same time connecting further potential providers of flexibility. Ageing transmission and distribution infrastructure meanwhile presents a growing challenge to system reliability and resilience. Electricity security requires targeted efforts to modernise and digitalise grid infrastructure.

Batteries and demand response measures supply the bulk of short-term flexibility by 2035 in both scenarios. Batteries are well suited to complement solar PV by charging during periods of high solar output and discharging during evening peaks. Demand response offers a cost-effective source of flexibility by shifting consumption away from peak periods by means such as flexible EV charging, or optimised use of smart air conditioners, heat pumps and power-to-heat in industry, though it depends on consumers being incentivised to participate, e.g. variable tariffs (see Chapter 4).

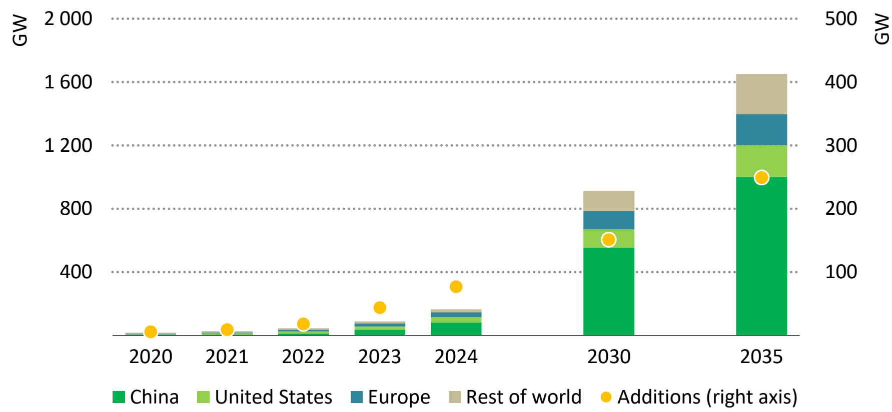
Long-established technologies remain important for the provision of flexibility. Dispatchable hydropower remains a key low-emissions contributor, though its effectiveness depends on robust water resource management, particularly in the face of increasing drought risks. Thermal power plants too continue to play an important role to provide ramping and seasonal flexibility, though their role increasingly shifts from bulk electricity generation to the provision of secure capacity once variable renewables start to account for significant shares of total electricity generation. This change in the role of thermal plants may require updating existing contracts, technical upgrades and a shift towards more flexible assets, such as peaking plants. Curtailment also becomes an integral feature of future power systems with high shares of variable renewables. While curtailment can be the result of an insufficiently flexible power plant fleet or a congested grid, it can also serve as a cost-effective alternative to overbuilding of grid and storage infrastructure.

Box 5.3 ⊳ Battery storage: a multi-tool for the electricity system

Battery storage plays an increasingly important role in electricity systems, providing short-term flexibility to help integrate rising shares of variable renewables, in particular solar PV, and to meet increasing residual peak demand (battery storage is not suitable for managing seasonal variability). In addition to energy shifting, batteries can provide a broad suite of services that are essential for electricity security. Their split-second responsiveness makes them ideal providers of ancillary services such as synthetic inertia, frequency regulation, voltage support and operating reserves, as well as secure capacity to maintain the adequacy of the power supply. If placed strategically in grids, batteries can also support congestion management, enabling the deferral of investment in transmission and distribution infrastructure. This is particularly valuable in regions where the expansion of power grids lags the pace of growth in demand, electrification or the deployment of variable renewables.

In 2024, 77 GW of battery storage was added globally, of which roughly 80% was utility-scale and 20% was behind-the-meter, up 75% from the level of additions in 2023. China continued to lead capacity growth, followed by the United States and Europe. The rapid expansion of battery storage is underpinned by dramatic declines in cost: thanks to innovation and economies of scale; lithium-ion battery prices have dropped by over 90% since 2010. Falling battery and solar PV costs, along with technology improvements, are enabling renewables-plus-storage projects worldwide.

Figure 5.13 ▷ Global installed battery storage capacity and additions, 2020-2024, and in the STEPS, 2030 and 2035



Battery storage capacity expands significantly in the STEPS

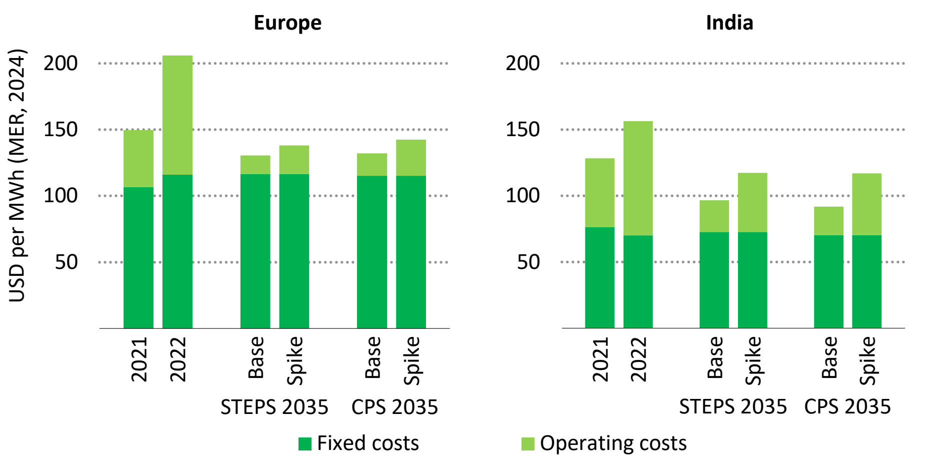
Rising shares of variable renewables in power systems are increasing demand for battery storage, costs are projected to decline further, and many governments support battery storage with targets, subsidies and policy reforms. In the STEPS, global installed capacity is set to reach 900 GW in 2030 and nearly 1 700 GW in 2035, 17% of total installed dispatchable capacity, with deployment broadening from advanced economies and China to India, Middle East and Southeast Asia (Figure 5.13). In the CPS, annual growth to 2035 is still strong, with global installed capacity rising to about 1 400 GW.

Impact of fossil fuel price volatility

In systems heavily reliant on fossil fuel-based generation, sustained fuel price spikes, such as those witnessed during the 2022 energy crisis triggered by the Russian invasion of Ukraine, can significantly raise the average cost of generating electricity, and consequently end-user electricity prices. Although the mechanisms of price formation and contracting vary among countries, important indicators of an electricity system exposure to fossil fuel price volatility include the share of fossil fuels in its generation mix, and the share of plants that rely on fossil fuels purchased on international markets.

In both scenarios, many regions see a decline in the share of fossil fuels in the electricity generation mix, though it is more rapid in the STEPS than in the CPS. In India, for example, coal and natural gas accounted for 75% of total electricity generation in 2022: record-level prices for imported coal and natural gas saw operating costs spike, and the annual average system cost of electricity rose to over USD 150 per megawatt-hour (MWh). By 2035, a lower share of imported fossil fuels in the electricity mix in both scenarios significantly reduces India's exposure to volatility in international fuel markets. A similar trend is observable in Europe. If wholesale fuel prices were to reach the same high levels in 2035 as they did in 2022, average system costs would increase by less than 10% in the STEPS and CPS in 2035, much less than the 40% increase seen in 2022 (Figure 5.14).

Figure 5.14 ⊳ Average system cost per unit of electricity in Europe and India in 2021 and 2022, and in 2035 by scenario



In both scenarios, rising shares of renewables make systems less susceptible to fossil fuel price spikes

Notes: MWh = megawatt-hour; MER = market exchange rate. Base = 2035 with 2035 STEPS/CPS coal and natural gas prices. Spike = 2035 with 2022 average coal and natural gas prices.

In liberalised electricity markets, even when fossil fuels supply only a small share of annual generation, spikes in their prices can push up wholesale electricity prices and make them more volatile. This is because spot prices usually reflect the cost of the most expensive plant running at a given moment, i.e. typically a natural gas plant when renewable output is low and demand is high. In the European Union, wholesale electricity prices more than doubled in 2022 due to record high natural gas and coal prices. If natural gas and coal prices were to return to those levels in 2035, average spot electricity market prices in Europe would again double from their base case levels in both scenarios. However, this increase would be significantly smaller in absolute terms than in 2022 because the much larger share of renewables in generation in 2035 in both scenarios significantly reduces the number of hours in which natural gas plants set the wholesale price. The size of the increase would be different in the STEPS and the CPS, reflecting the faster uptake of renewables in the former, but it would be smaller than it was in 2022 in both scenarios.

Shifting towards renewables and nuclear therefore can help insulate electricity consumers from fossil fuel price spikes. Although electricity systems with high shares of variable renewables may experience more weather-related variability, its impact on the annual average cost of electricity is much smaller than that of the historical volatility observed in natural gas and coal prices (IEA, 2024a).

5.2.3 Critical minerals and energy technology supply chains

Critical minerals security

In a time of high geopolitical tensions, critical minerals are a frontline issue for energy, economic and national security. A high degree of supply concentration and a recent raft of export restrictions underline that there are risks to security of supply, highlighting the urgent need to enhance the resilience and diversity of critical mineral supply chains. In December 2024, China restricted the export of gallium, germanium and antimony – key minerals for semiconductor production – to the United States. This was followed by announcements in early 2025 to include restrictions on tungsten, tellurium, bismuth, indium and molybdenum and seven heavy rare earth elements. Then in October 2025, new announcements significantly expanded the scope of controls for rare earths, including five additional elements (Box 5.4), while new controls were announced on a range of battery materials (IEA, 2025b). China is not the only country to have introduced export controls. In February 2025, the Democratic Republic of the Congo announced a four-month suspension of cobalt exports to curb falling prices, which was followed by an export quota system in October 2025.

Box 5.4 ▷ China's export controls on rare earths highlight supply chain vulnerabilities

China accounted for around 90% of all refined magnet rare earth supply and 94% of the global supply of permanent magnets in 2024 (IEA, 2025b). These materials and magnets are essential for cars, wind turbines, industrial machinery and digital technologies and artificial intelligence data centres. A notable development came on 4 April 2025 when the Chinese government introduced export controls on seven heavy rare earth elements, as well as all related compounds, metals and magnets. As export volumes fell sharply in April and May, many automakers in the United States, Europe and elsewhere struggled to obtain permanent magnets, with some forced to cut utilisation rates or even temporarily shut down factories. Even after trade volumes recovered, rare earth prices in importing countries remained elevated – with European prices reaching up to six-times those in China – hurting the cost competitiveness of rare earth-based products manufactured outside China. On 9 October 2025, China expanded the list of rare earth elements to include five new materials and announced further export controls on related products, equipment and technologies. The new controls require foreign companies to obtain a licence from China to export "parts, components and assemblies" containing Chinese-sourced rare earth materials or produced using Chinese rare earth technologies.

If 10%, around 1.5 kilotonnes, of rare earth exports were to be affected, this could disrupt the production of 6.2 million cars. The domino effects of these controls highlight the need for strengthened policy efforts to diversify rare earths and magnet manufacturing supply chains.

Broadening the scope of analysis to a wider set of 20 energy-related, multi-sectoral minerals reveals additional vulnerabilities in global supply chains (Figure 5.15). These minerals underpin a range of strategic industries, including high-tech, aerospace, defence and advanced manufacturing industries. While their individual market sizes may remain modest, disruptions in supply can generate disproportionate economic ripple effects across multiple sectors.

Figure 5.15 ⊳ Top producer, monthly price volatility, trade restrictions exposure and status as by-product of select strategic minerals

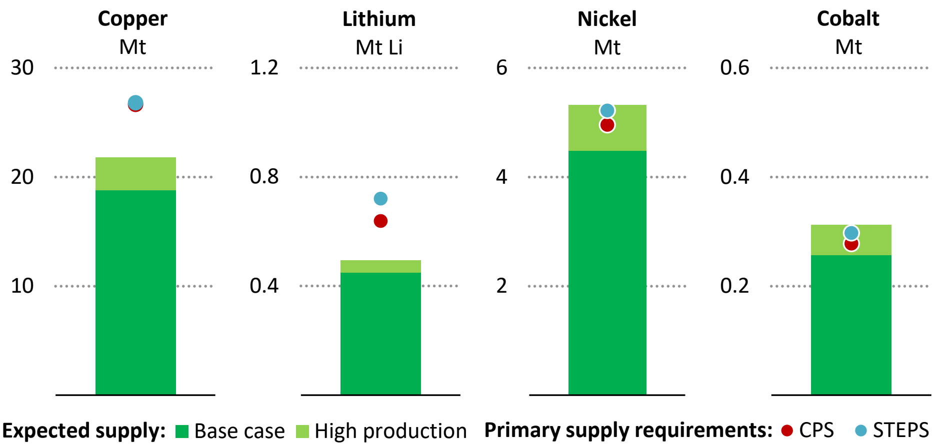
Critical minerals used in energy and other strategic sectors are exposed to a wide range of risks, including supply concentration, price volatility and by-product dependency

Notes: Top producer is for metal refining. Volatility (January 2014 – March 2025) is considered high when it is higher than that of both oil and LNG, medium when higher than oil but not LNG, and low when lower than oil and LNG. Other information is as of October 2025. By-product dependence is when over 50% of supplies are sourced as co-product or by-product. Titanium is for titanium metal; silicon is for high purity form.

Source: IEA (2025c).

This expanded group of minerals is exposed to several risk factors. Supply chains are often highly concentrated, with China accounting for an average of 70% of global refining capacity across 19 of the 20 minerals assessed. Price volatility is also a persistent concern: three-quarters of these minerals have exhibited higher price variability than crude oil, and half have been more volatile than natural gas. In many cases, production is tied to by-products of other mining activities, limiting the ability of supply to adjust flexibly to shifts in demand. Options for substitution also remain constrained. For minerals such as tantalum, titanium and vanadium, alternatives are either technologically unproven or entail cost and performance penalties. These structural supply-side challenges underscore the need for targeted policy responses to enhance supply chain resilience and diversification. This is a pressing concern in both scenarios, though supply concentration is likely to increase more in the CPS than in the STEPS due to the advantages of incumbency in a lower price environment: weaker demand in the CPS drives lower prices, favouring incumbents that generally sit lower on the cost curve and making diversification a more challenging proposition.

Figure 5.16 ⊳ Primary supply requirements for critical minerals and expected supply from existing and announced projects by scenario, 2035



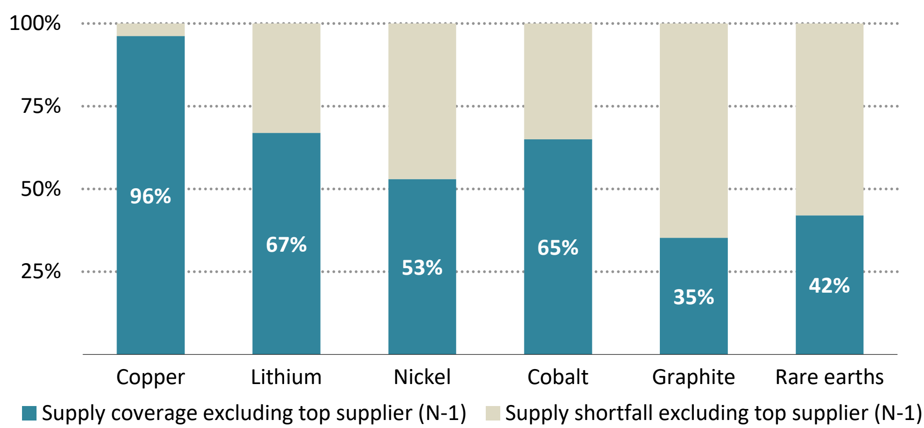
Supply-demand balances through to 2035 are improving compared to a few years ago, but major concerns remain, especially for copper

Notes: Mt = million tonnes; Mt Li = million tonnes of lithium metal content; CPS = Current Policies Scenario; STEPS = Stated Policies Scenario. Primary supply requirements are calculated as total demand net of secondary supply, and accounting for losses during refining operations. The base case includes production from existing and under construction assets, and projects with a high chance of moving forward. The high production case includes less certain projects at a reasonably advanced stage of development, including projects seeking financing or permits.

Supply-demand balances through to 2035 are improving compared with a few years ago (Figure 5.16). For nickel, cobalt, graphite and rare earths, expected supplies are set to catch up with projected demand growth under current policy settings, if planned projects proceed on schedule. But copper remains a major concern: in the STEPS, the current project pipeline points to a potential 30% supply shortfall by 2035 caused by declining ore grades, rising capital costs, limited resource discoveries and long lead times. There is also an anticipated shortfall for lithium driven by rapid demand growth, though the prospects for developing new lithium projects look much better than for copper. In the CPS, supply balances for most minerals are eased by slightly lower levels of demand than in the STEPS, but copper remains an exception, with a persistent supply gap. Bridging the gap requires a range of supply- and demand-side measures to stimulate investment in new copper supply, reduce project lead times, promote material efficiency and substitution, and scale up recycling.

Refined manganese and purified phosphoric acid (PPA) are emerging as materials of increasing importance for battery supply chains. Lithium iron phosphate (LFP) batteries, which rely on PPA, were used in almost half of new electric cars in 2024, up from less than 10% in 2020, while manganese-rich chemistries are rapidly gaining traction. However, supply of these key materials remains highly concentrated in China, which produces 95% of manganese sulphate and 75% of PPA: this highlights new vulnerabilities.

Figure 5.17 ▻ Refined critical mineral supply balances excluding the top supplier (N-1) in the STEPS, 2035



For most critical minerals, supplies from outside the leading producer are insufficient to meet demand outside the leading producer, showing high vulnerability to supply shocks

Notes: Percentage notes the N-1 supply coverage. The N-1 supply excludes the production volumes from the largest producer from the total global supply, and N-1 demand excludes consumption of that country from the total global demand. China is the top refined supplier for all minerals shown in 2035 based on the project pipeline except for nickel for which Indonesia is the top supplier.

Despite improving supply balances for many minerals, a high market concentration means that there is a risk of significant supply shortfalls, if for any reason, supply from the largest producing country were to be disrupted (Figure 5.17). For example, supplies of battery metals and rare earths from all other producing countries in 2035 would meet on average only half of the remaining demand when the supply and demand accounted for by the largest producer are excluded. This underlines the point that, even in a well-supplied market, critical mineral supply chains can be highly vulnerable to supply shocks, be they from extreme weather, a technical failure or trade disruptions.

A supply shock of critical minerals would have far-reaching economic consequences, bringing higher prices for consumers, reducing industrial competitiveness and even potentially impacting national security. In 2010, the price of rare earth elements spiked by as much as ten-fold when China held back exports. If a supply shock affecting battery metals or graphite were to result in a ten-fold material price surge, global average battery pack prices could increase by as much as 40-50%, and sustained increases could widen the manufacturing cost gap between China and other battery manufacturing regions. Prolonged disruption could also result in significant revenue and job losses for manufacturers. This emphasises the importance of targeted policy mechanisms and global collaboration to diversify supply sources, linking resource-rich countries with those possessing refining capabilities and downstream consumers. Through its Critical Minerals Security Programme, the IEA is scaling up efforts to bolster mineral security by building systems to enhance resilience against potential disruptions, supporting the acceleration of project development in diverse regions, and deepening market monitoring capabilities.

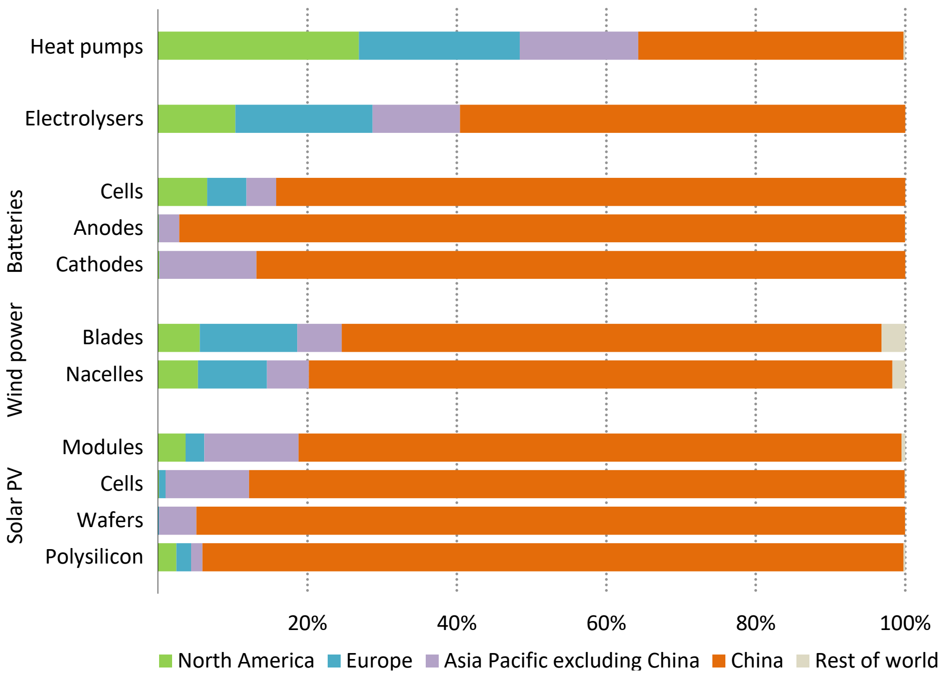
Energy technologies

The combined market size for five key clean energy technologies, i.e. batteries, heat pumps, electrolysers, solar PV, wind power and EVs, amounted to around USD 900 billion in 2024. EVs accounted for the largest share of the total by some margin, followed by solar PV, batteries for stationary storage applications and wind power. Tracking the diversification of manufacturing capacity of these energy technologies is an important indicator of energy security. Excessive concentration may pose a risk of supply chain disruption, whether from natural disasters, accidents, geopolitical conflicts or deliberate actions to manipulate supply or price.

The installed manufacturing capacity of these technologies is highly geographically concentrated, notably in China (Figure 5.18). In 2024, China accounted for over 80% of installed manufacturing capacity in every part of the solar PV value chain, and nearly 80% for nacelles and over 70% for blades of global manufacturing capacity for wind power components. The position of China in battery manufacturing is even stronger, accounting for at least 85% of global production in all parts of the value chain, and over 95% in the case of battery anodes. Manufacturing capacity is more diversified in the case of heat pumps and electrolysers for hydrogen production.

Installed manufacturing capacity, however, exceeded production in 2024 by very substantial margins for some clean energy technologies. For example, global installed manufacturing capacity of battery cells was around 3 400 gigawatt-hours (GWh) in 2024, but combined global demand from EVs and stationary applications was around 1 110 GWh, resulting in an average utilisation rate of around one-third.[2] The global average utilisation rate of solar PV module manufacturing facilities was also low at around 50%. Given that the global surplus of capacity relative to present demand for these technologies is concentrated in China, its share in actual production is estimated to be somewhat lower than its share in installed manufacturing capacity.

Figure 5.18 ▷ Installed manufacturing capacity of selected energy technologies by region, 2024



Installed manufacturing capacity for selected clean energy technologies is highly geographically concentrated

The evolution of installed manufacturing capacity and actual output depends on several factors, including the demand outlook for individual technologies, the extent to which policies support the localisation of manufacturing capacities, and the international trade environment. The forthcoming edition of the IEA *Energy Technology Perspectives* will explore the outlook for global supply chains for selected energy technologies, among other issues.

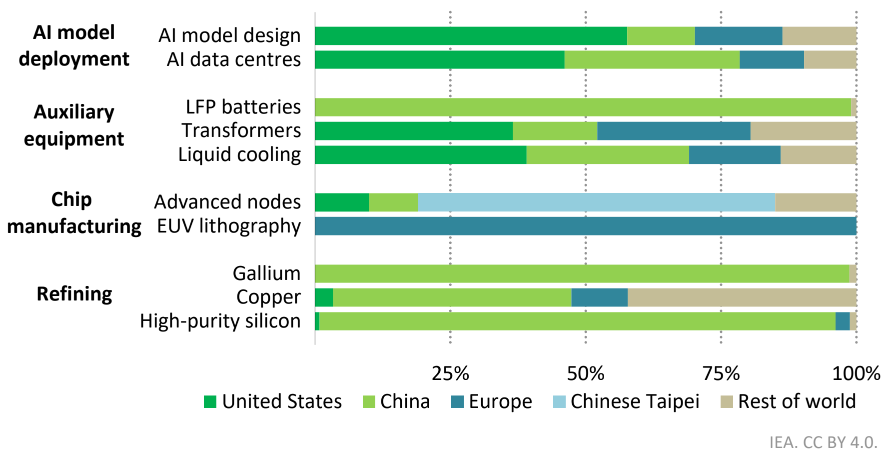
[2] Excludes EV and battery stockpiling.

Box 5.5 ⊳ Embodied intelligence: material supply chains for AI

Artificial intelligence (AI) is becoming increasingly linked to the energy sector as data centres account for a growing share of electricity consumption (see Chapter 4). However, this is not the only way in which data centres and the energy sector are connected. Data centres are also becoming important users within broader supply chains of energy-related materials and energy technologies. These supply chains, and the position of data centres within them, are not yet well understood.

China dominates the production and supply of critical minerals used in manufacturing chips. It refines 95% of the high purity silicon that goes into the chips used in data centre servers and fibre optic cables. With a 44% market share, it is also the leading global producer of refined copper, which is critically important for the power transformers, electrical wiring and on-chip electrical circuits in data centres. As progress in shrinking the 2D footprint of transistors stalls, the industry is turning towards 3D stacking of chip components, and this may increase the copper intensity of advanced chips. China also accounts for 99% of global refined gallium, which is increasingly being used for advanced transistor-based power electronics and optical computing applications such as optical memory interconnects.

Figure 5.19 ⊳ Market share of critical components for data centres and AI supply chains by region/country



No one region dominates all steps in the highly complex supply chain for data centres, but individual steps show high degrees of concentration

Note: AI = artificial intelligence; LFP = lithium iron phosphate; EUV lithography = extreme ultraviolet lithography machines.

Various countries dominate different parts of the chip manufacturing supply chain. European companies hold a near monopoly on the extreme ultraviolet lithography machines used to make the most advanced chips, which are in turn largely manufactured in Chinese Taipei. The United States holds a dominant position in chip design software and chip design, and companies in Japan and Korea dominate markets for critical AI chip components such as high-bandwidth memory.

Cooling technologies are likely to become more critical as AI-specialised chips become denser in terms of power and need to dissipate more heat. The supply chain for liquid cooling technologies involves a mix of companies from the United States, China and Europe, as does the supply chain for transformers, while China dominates the global supply chain for the LFP batteries that are increasingly used in data centres because of their power and energy density, long lifecycles and safety and thermal stability (IEA, 2025c).

While the United States dominates frontier AI model design and AI-optimised data centre deployment, the full supply chain presents a more complicated picture. As data centres increase in number and as their needs develop, their supply chains for materials and energy-related technologies will increasingly overlap with supply chains critical to the energy sector. For example, the extent to which progress is made in closing the projected demand and supply gap for copper will have a material impact on both data centres and the energy sector, since both are projected to be a key source of copper demand growth. Monitoring how the material footprint of AI and data centres evolves will be critical to anticipating some key energy security risks.

S P O T L I G H T

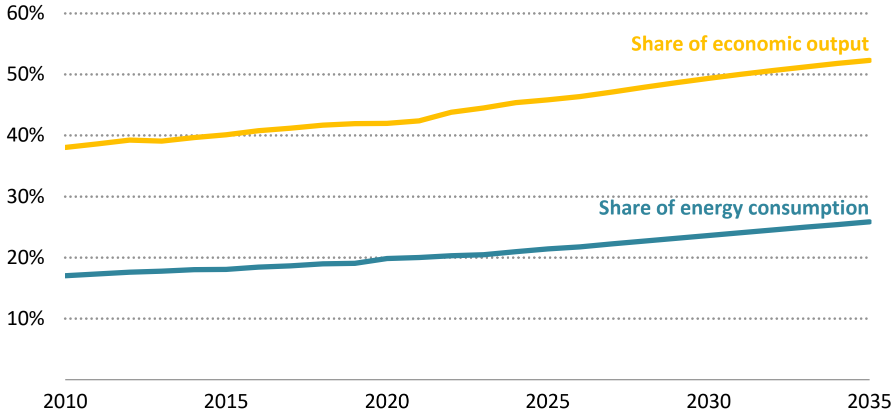
Building blocks of the Age of Electricity

Electricity accounts for 21% of global total final consumption. Yet, this understates its economic contribution because it provides the key energy input for high value-added sectors such as advanced manufacturing, AI and digital services. Electricity is already the key source of energy for sectors accounting for over 40% of the global economy. By 2035, this rises to around 50% in the STEPS (Figure 5.20).

An interlinked set of materials and technologies are critical to control and store electrical energy while at the same time having important applications in many sectors. As the global energy system moves into the Age of Electricity, these materials and technologies come to play an ever more important role. Who controls their supply chains, who manufactures these technologies, and who leads in their innovation will have major implications for both energy and economic security.

Copper is a critical example. It is used directly in the energy sector in grids, batteries, solar and wind power, as well as widely in construction, industrial equipment, data centres, phones, computers and semiconductors. Copper can be substituted by aluminium for some applications, albeit with costs in terms of performance and environmental impact. However, there are many applications where there are currently no substitutes such as in lithium-ion battery anode current collectors, high-performance electronics, high-performance transformers and motors, and subsea power cables.

Figure 5.20 ⊳ Electricity as a share of energy consumption and the share of electricity consuming sectors in economic output in the STEPS, 2010-2035



Role of electricity to fuel economic output is two-times higher than its share in total final consumption

Similarly, rare earth elements are critical in energy applications such as EV motors, nuclear and wind turbines, aircraft engines and conventional cars. They are also essential in computer hard drives, smartphones, defence technologies and magnetic resonance imaging machines. The effects of shortages are quickly felt. A select number of rare earths were subject to export restrictions in April 2025, and many automakers around the world had to curtail production lines in short order due to supply constraints of rare earth permanent magnets.

Lithium-ion batteries are another example. As well as being used in the energy sector, such as in EVs and battery storage, they are critically important for portable electronics, like smartphones, laptops and cameras, and in defence and aerospace applications, such as drones, communication equipment and satellites, as well as some types of medical equipment. There is no substitute for lithium-ion batteries in applications where weight, compactness and reliability are critical. Data centres are increasingly shifting to lithium-ion batteries for uninterrupted power supply units because of the durability and power density that they offer. The critical importance of lithium-ion batteries for modern electronic equipment across sectors can scarcely be overstated.

Semiconductors, transistors and integrated circuits are also relevant in this context. They convert electricity into information, allowing the processing and storage of the data underpinning modern economies and consumer goods. The rise of AI means that data centres and the specialised AI-optimised integrated circuits they house are rising in importance for the energy sector. However, semiconductors are also increasingly being used in the energy sector for power conversion and control, i.e. power electronics. Wide bandgap semiconductors such as silicon carbide and gallium nitride are transforming power electronics by allowing operations at higher voltage, temperature and frequency. Applications of advanced power electronics include EV batteries, solar PV inverters, and advanced transformers for data centres or high-voltage direct current cables. Power electronics and the technologies they work with require critical minerals like gallium, germanium, and neodymium and yttrium.

This interrelated set of materials and technologies have innovation and supply chain spillovers. For example, innovation in semiconductor manufacturing has fed into innovation in solar PV manufacturing, while data centres and EV batteries rely on similar power electronics to convert and control electricity with unrivalled precision. In the Age of Electricity, innovation leadership, energy security and economic security will increasingly be linked to these technologies. Investment in energy innovation is often, in this sense, investment in innovation more broadly.

5.2.4 Extreme weather events

Extreme weather events are an energy security risk today

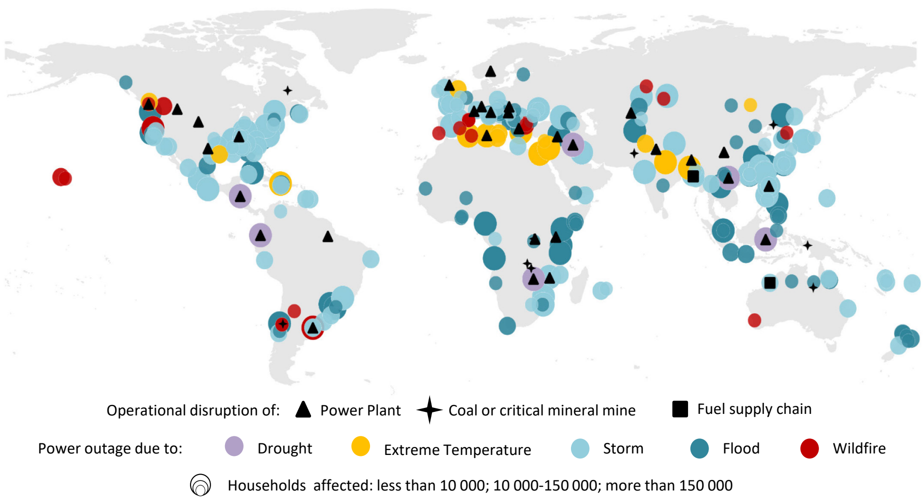
Natural hazards, which include both geophysical risks such as earthquakes and tsunamis, and extreme weather events such as storms, floods, extreme temperatures, droughts and wildfire, pose a perennial threat to energy infrastructure around the globe. They are among the most frequent causes of energy system or supply chain disruptions each year.[3] They can damage energy assets, disrupt operations, and hinder the safe and timely transport of key energy commodities around the world. Extreme weather events that caused disruption to energy systems in 2023 are highlighted in this section, alongside new analysis on the impact of extreme heat on the electricity system.

Extreme weather events threaten the reliable supply of energy through disruptions and outages. They also increase the cost of energy supply through loss, damage, higher insurance premiums, and the need to build more resilient infrastructure. A new IEA dataset of extreme weather impacts on the energy sector shows that in 2023 alone nearly 300 events of extreme temperatures, storms, floods, droughts and wildfires caused operational disruptions of critical energy infrastructure. The power sector was affected by about 95% of these events, emphasising its vulnerability to extreme weather.

[3] In September 2025, the IEA held a High Level Roundtable on Strengthening Energy Infrastructure Resilience: Managing risks from natural hazards and extreme weather to explore this subject further.

The IEA dataset shows that extreme temperatures, storms, floods, droughts and wildfires were responsible for reported power cuts to more than 210 million households in 2023 (Figure 5.21). Storms and floods accounted for 46% and 33% of the incidents respectively and together caused reported power cuts to 95 million households. Heatwaves and cold spells accounted for only 8% of the disruption events caused by extreme weather in 2023, but they were responsible for power cuts to more than 75 million households. Electricity networks are especially vulnerable to extreme weather events: damage to substations and electricity grids or the pre-emptive shutting off power lines, e.g. during high winds in wildfire prone areas, together account for around 85% of the incidents in our dataset of 2023 events.

Figure 5.21 ⊳ Power outages and operational disruption of energy infrastructure caused by extreme weather events in 2023



Extreme temperatures, storms, floods, droughts and wildfires were responsible for reported power cuts to more than 210 million households

Notes: 2023 provides a snapshot of the impacts of extreme weather events on energy infrastructure. It does not necessarily represent an average weather year, as weather is variable. Outage numbers are likely underestimated due to variability of reporting by region. Events are recorded as a single type, which consolidates compound effects such as storms leading to floods.

Sources: IEA analysis based on CRED (2025); GDACS (2025); ReliefWeb (2025).

Other parts of energy systems also suffer damage and disruption from extreme weather. In 2023, extreme weather caused disruption to a wide range of energy assets including power plants, fuel supply chains, coal mines and critical mineral mines. Hydropower was disrupted by drought-related water scarcity in Central and South America and by damage caused by floods in Canada and Norway. Storms and wildfires led to damage and safety-related curtailments in wind, solar PV and nuclear plants. Storms and floods caused the closure of

LNG terminals in Bangladesh and led to LNG shortages for gas power plants. Floods also caused damage and disruption to a coal mine and several critical mineral mines.

The scale of the risks to the energy system from extreme weather events depends on exposure and vulnerability, and how critical an asset is within a specific energy system. For example, an outage in a critical transmission line might be more consequential than an outage in a small solar PV plant (Box 5.6). The impact of extreme weather on the energy sector can also extend beyond individual assets and have significant economic repercussions. For example, storms can disrupt oil and gas infrastructure, causing price impacts to ripple across markets. With the rise of electrification, the vulnerability of electricity grids to extreme weather events deserves particular attention. Modern economies are dependent on uninterrupted supplies of electricity, and short outages can have large economic costs.

A better understanding of system resilience hinges on improved data collection and reporting on the causes and impacts of outages and disruption. While several advanced economies already require detailed reporting on the causes of outages in power and fuel distribution systems, many countries do not. Investing in the monitoring and reporting of incidents could improve planning by documenting the impact of diverse types of extreme weather on various parts of the energy system, and the frequency with which such impacts occur.

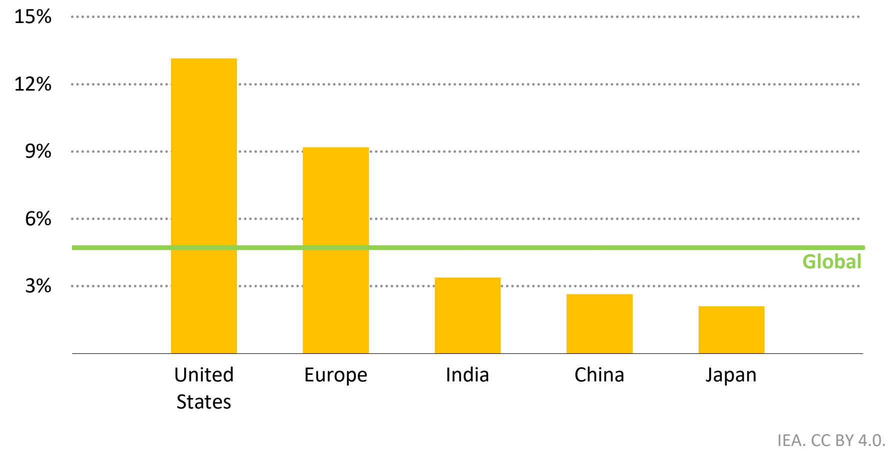
A forthcoming IEA special report will further investigate the resilience of energy assets to extreme weather, natural hazards and climate change. A key finding from this emerging work is that solar PV – the world's fastest growing renewable electricity source – faces one of the highest natural hazard-related risks of destruction due to its unique vulnerability to hailstorms (Box 5.6).

Box 5.6 ⊳ Destruction risk of severe hailstorms to solar PV assets

In addition to disrupting supply, extreme weather can cause significant damage to energy assets. No global figure is available today for the total damage done to energy infrastructure by extreme weather, but recent insurance claims data suggest that hail damage to solar PV represents the fastest growing, and in some regions the largest, natural catastrophe insurance claim type for power generation assets, averaging more than USD 50 million per claim (GCube Insurance, 2023; Hutchins, 2025). Based on hailstorm patterns, we estimate that almost 5% of installed global solar PV capacity, about 47 GW, risks experiencing at least one severe hailstorm during its lifetime (Figure 5.22). Replacing this amount of PV capacity in case of severe loss would result in costs of about USD 640 million per year.

Geographical disparities in hailstorm risks highlight regional hotspots, including the US Great Plains, the southern Himalaya foothills, and areas around the Mediterranean Sea (Prein and Holland, 2018). Assets in the United States and Europe are particularly exposed, with around 13% and 9% respectively of current installed capacity expected to face a severe hailstorm during their operational lifetime, while in China and India the equivalent figure is around 3%. Measures to reduce the risk of total asset loss include increasing the thickness of front glass material and making use of hail stowage solutions which allow panels to be tilted vertically during storms. We estimate that at least 4% of global solar PV capacity would benefit from using more resilient protective glass, with a cost premium of 5-10% at current prices.

Figure 5.22 ▹ Exposure risks of solar PV assets to severe hailstorms



Severe hailstorms pose significant risks to solar PV assets, which are most acute in the United States

Notes: The analysis covers utility-scale solar PV parks. The lifetime of a utility-scale solar PV park is assumed to be 25 years. Severe hailstorms are defined as storms with hailstones larger than 3 cm (ping-pong ball size).

Sources: IEA analysis based on AXIS Capital (2025); Bang and Cecil (2019); Cecil and Bang (2025); Cui et al., 2025; Murillo, Homeyer and Allen (2021); Global Energy Monitor (2025).

Special focus: impact of extreme heat on energy security

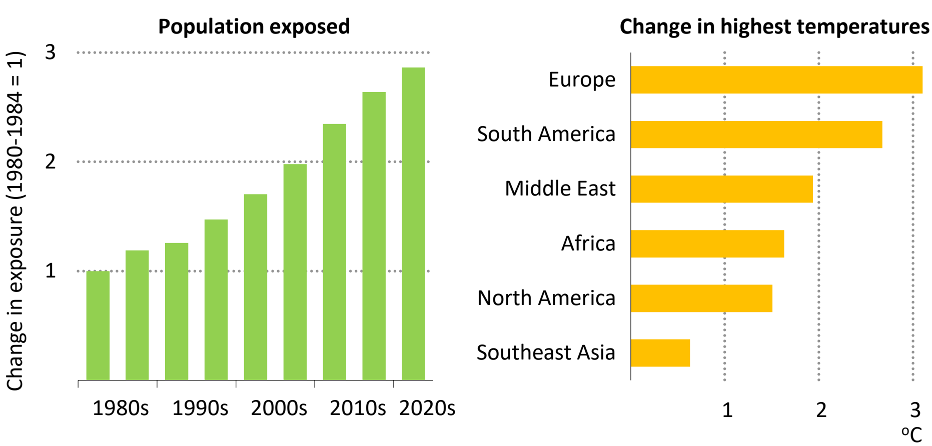
Extreme heat events are increasingly posing a threat to the resilience of the energy system, particularly the electricity sector. In extremely hot weather, electricity demand increases as air conditioners work harder to keep buildings cool. In addition, extremely hot weather may also lead to thermal power plants having to reduce their output and to falling solar PV panel efficiency. Moreover, the transfer capacity of transmission lines decreases at high ambient temperatures due to increased resistance, while sagging lines can reduce clearances to below regulated standards, forcing system operators to de-energise lines. Hot temperatures can also lead to the forced shutdown of overheated substations.

Such impacts from extreme heat can coincide with other events that reduce the availability of power system infrastructure, such as droughts that reduce hydropower output, long periods of low wind output, or increased wildfire risk. The way that these risks cascade in times of stress is a crucial factor for an assessment of overall system vulnerability. The impact of extreme heat on electricity demand and the derating, or reduction in output, of power plant capacity is the focus in this section.

Both the number and duration of heatwaves is growing (Figure 5.23). IEA analysis of data from the Copernicus Climate Change Service indicates that the number of people across the world exposed to high temperatures has almost tripled since the early 1980s (ECMWF, 2025). The distribution is not uniform, with Europe, South America and the Middle East seeing the biggest rise in extreme temperatures). In addition to the magnitude of high temperatures, the duration of high temperatures is increasing. During the first half of the 2020s, areas on every continent except Antarctica experienced the equivalent of an additional month of high temperatures compared with the 1980s.

Electricity system peak demand is increasing, driven in large part by an increase in cooling demand (section 5.2.2). System planners factor in electricity demand spikes from peak temperatures based on historical experience, the size of grid infrastructure and an assessment of power system adequacy. However, peak temperatures occasionally exceed the usual maximum of a region, and changes in the climate are driving an increase in the frequency and intensity of these extreme peak temperatures (IPCC, 2021).

Figure 5.23 ⊳ Population exposure to days with high temperatures, and change in the highest temperatures by region, 1980-2024



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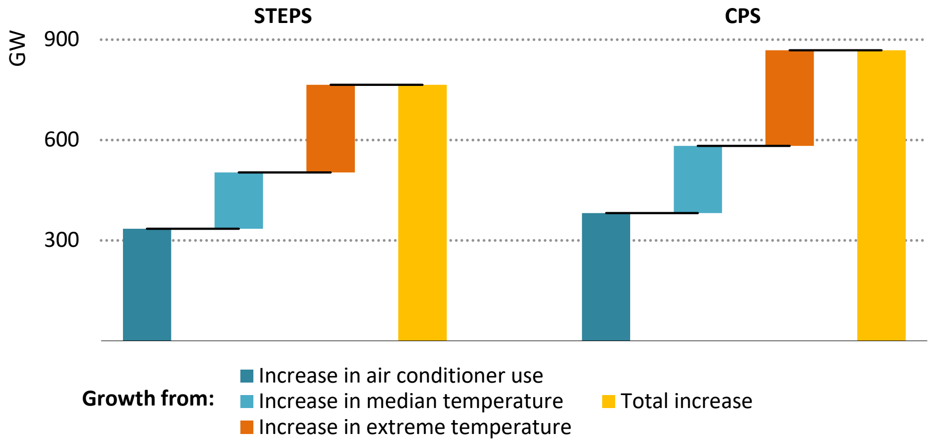
Changing weather patterns increased the number of people exposed to extreme heat and the changes in extreme temperatures vary by region.

Notes: °C = degree Celsius. Population exposure to high temperatures is derived from the population exposed to days where the minimum temperature is above 20 °C and the maximum temperature is above 35 °C. Highest temperatures are the average of those above the 95th percentile for the period 2020-2024 compared to 1980-1984.

Sources: IEA analysis based on data from CIESIN (2018); ECMWF (2025); JRC (2023).

Increasing uptake and use of air conditioning leads to an increase in peak demand across markets by 2035 in the STEPS of around 330 GW. At the same time, the rise in average temperature and in extreme heat events adds an additional increase of 430 GW to peak demand. More than 50% of this additional increase is associated directly with extreme heat events. There is a small difference between the CPS and the STEPS in terms of the rise in temperature and extreme heat incidents by 2035, but these factors are less important as a differentiator of peak demand growth than the types of air conditioners installed in the two scenarios (Figure 5.24).[4]

Figure 5.24 ⊳ Aggregated peak electricity demand growth related to cooling and impact of extreme heat by scenario, 2035



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Extreme heat increases peak demand by more than 250 GW in both outlooks, equivalent to around half of demand growth from cooling with median temperatures

Notes: GW = gigawatt; STEPS = Stated Policies Scenario; CPS = Current Policies Scenario. The extreme temperatures impact corresponds to the difference between the median and the top-three peak demand values across 30 years of weather data. The difference in the growth from the increase in median temperature is primarily due to differences in the energy efficiency of cooling, as the median temperature in 2035 is similar in both scenarios.

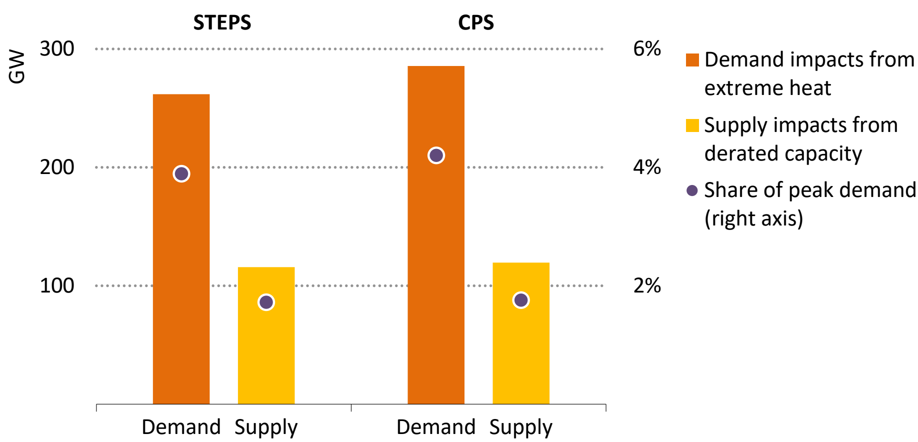
In addition to increasing cooling demand, extreme heat can also affect the reliability of power generation capacity, particularly in thermal power stations. High temperatures can decrease generation capacity through physical decreases in production efficiency, regulatory constraints on the discharge of water used for cooling, or, ultimately, the forced outage of assets. Analysis of empirical data from the European Union and United States indicates that forced outages of thermal power stations are more likely to occur, last longer and leave a

[4] In the focus of this analysis to 2035, there is essentially no difference in temperature outcomes between the two scenarios, and therefore differences between the scenarios in terms of the impact of cooling applications on peak demand depends on factors within the energy system, such as efficiency.

larger share of capacity unavailable at extreme high temperatures (Sergio and Colelli, 2025; Coffel and Mankin, 2021; Murphy, Sowell and Apt, 2019). Based on our analysis of existing power plant locations, historical and projected temperatures, and existing literature on the effects of high temperatures, we estimate that the global fleet of thermal power stations are likely to face a substantial increase in forced outage incidents due to extreme heat. If covered by higher reserve margins, it would require an additional 115 GW of installed capacity by 2035 in the STEPS, and around 120 GW in the CPS.

In a worst case scenario where the derating of power capacity coincides with additional demand due to extreme temperatures, the combined effects amount to a 6% increase in the total capacity needed to meet projected peak demand in both the scenarios (Figure 5.25). This is a substantial amount, equivalent to around one-half to one-third of typical reserve margins, and it highlights the importance of considering extreme temperatures during capacity adequacy planning. However, this analysis excludes two important effects. First, it does not consider the compounding effects of other supply disruptions which may be correlated with extreme temperatures, such as decreased hydropower output and lower wind output. Second, it does not consider the increased risk of reduced transmission line availability due to heat-related derating or equipment failures.

Figure 5.25 ⊳ Demand and supply impacts from extreme heat and equivalent share of peak demand by scenario, 2035



System operators may have to consider additional capacity margins equivalent to around 6% of projected peak demand in both scenarios by 2035

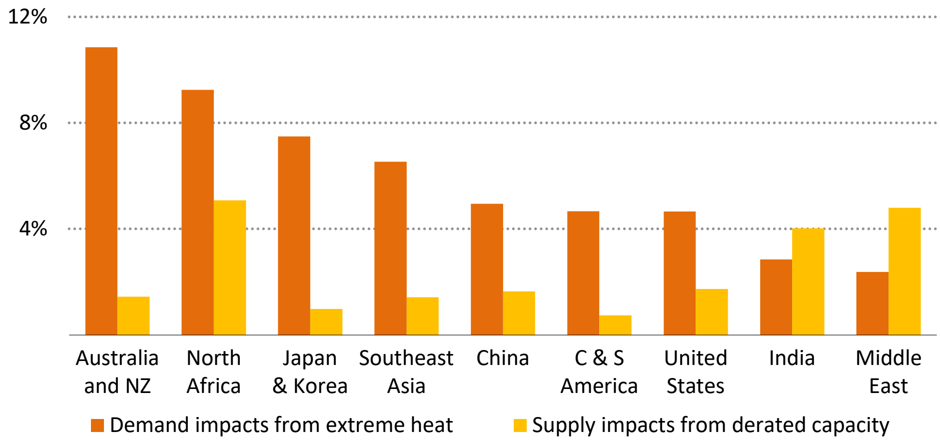
Notes: STEPS = Stated Policies Scenario; CPS = Current Policies Scenario. The capacity losses estimated here are defined as the difference between capacity available at the temperatures generators experience during peak demand under extreme heat versus those during median peak hours over 30 weather years.

Sources: IEA analysis of supply impacts based on observed maximum temperatures from Harris et al. (2020), and thermal power generation locations from Global Energy Monitor (2025); and thermoelectric power curtailment rates from Sergio and Colelli (2025); Coffel and Mankin (2021); Murphy, Sowell and Apt (2019).

The impact of extreme heat depends on regional characteristics (Figure 5.26). Some regions are badly affected because they see high variability in extreme temperatures between years, which leads to a large difference between designing for median peak temperatures and planning for extreme peak temperatures; because they have large shares of cooling in peak demand, and therefore a high sensitivity of demand to peak temperatures; or because they have high shares of thermal capacity, which may reduce capacity availability during peak temperatures. In some regions, an increase in peaks of extreme heat does not raise annual peak demand, because peak demand is still driven by winter heating rather than summer cooling.

In the regions most affected, in a worst case scenario where these effects coincide, the combined impact of increased peak demand and capacity derating due to extreme heat reaches as much as 10% of peak demand in certain regions by 2035 in the STEPS. Levels of derating are at a similar level in the CPS. This is equivalent to around two-thirds of typical reserve margins in these regions, and underlines the need to consider projected increases in extreme peak temperatures as well as projected increases in median peak temperatures in future capacity adequacy and contingency planning exercises.

Figure 5.26 ▷ Impact of extreme heat on peak demand and derated power supply by region in the STEPS, 2035



Combined effects of extreme temperatures on peak demand and capacity derating reach 10% of projected peak demand in the most affected regions

Notes: NZ = New Zealand; C & S America = Central and South America. The capacity losses estimated here are defined as the difference between capacity available at the temperatures generators experience during peak demand under extreme heat vs those during median peak hours over 30 weather years. Only includes regions where extreme heat increases the summer electricity demand beyond the typical winter demand peak.

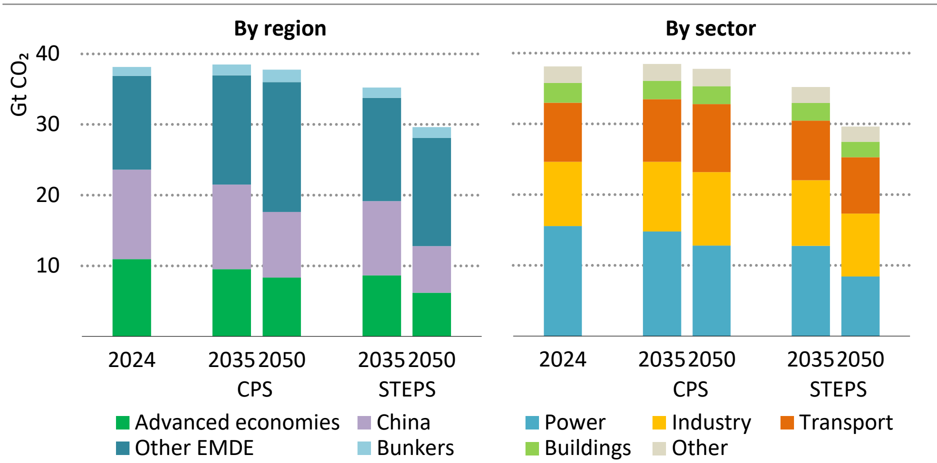
Sources: IEA analysis of supply impacts based on observed maximum temperatures from Harris et al. (2020), and thermal power generation locations from Global Energy Monitor (2025), and thermoelectric power curtailment rates from Sergio and Colelli (2025); Coffel and Mankin (2021); and Murphy, Sowell, and Apt (2019).

5.3 Emissions

Energy-related carbon dioxide (CO_2) emissions rose by nearly 1% in 2024 to reach an all-time high of 38.2 gigatonnes (Gt), though the rate of emissions growth has slowed in recent years. Advanced economies, China and the other emerging market and developing economies were each responsible for around one-third of global energy-related emissions in 2024, with international bunkers for aviation and shipping accounting for the rest. Emissions follow divergent trajectories in the STEPS and CPS, but they remain high across the outlook period. Both scenarios result in an increase in global temperatures that is incompatible with internationally agreed climate goals.

Global energy-related CO_2 emissions peak in the next few years in the STEPS and decline to around 8% below their current level by 2035. Emissions in the advanced economies grouping peaked in 2007 and have since declined by 20% while their economies have grown 30%. The STEPS sees a continuation of this trend, with advanced economy emissions falling by a further 15% from their 2007 peak by 2035. Per capita emissions in China now exceed average per capita emissions in advanced economies as a group. In the STEPS, emissions in China peak before 2030, and then decline by around 15% from their current level by 2035. Emissions in emerging market and developing economies other than China continue to rise through to 2035. This diverse group includes regions with high per capita emissions such as the Middle East and very low per capita emissions such as India and Africa. By 2050, global energy-related CO_2 emissions are just under 30 Gt, around 20% below the level of 2024.

Figure 5.27 ▷ Emissions by region and sector in 2024 and by scenario, 2035 and 2050



Energy-related emissions peak and decline in the STEPS, reflecting power sector reductions in China and advanced economies, while emissions plateau in the CPS

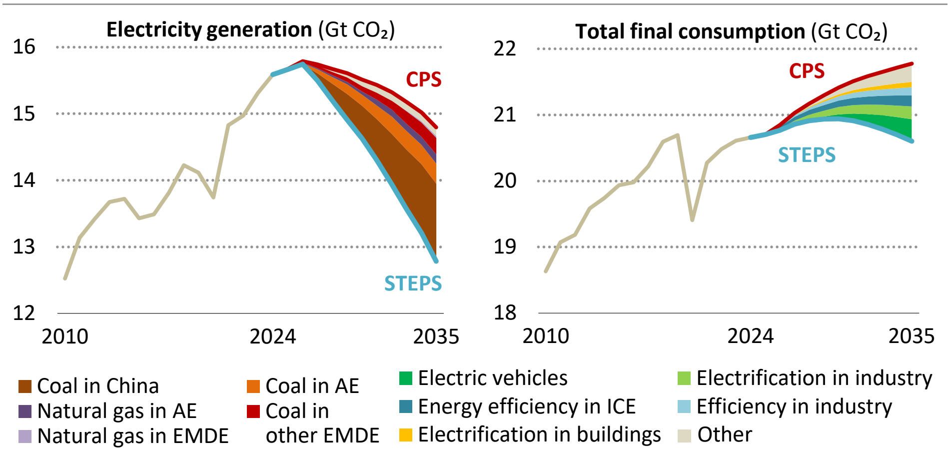
Note: Gt CO_2 = gigatonnes of carbon dioxide; STEPS = Stated Policies Scenario; CPS = Current Policies Scenario; EMDE = emerging market and developing economies.

Trends in the electricity sector do much to shape the emissions pathway projected in the STEPS. By 2035, global electricity sector emissions are almost 20% lower than in 2024, offsetting continued growth in emissions in the transport and industry sectors. By 2050, electricity sector emissions are almost 50% below their 2024 level. Emissions from industry and transport both peak before 2050, but they are still very close to their current level in that year (Figure 5.27).

In contrast, global energy-related emissions in the CPS do not peak before 2030 and are still marginally higher in 2035 than their levels in 2024. They then stay more or less flat through to 2050. Both advanced economies and China see a drop in emissions to 2035 in the CPS, although this is more muted than in the STEPS. However, emissions in emerging market and developing economies other than China increase more strongly between 2024 and 2035 than in the STEPS, pushing up the global total.

5

Figure 5.28 ▷ Decomposition of the difference in CO_2 emissions by driver and scenario, 2010-2035



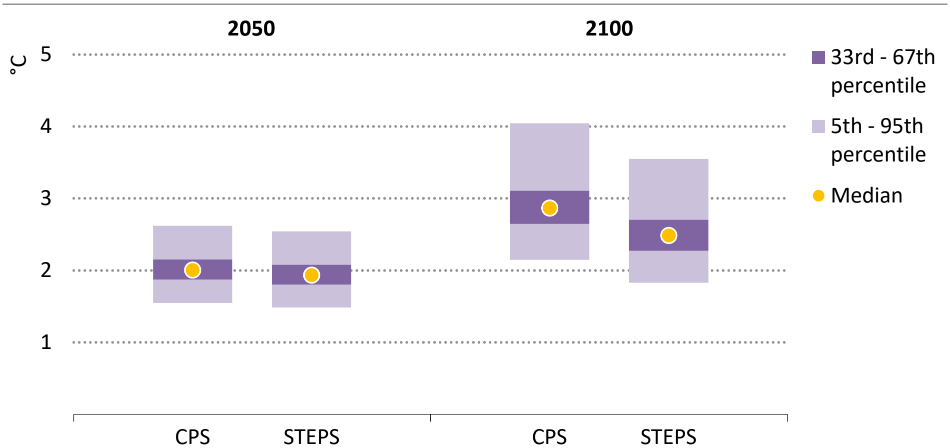
Increased coal-fired electricity generation drives the main difference in emissions between the scenarios, though end-use sectors in the CPS also see higher emissions

Note: Gt CO_2 = gigatonnes of carbon dioxide; AE = advanced economies; EMDE = emerging market and developing economies; ICE = internal combustion engine.

Emissions from coal-fired electricity generation in China are 1.2 Gt higher in the CPS than in the STEPS by 2035, which accounts for two-thirds of the difference in emissions from electricity generation between the two scenarios (Figure 5.28). Coal-fired electricity generation emissions are around 0.3 Gt higher in advanced economies in the CPS. The higher level of emissions from coal-fired power generation in the CPS largely reflects slower deployment of renewables. Other differences between the two scenarios in 2035 stem from: natural gas-fired power generation emissions, around 0.2 Gt higher in the CPS, again as a result of slower uptake of renewables; road transport sector emissions, around 0.3 Gt higher in 2035 in the CPS as a result of slower adoption of EVs and more sluggish improvements in energy efficiency; and industrial production emissions, around 0.6 Gt higher in the CPS because increases in technical efficiency are lower in the CPS than in the STEPS and because lower levels of recycling and material efficiency in the CPS mean more emissions-intensive goods are produced.

The emissions pathways in the STEPS and the CPS lead to different temperature outcomes (Figure 5.29). In both scenarios, the long-term global mean temperature rise exceeds 1.5 °C around 2030 and continues to rise to close to 2 °C around 2050. In the CPS, warming increases steadily after this by around 0.2 °C per decade to reach about 2.9 °C by 2100 and still higher temperatures thereafter. In the STEPS, however, the rate of warming slows after 2050, reflecting lower emissions of greenhouse gases (GHG) than in the CPS, and reaches around 2.5 °C by 2100**.**

Figure 5.29 ⊳ Temperature rise by scenario in 2050 and 2100



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Median temperature rise in 2100 is 2.9 °C in the CPS and 2.5 °C in the STEPS; in the CPS there is about an 8% chance of a temperature rise above 4 °C in 2100

Notes: STEPS = Stated Policies Scenario; CPS = Current Policies Scenario. Figure shows the long-term global mean temperature rise equal to the mid-point of a 20-year average of the combined land and marine near-surface temperature anomaly relative to 1850-1900, corresponding to the Intergovernmental Panel on Climate Change Sixth Assessment Report definition of warming of 0.85 °C between 1995-2014 (IPCC, 2021).

Source: IEA analysis based on the outputs of MAGICC 7.5.3.

The long-term temperature rise in this edition of the STEPS is around 0.1 °C higher than in the *World Energy Outlook-2024*, the first year in which the gap between climate outcomes of stated policies and international targets to limit climate change has widened rather than narrowed. This is mainly due to higher levels of emissions of CO_2 and methane in the STEPS 2025 than in the STEPS 2024.

Inherent uncertainties in the earth's response to future GHG emissions and warming mean that significantly higher temperatures cannot be ruled out. There is, for example, roughly a 15% chance of warming above 3 °C by 2100 in the STEPS, and an 8% chance of warming above 4 °C in the CPS. Future warming from current levels is inevitable in any scenario and carries with it risks. Those risks become extreme at the upper end of the levels of warming possible in the STEPS and especially in the CPS.

5.3.1 Air pollution and human health

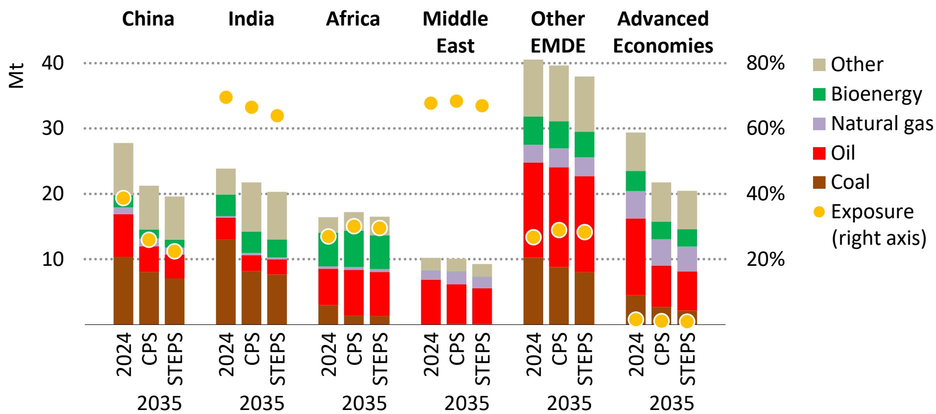
In 2024, air pollution caused more than 16 000 premature deaths per day, nearly five-times those from road accidents. Pollution-related diseases also limit economic productivity: it is estimated that around 1.2 billion workdays are lost every year due to air pollution, and that the total cost of air pollution[5] is around USD 6.4 trillion, or 5.6% of global gross domestic product (GDP) (OECD, 2016). In heavily polluted countries, the costs can be much higher; they are estimated to exceed 11% of GDP in parts of India, Pakistan and Bangladesh (World Bank, 2025). However, a shift to clean energy can lead to an immediate improvement in air quality. For example, phase outs of coal use for electricity and heating in parts of Canada and Beijing in the 2010s resulted in air quality improving by more than two-thirds within several years (Government of Ontario, 2025; Clean Air Fund, n.d.).

Air pollution emissions from energy-related sources are primarily driven by the combustion of fossil fuels and solid bioenergy (Figure 5.30), with significant variations around the world. Today in China and India, coal use in the power sector is the single biggest contributor to emissions, but in the Middle East and Africa, oil use, mostly for electricity and transport, plays the largest role. In African and other emerging market and developing economies, the continued reliance on traditional bioenergy for cooking and heating is a major source of pollution.

In the CPS, total global pollution emissions fall by around 10% between 2024-2035. This is mainly from reductions in China and advanced economies, where declining coal use in power generation and turnover of older vehicles in transport lead to sharp declines in air pollution emissions. In other regions, emissions decrease only marginally or even increase due to continued fossil fuel use and slow progress related to clean cooking. Because more and more people live in cities, especially in regions where population growth is highest, the modest drop in emissions is not enough to significantly reduce the share of people breathing heavily polluted air, which remains around 30% globally by 2035, similar to today's level. The STEPS sees similar trends to the CPS play out among many regions, but with more rapid coal reductions globally and reduced emissions from oil in the Middle East. This leads to about a 15% decline in total emissions to 2035 globally, although the number of people exposed to heavily polluted air remains similar to that in the CPS in that year.

[5] Economic costs associated with mortality, poor health outcomes, productivity loss and cognitive impacts.

Figure 5.30 ▷ Total air pollution emissions and share of population exposed to heavy air pollution by region in 2024 and by scenario in 2035



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Air pollution emissions and exposure to heavily polluted air decline in advanced economies and China, but see little or no improvement in other parts of the world

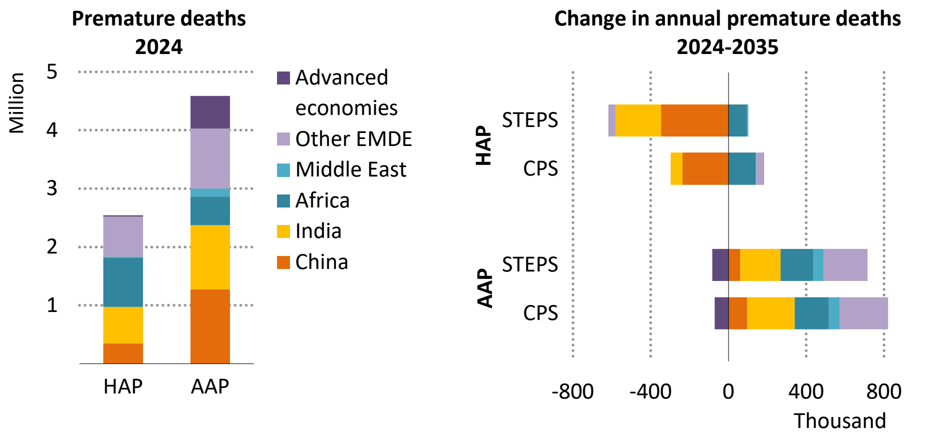
Notes: Total air pollution = sulphur dioxide (SO_2), nitrogen oxides (NO_X) and fine particulate matter ($PM_{2.5}$). Other = process emissions and combustion emissions from other fuels. Mt = million tonnes. Heavily polluted air corresponds to having a $PM_{2.5}$ density more than 35 microgrammes per cubic metre, in accordance with the World Health Organisation Interim Target 1 (WHO, 2021).

Source: IEA analysis based on International Institute for Applied Systems Analysis (IIASA).

Despite some progress on access to clean cooking, continued high levels of emissions and urbanisation mean that more people are exposed to heavily polluted air by 2035 than today in both scenarios. However, a very different trend emerges in health outcomes connected to household and ambient air pollution in the next decade. The decline in deaths from household air pollution seen in recent years continues, but slows in both scenarios. By 2035 there are around 2 million deaths per year in the STEPS, and 2.4 million in the CPS. The biggest improvements are in China and India, where clean cooking access rates reach 100% and 92% by 2035 respectively in the STEPS. However, premature deaths are set to rise in Africa in both scenarios due to rapid population growth and insufficient progress on clean cooking access (see Chapter 6).

The outlook for premature deaths from ambient air pollution is bleak: they increase in all but advanced economies in both scenarios (Figure 5.31). Globally, annual deaths from ambient air pollution rise to 5.3 million in 2035 in the CPS and to 5.2 million in the STEPS. China, India and Africa together account for about 60% of the increase in deaths to 2035 in both scenarios, but there are large rises elsewhere, particularly in per capita terms.

Figure 5.31 ⊳ Premature deaths from air pollution by type and region in 2024, and change by scenario, 2024-2035



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Premature deaths from household air pollution were around 2.5 million in 2024 and decline in both scenarios; those from ambient air pollution rise in both scenarios, but more so in CPS

Note: HAP = household air pollution; AAP = ambient air pollution; STEPS = Stated Policies Scenario; CPS = Current Policies Scenario; EMDE = emerging market and developing economies.

Source: IEA analysis based on IIASA modelling.

5.4 Investment and affordability

5.4.1 Energy investment

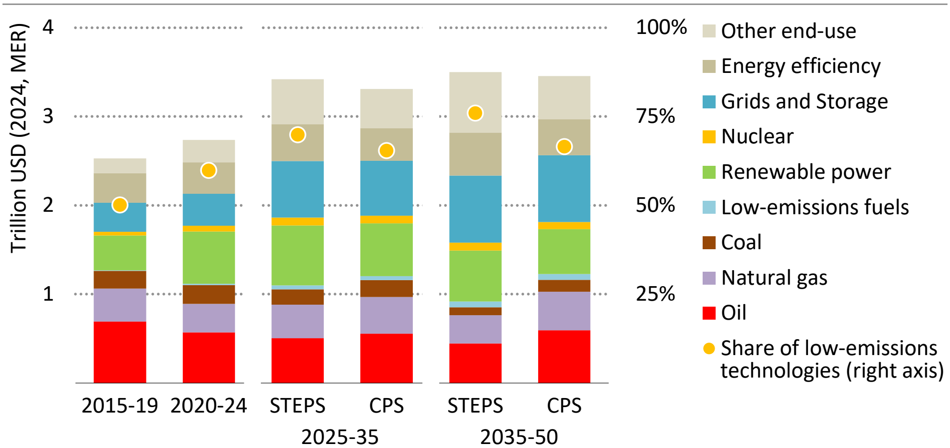
Investment in the energy sector is projected to reach USD 3.3 trillion in 2025, which is over 20% more than in 2015. Renewables electricity generation, principally solar PV and wind, and the electrification of end-uses, mainly EVs, are responsible for most of the increase. Energy investment is unevenly distributed: while China, United States and Europe have all ramped up spending, many countries in Africa and Latin America now see lower levels of investment in their energy sector than a decade ago. Even so, these regions encompass over 25% of the global population and are projected to expand their energy demand by nearly 20% by 2035 in the STEPS.

The share of global spending on low-emissions technologies has been rising steadily, driven in large part by heightened concerns over energy security since 2022. It is expected to account for two-thirds of total energy investment in 2025. Net importers of fossil fuels are responsible for 70% of the growth in low-emissions technology investment that has taken place over the last five years.

Investment in the STEPS stabilises at around USD 3.6 trillion in 2035 and stays relatively flat to 2050 (Figure 5.32). The level of investment in the CPS is nearly 5% lower in 2035 but broadly equal to the STEPS in 2050, yet the structure of investment differs, reflecting the different reading of policy settings used in these scenarios. Investment in the CPS is directed more towards maintaining the current energy system and responding to rising energy demand with conventional sources. Conversely, investment in the STEPS reflects more on new technologies, notably those that provide for electrification of energy end-uses, such as heat pumps and EVs.

Accelerating spending on low-emissions technologies in the STEPS means that their share of total investment increases by almost ten percentage points to reach 75% in 2035. Investment in the CPS is higher for natural gas and lower for renewables and the share of investment in low-emissions fuels and technologies increases by a small margin to reach about 70% of total energy investment in 2035.

Figure 5.32 ▷ Average annual energy investment by type and scenario, 2015-2050



Share of low-emissions technologies in total global energy investment continues to rise in both scenarios, though marginally less in the CPS

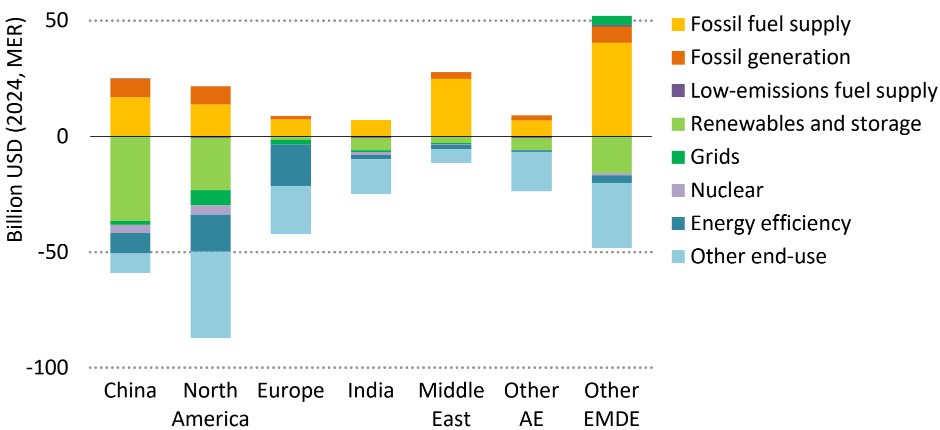
Note: MER = market exchange rate; STEPS = Stated Policies Scenario; CPS = Current Policies Scenario.

Supply, power and end-use

Between 2025 and 2035, annual investment in the supply of oil and natural gas decreases by about 5% in STEPS as uncertainties around oil demand are partially compensated by new LNG capacity additions, but increases by about 7% in the CPS. Meanwhile, spending on coal declines in both scenarios. By mid-century, investment in the electrification of energy demand, efficiency and renewables for power are about 20% lower in the CPS than in the STEPS, while spending on oil, gas and coal is almost 60% higher (Figure 5.33).

Solar PV accounts for 30% of power sector investment today. China was responsible for 60% of the additional solar PV capacity added in the world in 2024, increasing its overall solar PV capacity by more than 300 GW. In both scenarios, global annual solar PV investment declines in dollar terms to 2035. This reflects continued reductions in capital costs, which mean that adding a given amount of capacity to the system costs less year-by-year. As a result, even with continued new capacity additions, total investment in renewables declines. Investment in electricity grids and battery storage is projected to increase robustly in both scenarios, with combined annual investment of around USD 800 billion by 2035 – more than the amount invested in low-emissions power.

Figure 5.33 ⊳ Investment by type and by region/country in the CPS relative to the STEPS, 2035



Investment in solar PV and wind is around USD 80 billion lower in the CPS than in the STEPS, while investment in fossil fuels is nearly USD 150 billion higher

Note: MER = market exchange rate; AE = advanced economies; EMDE = emerging market and developing economies.

Investment in renewables in the CPS in 2035, at just over USD 500 billion, is below the level in the STEPS at USD 600 billion. Spending on nuclear increases in both scenarios as several countries take final investment decisions on large new reactors, pushing the current investment level up 40% to over USD 100 billion per year in the STEPS, and by about 30% to over USD 90 billion per year in the CPS. Global investment related to grids is similar in the two scenarios at around USD 730 billion in STEPS and USD 715 billion in CPS in 2035. Higher shares of renewables in the STEPS mean that investment in grids is slightly higher than in the CPS by 2035, but spending on transmission and distribution is mostly driven by electricity demand growth and line refurbishments, which are similar in both scenarios (see Chapter 3). Battery storage investment is about 15% higher in the STEPS in 2035 than in the CPS.

Overall investment in energy efficiency and other end-use (including electrification) stands at around USD 0.8 trillion per year and increases by about 40% in the STEPS to 2035, and reaches USD 1.1 trillion, and by about 15% in the CPS to reach USD 0.9 trillion. This is largely driven by existing energy efficiency policies and standards, including CO_2 emissions standards in transport, mandatory building codes and minimum energy performance standards for appliances, air conditioners and industrial electric motors. It is also driven by continued increases in energy demand due to economic growth. Energy efficiency investment is USD 70 billion higher in the STEPS than in the CPS in 2035, reflecting uptake of more efficient appliances in the STEPS and higher efficiency standards in new buildings. Electrification of heat and mobility broadens in both scenarios where current supportive policies or where technologies like heat pumps and EVs are already cost competitive. In the STEPS, this translates into an annual investment increase of about USD 300 billion related to electrification in 2035, double the current level.

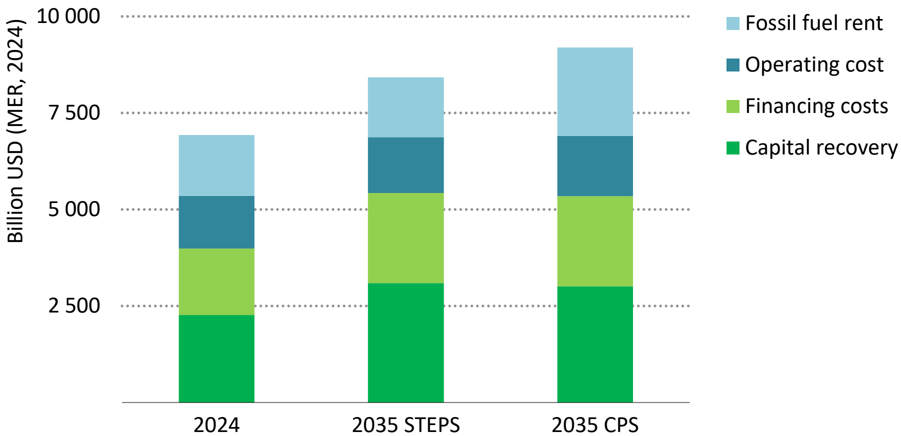
Total energy costs

Investment trends only provide a partial view of the overall costs of energy in each scenario. In practice, investment in energy infrastructure, such as power plants, grids and LNG terminals, are paid back gradually over time by consumers. Likewise, household energy investment, such as EVs, heat pumps and retrofits can either be paid for upfront or financed over several years. This means that capital and financing costs – for both suppliers and consumers – should be seen as an essential element of total energy costs over time.

Other components also need to be considered, including operating costs and fossil fuel rents. Operating costs are the sum of spending needed to maintain capital assets and to ensure the continuing production, transport and storage of energy. Fossil fuel rents, an additional cost to energy consumers, are defined as the revenue from fossil fuel sales minus the full costs of production, including financing costs. These rents mostly accrue to governments in the form of taxes, royalties or income from national oil and gas or mining companies. They are distinct from profits made by renewable developers or utilities, which are fully captured in financing costs.

Taking these factors into account, operating today's global energy system costs about USD 7 trillion annually (Figure 5.34). These costs rise in both scenarios as energy services are delivered to a growing global economy and an increasing number of people, yet costs in 2035 are nearly 10% lower in the STEPS than in the CPS. With a higher level of electrification and more investment in capital-intensive technologies, including end-use equipment such as EVs and heat pumps, the STEPS sees slightly higher rates of capital recovery than the CPS. These, however, are offset by higher operating costs in the CPS that reflect higher fossil fuel prices, and by higher fossil fuel rents that reflect both higher fuel prices and higher demand levels for fossil fuels. Fossil fuel rents total USD 1.6 trillion in the STEPS in 2035, and USD 2.3 trillion in the CPS.

Figure 5.34 ⊳ Total energy costs by type and scenario, 2024 and 2035



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Total energy delivery costs rise in both scenarios, driven by increased capital recovery and financing costs, while operating costs and fossil fuel rents are notably higher in the CPS

Note: MER = market exchange rate; STEPS = Stated Policies Scenario; CPS = Current Policies Scenario.

5.4.2 Affordability for households

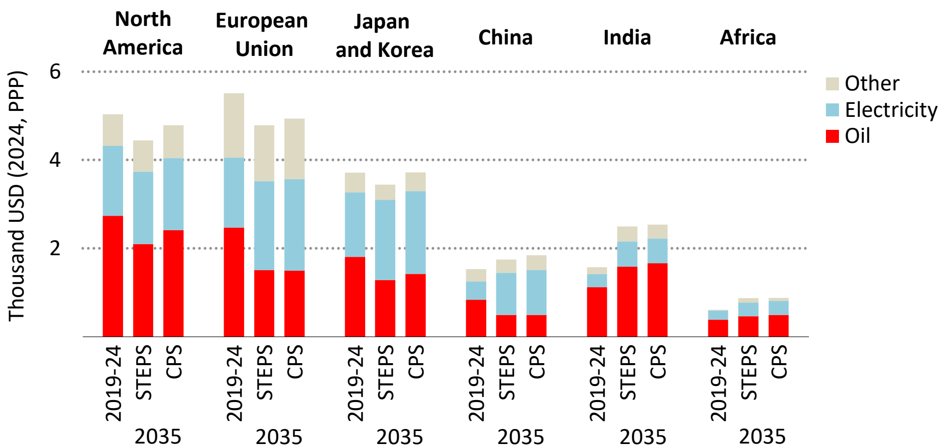
Affordable energy is fundamental to social and economic well-being, underpinning everything from household comfort and mobility to industrial productivity and national competitiveness. Total costs of energy to all consumers today are around USD 9 trillion each year, or about 10% of global GDP. Over one-third of it is paid by households to meet energy service demands at home and to provide personal mobility. Household energy bills typically reflect commodity prices and energy delivery costs, but they are also affected by policy and market design: taxes, subsidies and environmental surcharges can substantially influence the final price paid by consumers. Today, oil and electricity dominate household energy bills, accounting for approximately 50% and 30% respectively of the total.

Household energy bills in advanced economies averaged around USD 4 700 at purchasing power parity (PPP) [6] per year over the 2019-2024 period. In the STEPS, this falls to around USD 4 100 (PPP) in 2035 (Figure 5.35). This reflects mostly gains in efficiency and increased electrification, for example through improved energy performance in buildings and a higher share of EVs in the passenger vehicle fleet, leading to lower natural gas and oil consumption. While these trends are also visible in emerging market and developing economies, their average household bills increase by nearly 15% as rapid economic growth is translated into higher levels of appliance and vehicle ownership. In the STEPS, households in advanced

[6] Energy bills expressed in purchasing power parity terms account for differences in income levels and cost of living across regions, offering a meaningful proxy for affordability and the relative cost to households.

economies spend on average USD 200 more per year in 2035 than in 2024 on clean energy equipment such as EVs, heat pumps and building retrofits. This projection assumes that a large share of households spread payments for such purchases over several years.

Figure 5.35 ▷ Total average annual household energy bills by energy source and scenario in selected regions, 2019-2024 and 2035



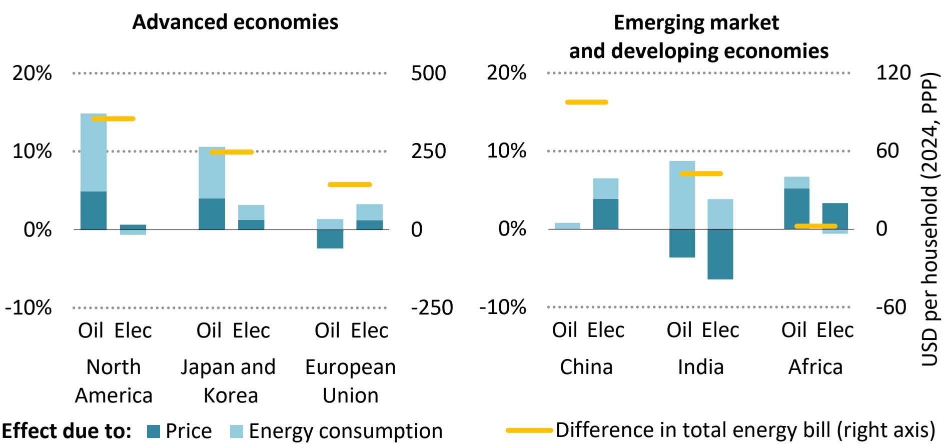
Electricity accounts for a growing share of household energy bills across most regions in both scenarios

Notes: PPP = purchasing power parity; STEPS = Stated Policies Scenario; CPS = Current Policies Scenario. Household energy bills include all relevant taxes, subsidies and environmental surcharges, but do not include the costs of energy equipment.

In the CPS, the average annual household energy bill in advanced economies is 6% higher in 2035 than in the STEPS. Slower efficiency gains in buildings and a less rapid uptake of EVs than in the STEPS mean that more energy must be bought to meet the same level of energy service demand. Wholesale oil and natural gas prices are also higher in the CPS, and these prices mostly get passed through to consumer energy bills. The STEPS involves a higher initial outlay than the CPS to improve the efficiency of homes and buying efficient EVs, but this is offset by lower ongoing energy bills over time. In a similar way, the implementation of fossil fuel subsidy reforms and the introduction of CO_2 prices in some regions in the STEPS slightly increase consumer energy bills relative to the CPS, but this is more than offset by lower fuel prices and the lower level of energy consumption needed to meet the same energy needs.

One of the main differences in household energy bills between the two scenarios concerns the shares accounted for by oil and by electricity. This is particularly evident in markets with differing rates of EV sales. While the upfront costs of EVs remain higher than those of conventional vehicles in most markets, EVs tend to have lower operating costs, leading to lower lifecycle expenditure. Lower EV sales in the CPS are reflected in higher levels of spending on gasoline and diesel, leading to overall higher energy bills in some markets compared to the STEPS (Figure 5.36).

Figure 5.36 ⊳ Household energy bills for electricity and oil by effect in selected region/country in the CPS relative to the STEPS, 2035



IEA. CC BY 4.0.

Energy bills are higher in the CPS than the STEPS as energy prices are generally higher, and a higher level of consumption is needed to provide equivalent energy services

Notes: PPP= purchasing power parity; Elec = electricity. Total household energy bill includes oil products, i.e. gasoline, diesel, fuel oil and liquefied petroleum gas, and electricity, as well as natural gas, bioenergy, coal and district heating.

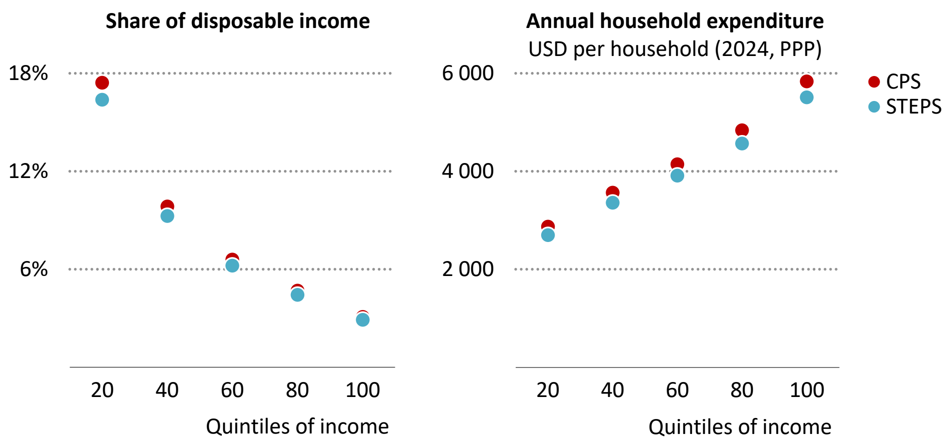
In advanced economies, key importing regions in Asia such as Japan and Korea see higher household energy bills in 2035 in the CPS than in the STEPS primarily because oil and natural gas imports cost more in the CPS. European Union retail oil prices are slightly lower in the CPS as the STEPS includes CO_2 pricing at the pump as set out in the recently tabled EU Emissions Trading Scheme II. But lower oil consumption per household in the STEPS offsets this, and the average overall household bill is lower than in the CPS.

In India and parts of Southeast Asia, retail prices for fossil fuels are lower in the CPS than in the STEPS because the CPS does not include fossil fuel subsidy reform. However, households still face higher energy bills in the CPS because slower improvement in the efficiency of vehicles and household appliances, especially air conditioners, increases overall fuel consumption.

In China, the high level of electrification in both scenarios means that households are less affected than their counterparts in many other countries by the increase in global oil prices in the CPS. They are comparatively more exposed to higher electricity prices, but this is moderated by the efficiency of EVs relative to conventional vehicles.

In Africa, average household electricity consumption is higher in the STEPS than in the CPS in part because more people gain access to electricity and clean cooking. However, this increased access is almost completely offset by higher efficiency, and it has no visible impact on average household energy bills.

Figure 5.37 ⊳ Household energy bills relative to disposable income and expenditure in advanced economies by income decile and scenario, 2035



Wealthier households see a higher absolute increase in energy bills in the CPS, while lower income households see energy take up a bigger share of their disposable income

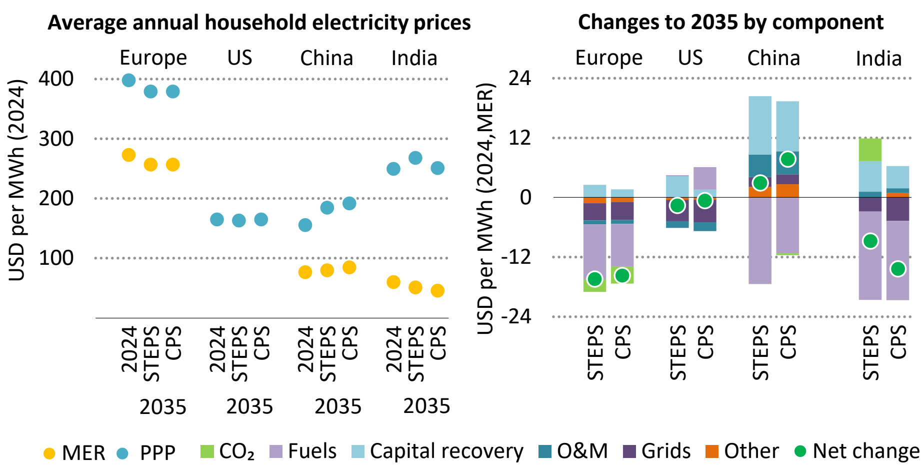
Note: PPP = purchasing power parity; STEPS = Stated Policies Scenario; CPS = Current Policies Scenario.
Source: IEA analysis based on national survey data, for further details see IEA (2024b).

Higher household energy bills in the CPS affect various segments of the population in different ways (Figure 5.37). In 2035 higher income households are more affected in absolute terms, and annual energy bills for the top 10% income increase by more than USD 300 (PPP) in advanced economies: these households tend to consume more energy overall, particularly for transport, and are exposed to higher oil prices in the CPS. However, lower income households are more impacted in relative terms, as they generally already spend a larger share of disposable income on energy than higher income households. Moreover, it is often more difficult for them to invest in energy efficient technologies which reduce energy bills over time, such as heat pumps, EVs, solar panels and building insulation, because of the upfront cost. Although CO_2 taxes or prices are one lever among many to push energy investment toward lower emissions outcomes, it is important to design such measures carefully to avoid regressive outcomes, for example by using some or all of the revenues to fund targeted schemes to assist vulnerable households (IEA, 2024b).

Residential electricity prices

Electricity accounts for a rising share of household expenses so electricity prices have a significant effect on energy affordability. While electricity prices vary significantly between consumer groups and countries because of differing resources, technologies, regulations, taxes and subsidies – with households often facing higher prices than industrial consumers – their development over time typically reflects the average cost of supplying a unit of electricity. The average cost includes: capital recovery, i.e. annuities paid over the economic lifetime of generation assets to recoup upfront investment; fuel costs; operational and maintenance costs; and emissions-related costs. (Though revenue from carbon taxes or emissions allowance auctions can be directly or indirectly returned to consumers.) It also includes grid costs, which mainly reflect the capital recovery through grid tariffs of investment in grid expansion and replacement, and are often an explicit component of end-user electricity prices.

Figure 5.38 ▹ Household retail electricity prices in selected country/region by scenario, 2024 and 2035, and by contributing factor in 2035



Residential electricity prices increase in China and decrease in Europe, United States and India, where rising capital intensity is offset by declining fuel costs

Notes: MWh = megawatt-hour; MER = market exchange rate; PPP = purchasing power parity; O&M = operation and maintenance; STEPS = Stated Policies Scenario; CPS = Current Policies Scenario. Other includes taxes, subsidies and other surcharges.

Household electricity prices vary significantly across countries and regions. Europe has some of the world's highest prices, which are projected to decline slightly by 2035 in both scenarios as the share and the fuel price of natural gas-fired generation declines. Electricity prices in the United States remain significantly lower than in Europe due to many factors, including significantly lower costs for natural gas-fired generation in the United States, even as domestic gas prices trend upward in both scenarios. In the STEPS, household electricity prices decline modestly by 2035 as renewables generation expands, while in the CPS they rise with the growing share of gas-fired generation.

In China and India, household electricity prices are significantly lower than in most advanced economies, although the differences are smaller after adjusting for purchasing power parity. These prices, however, are more tightly regulated and do not always fully reflect actual costs. In the STEPS, household electricity prices in China remain relatively stable to 2035, with reductions in fuel costs offsetting increases in capital recovery payments. In the CPS, China experiences a slight rise in household electricity prices because the share of renewables in power generation expands more slowly than in the STEPS, and coal and natural gas prices remain higher. In India, household electricity prices decline in both scenarios: the rising share of renewables in the electricity mix leads to a reduction in fuel costs that outweigh an increase in capital recovery payments (Figure 5.38).

5.4.3 Energy employment

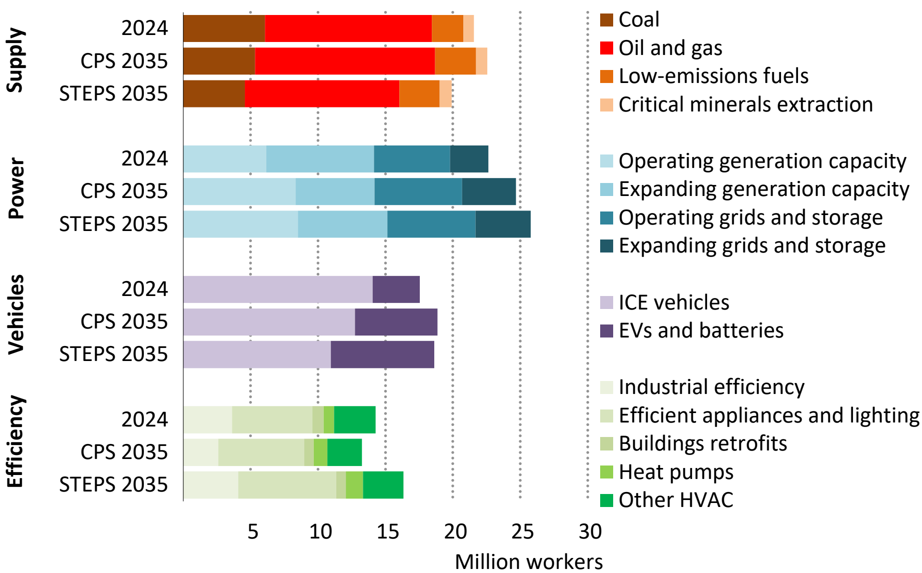
Energy employment worldwide expanded by 2.2%, 1.7 million jobs, in 2024. This outpaced economy-wide growth in employment of 1.3%. Employment in the power sector rose by 4%, driven by increasing investment to meet rapidly rising demand for electricity. Much of the job growth was concentrated in construction and manufacturing roles to build new energy infrastructure. Policy shifts, tariff uncertainty and geopolitical risks are now reshaping market expectations, leading many firms to take a cautious approach to hiring and job vacancy rates are already falling across major economies. As a result, the IEA projects job growth in energy to slow to 1% in 2025. Despite near-term headwinds, employment in energy is expected to rise in the medium and long term in both scenarios, driven by robust growth in low-emissions power generation, grids and EVs, though its pace hinges on the availability of skilled labour.

The power sector consolidated its position as the largest provider of employment in the global energy industry with 22.6 million jobs as the Age of Electricity gathers pace. The power sector has added jobs at twice the pace of the broader energy industry over the past four years, with solar PV and grids accounting for 40% of all new energy jobs. Looking ahead, low-emissions power generation and grids remain the main employment growth engines in both scenarios, boosted by rising electricity demand, increasing flexibility needs and the expanding integration of AI.

Fuel supply-related jobs totalled 20.8 million in 2024. Employment in oil and natural gas staged an uneven recovery, with firms maintaining lean staffing levels. The latest LNG investment cycle has been marked by shortages of welders, pipefitters and electricians, driving up costs (Reuters, 2024). Oil and gas employment expands by nearly 1 million to 2035 in the CPS, but falls by 920 000 in the STEPS, reflecting its faster pace of electrification, the more rapid adoption of renewables and the increased focus on efficiency. The coal sector sees a decline in employment by 2035 in both scenarios, though fewer jobs are lost in the CPS as it projects more use of coal in power generation in emerging market and developing economies such as China and India.

Both scenarios project higher sales of EVs. However, the EV sales share is lower in the CPS, reaching 40% by 2035 versus 50% in the STEPS, rising from current levels of around 20%. As a result, EV-related jobs increase more in the STEPS than in the CPS by 2035, 4.2 million jobs versus 2.6 million jobs. Efficiency gains are higher in the STEPS, reflecting less fossil fuel use in electricity generation, lower system losses, broader adoption of efficient electrification in transport, and more ambitious efficiency policies. This translates into more efficiency-related jobs in the STEPS by 2035, while in the CPS efficiency employment declines, largely due to losses in jobs related to energy efficiency in industry (Figure 5.39).

Figure 5.39 ⊳ Global energy-related employment by type and scenario, 2024 and 2035



Employment in the energy sector expands in both scenarios, though the distribution of jobs varies by field and skilled labour shortages shape the pace of the growth

Note: ICE = internal combustion engine; HVAC = heating, ventilation and air conditioning; STEPS = Stated Policies Scenario; CPS = Current Policies Scenario.

Energy-related employment is projected to expand in the medium and long term in all IEA scenarios, but the pace of growth depends on the availability of specialised workers. Trained and skilled workers are already in short supply. The energy sector relies more heavily on skilled labour than the wider economy: technical roles, including skilled trades, technicians and plant operators make up over half the energy workforce, more than double their 25% share in the broader economy. Among them, skilled trades – the largest occupational group in the energy sector and the main source of new jobs – are emerging as the most critical bottleneck. IEA analysis suggests that six-out-of-ten occupations in the energy sector where shortages are most acute are in skilled trades, e.g. electricians, grid line workers, solar PV installers, pipefitters, welders, and heating, ventilation and air conditioning installers.

This raises the importance of the education system in meeting future energy workforce needs in both scenarios. Widespread trade shortages limit the ability of the energy sector to attract workers from other industries, and its specialised requirements make transfers difficult. Addressing the growing labour needs of the energy sector requires co-ordinated policies to expand and modernise vocational education and training (VET) systems.[7] Priorities identified in the recent IEA Future of Energy Skills workshop include expanding certification capacity, modernising training to match emerging technologies, strengthening provider-employer partnerships, improving the perception of vocational degrees, and broadening access to VET programmes, particularly for young people and underrepresented groups.

Demographic pressures are exacerbating labour shortages, though in different ways in different regions. In advanced economies, retirements are outpacing new entrants: nearly 30% of union electricians in the United States may retire within a decade; in Japan 36% of workers in the construction industry are aged 55 or over, while only 12% are aged 29 or younger; and Canada expects retirements of 700 000 trade workers by 2028. The challenge is most acute in nuclear and grids, where for every young person joining, there are 1.7 and 1.4 workers, respectively, nearing retirement, well above the economy-wide average. Cultural preferences for university over vocational paths add to the difficulties. In emerging market and developing economies, the challenge stems less from ageing than from skill gaps: in recent years, fewer than 5% of workers aged 19-24 received formal vocational education in India, and tradespeople like electricians and welders remain scarce in South Africa despite high unemployment levels. Underinvestment in vocational education, low certification rates, weak industry-education links and the migration of skilled workers compound these mismatches. Countries like India and Indonesia are seeing a rising share of young people entering energy-relevant degrees, but most regions need stronger action and better co-ordination between policy makers, industry and labour unions.

These shortages are already constraining energy operations. The IEA annual Energy Employment Survey received input from over 600 energy firms, trade unions and educators, and half of companies reported critical hiring bottlenecks, a steady increase over previous years. The most common impacts included project delays, longer lead times and cost overruns. Competitiveness also hinges on the ability of the energy sector to adapt to emerging skill needs and shifting roles, with AI and digital capabilities standing out as an especially pressing gap. Investing to develop digital talent and reskill existing workers is critical in both the scenarios. Some early successes have come from industry-university partnerships and company-led training platforms.

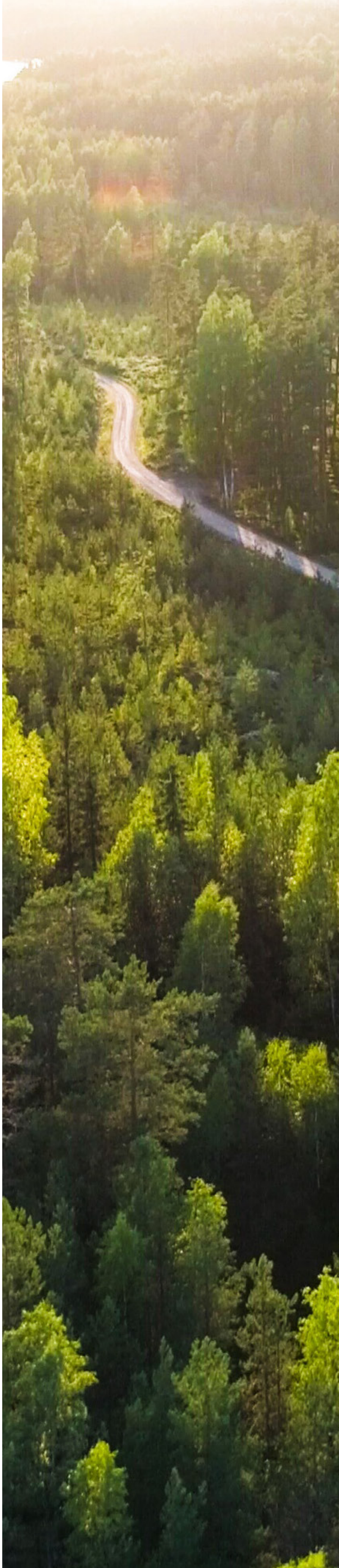
[7] Vocational education and training systems refer to the structures and institutions that provide the skills, knowledge and practical experience needed for specific occupations.

PART C
OUTLOOKS BASED ON GOALS AND PLEDGES

Part C of the *World Energy Outlook* explores what would need to happen for the energy sector to meet internationally agreed climate and sustainable development goals.

Chapter 6 presents the Accelerating Clean Cooking and Electricity Services Scenario. This new scenario explores the fuels, policies and investment that would be needed to meet the goal of achieving universal access to clean cooking and electricity.

Chapter 7 presents an updated Net Zero Emissions by 2050 Scenario. It explores what could be done by 2050 in the context of limiting the increase in global warming to 1.5 °C by 2100, taking account of the latest data on emissions, technology deployment and investment.



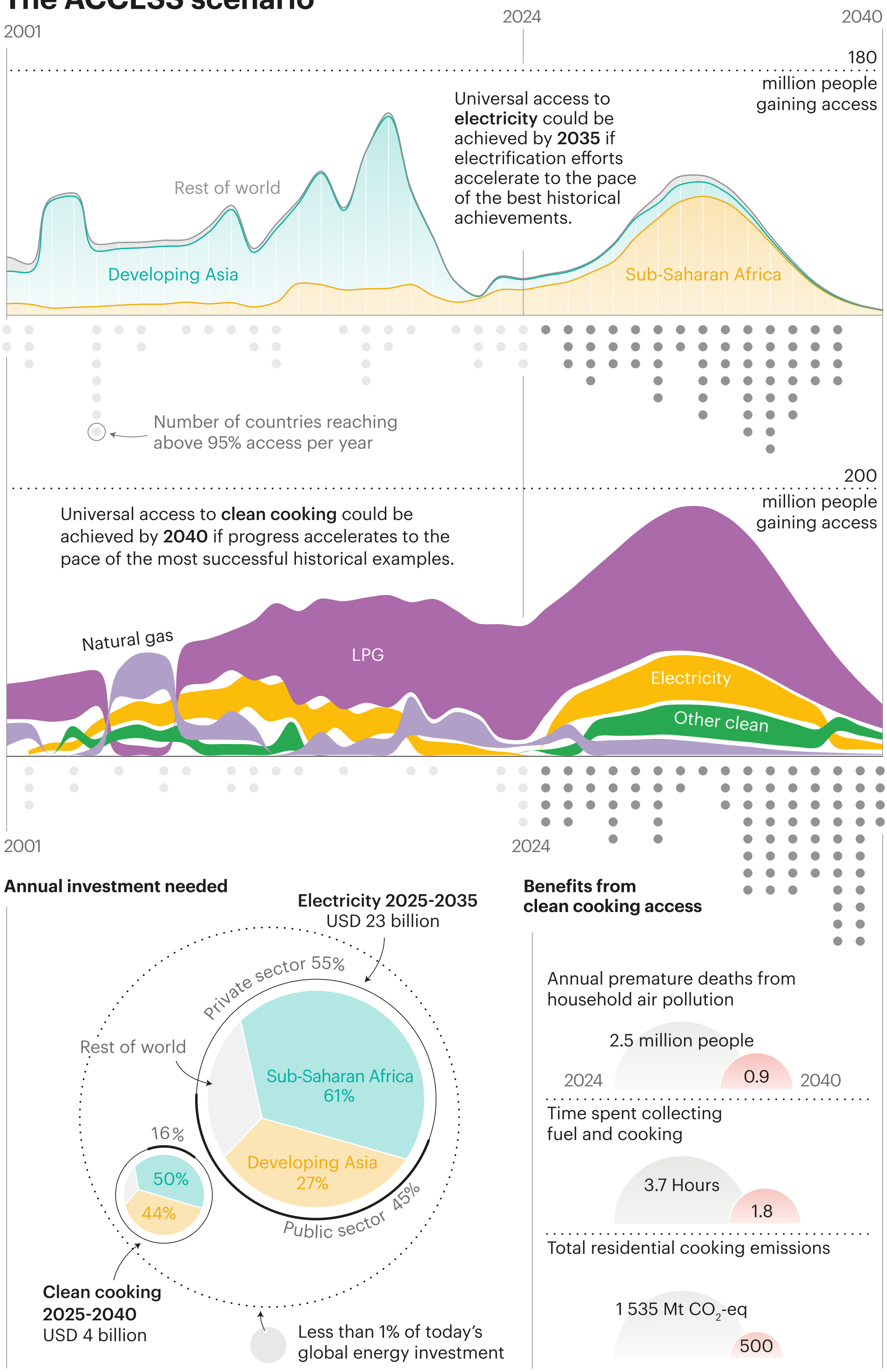
Achieving access for all

A roadmap for universal energy access

SUMMARY

- Today around 2 billion people lack access to clean cooking and some 730 million remain without electricity – deficits which have far-reaching implications for health, economic opportunity and global development. Since 2010, 1.5 billion people have gained access to clean cooking and 1 billion to electricity, demonstrating that rapid progress is possible. Our new Accelerating Clean Cooking and Electricity Services Scenario (ACCESS) outlines a country-by-country pathway to universal access that draws on lessons about what has worked best in recent years.
- Universal clean cooking access is achieved in the ACCESS around 2040. Over 60% of households gaining access to clean cooking do so through the use of liquefied petroleum gas and a further 18% with the use of electricity. Bioethanol, biogas and solid biomass each account for around 4-6% of households that gain access, while natural gas plays a limited role in dense urban areas with planned infrastructure. The benefits of this transition by 2040 are immense: it cuts premature deaths due to household air pollution by almost two-thirds, significantly reduces the time spent cooking, and delivers net emissions reductions of 1.25 gigatonnes carbon dioxide equivalent (CO_2-eq) annually.
- The global electricity access gap closes just after 2035. Over 45% of new connections are from grid extensions; 30% from mini-grids, which are a good match for dense, remote communities; and 25% from stand-alone systems, including solar home systems, which are the best option in areas where grid and mini-grid expansion is unlikely to be feasible in the near term. By 2040, newly connected users add 270 terawatt-hours (TWh) to global electricity demand, contributing up to 45% of the total increase in residential electricity demand in some regions. This is met largely by hydropower, natural gas, and solar photovoltaics (PV), with solar powering most mini-grids and nearly all stand-alone systems.
- Closing the access gap worldwide requires USD 4 billion each year for clean cooking from now until 2040, and around USD 23 billion each year for electricity until 2035. While it is encouraging that private sector involvement is expanding, public and concessional financing remains vital to attract capital to underserved segments, especially in riskier markets where public finances are constrained.
- Expanding energy access can support productivity improvements in agriculture and local industry, helping to drive broader economic and energy demand growth. However, the speed at which energy demand increases once access has been gained may be constrained by the cost of energy, the affordability of new equipment and appliances, grid reliability, and the availability of maintenance services.

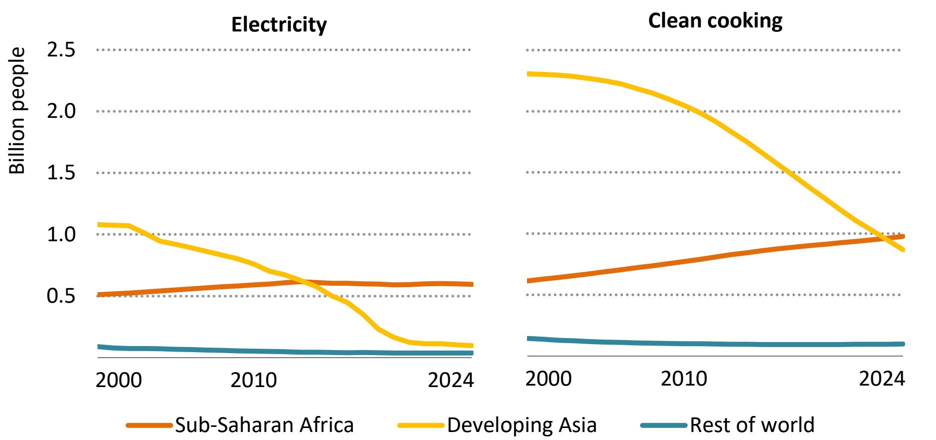
The ACCESS scenario



6.1 Introduction

Even as global energy demand continues to rise, billions of people in around 100 countries remain without access to basic modern energy services. Today nearly 2 billion people lack access to clean cooking and 730 million people lack access to electricity (Figure 6.1). Millions of households, businesses and public institutions such as clinics and schools operate without reliable modern energy. This limits productivity and hinders socioeconomic development. It also perpetuates the use of traditional biomass, with damaging consequences for health and the environment.

Figure 6.1 ▷ Population without energy access, 2000-2024



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Many countries in developing Asia have made rapid progress to extend energy access, but this has not been replicated in some other regions, notably in sub-Saharan Africa

Note: 40% of the rest of world population without access to electricity is in Latin America and the Caribbean and over 70% for clean cooking.

Rapid progress has been made in recent decades in some regions and countries. Since 2010, 1.5 billion people have gained access to clean cooking and around 1 billion people have gained access to electricity, with notable advances in China, India, Indonesia and Cambodia. In sub-Saharan Africa, however, the number of people without access to modern fuels for cooking has increased over the same period. As major middle income countries approach or achieve universal access, overall global progress has begun to slow, leaving the access gap concentrated in low-income countries, including fragile or conflict-affected states. Lower budgets available for international development assistance compound the challenge of regaining momentum.

However, the outlook for extending access to modern energy in these countries has been gradually improving in recent years. Private sector business and finance are participating more actively in the provision of energy access, and innovative technologies and business models are providing new and more cost-effective ways to broaden access to modern energy services. Growing experience with financing energy access projects is making it easier for companies to secure finance at scale, and a surfeit of solar photovoltaics (PV) and battery production capacity in China is lowering the cost of solar home systems. Energy access has also attracted recent political attention, with clean cooking featuring in the G7 and G20 communiqués, building on the political commitments in the 2024 Clean Cooking Declaration, and with renewed efforts on electricity access being reflected in the Dar Es Salaam Declaration and Mission 300.[1]

The **Accelerating Clean Cooking and Electricity Services Scenario** (ACCESS) charts a path to achieve universal access to clean cooking and electricity based on the best rates of progress achieved historically. Explored in this chapter, the ACCESS prioritises cost-effective and proven measures to improve access, considering all relevant fuels and technologies, and the infrastructure, policies and financing needed to scale them up. It draws on new modelling developed by the IEA based on a country-by-country analysis. It examines distinct pathways for rural and urban areas that take account of the rates of progress achieved in countries sharing similar characteristics in terms of demography, levels of prosperity, resource availability and institutional governance. The modelling assesses the availability and cost of potential solutions and selects the option that is most affordable relative to household incomes and that maximises consumer benefits.[2] The pace at which people gain access varies across the IEA scenarios, and the various trajectories are summarised in Box 6.4.

The ACCESS pathway and its energy implications are the principal focus of this chapter. The scenario examines the current landscape based on the most recent IEA tracking data, the trajectory to reach universal energy access and the implied investment requirements for access to clean cooking and to electricity. It explores how progress to achieve energy access can lay the foundation for broader energy development, helping economies and societies achieve better prosperity and health.

6.2 Clean cooking

6.2.1 State of play

Today, there are still around 2 billion people without access to clean cooking – a quarter of the world's population.[3] Most cook with firewood, charcoal, kerosene and animal dung

[1] The IEA Clean Cooking Summit took place in May 2024 in Paris with participants from governments, private sector, development partners, international organisations, philanthropies and civil society. The Declaration pledged signatories to make clean cooking a priority and to enhance efforts to reaching universal access.

Adopted by African Heads of State and Government in January 2025, the Dar Es Salaam Declaration outlines measures to provide access to electricity for 300 million Africans by 2030.

[2] Full documentation of the modelling approach for the ACCESS is available in the 2025 Global Energy and Climate Model methodology (IEA, 2025a) is published in parallel with the *World Energy Outlook 2025*.

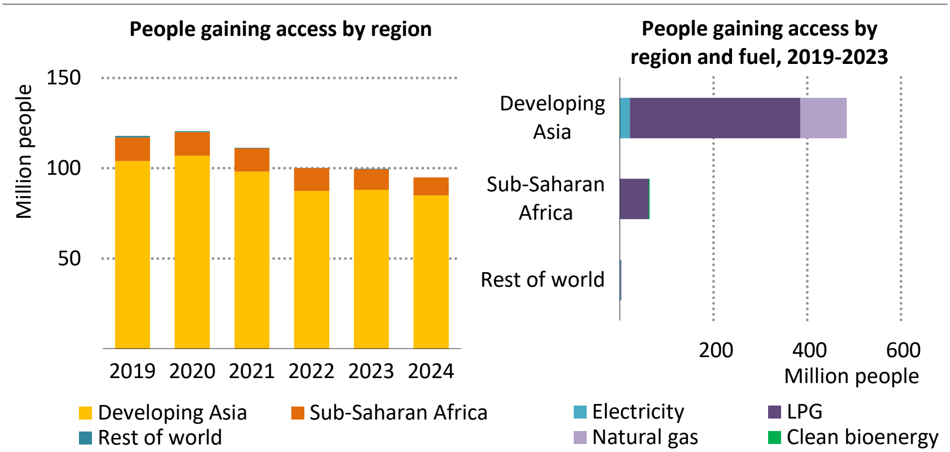
[3] Access to clean cooking means having the use of a stove-fuel combination that achieves at least Tier 4 for fine particulate ($PM_{2.5}$) emissions and Tier 5 for carbon monoxide emissions in line with the World Health Organization definitions.

burned in basic cookstoves or over open fires. This traditional use of biomass leads to poor indoor air quality and has serious health consequences. It also requires time-intensive gathering of fuel and cooking, which restricts the amount of time people have available for more productive activities.

Some regions have made significant progress to provide access to clean cooking in recent decades; others, notably sub-Saharan Africa, have seen the number of people without access rise as population growth outstrips gains in access. Since 2010, almost 1.5 billion people in Asia and the Latin America and the Caribbean region (LAC) gained access to modern cooking stoves and fuels, reducing the number of those without access worldwide by a third in the span of 15 years. In 2023, nearly 90% of the population in the LAC region and 77% of the population in developing Asia had access to clean cooking, up from 87% and 52% respectively ten years ago. This progress has been driven by major government initiatives to provide clean cooking. Around three-quarters of those gaining access have done so with the use of liquefied petroleum gas (LPG). Yet, in sub-Saharan Africa, the number of people without access to clean cooking has risen to around 1 billion today, up from 840 million a decade ago. Only around 23% of people in sub-Saharan Africa had access to clean cooking in 2023.

6

Figure 6.2 ▷ Clean cooking access by region and fuel



Most people gaining access to clean cooking in the last five years live in developing Asia, and most have gained access by using LPG

Notes: LPG = liquefied petroleum gas. Clean bioenergy includes biogas, bioethanol and clean advanced biomass cookstoves (Tier 4-5). Preliminary indicators were used to estimate regional access gains in 2024. Over 70% of the rest of world population without access is in Latin America and the Caribbean.

Sources: IEA analysis based on World Health Organization Cooking fuels and technologies database (2025).

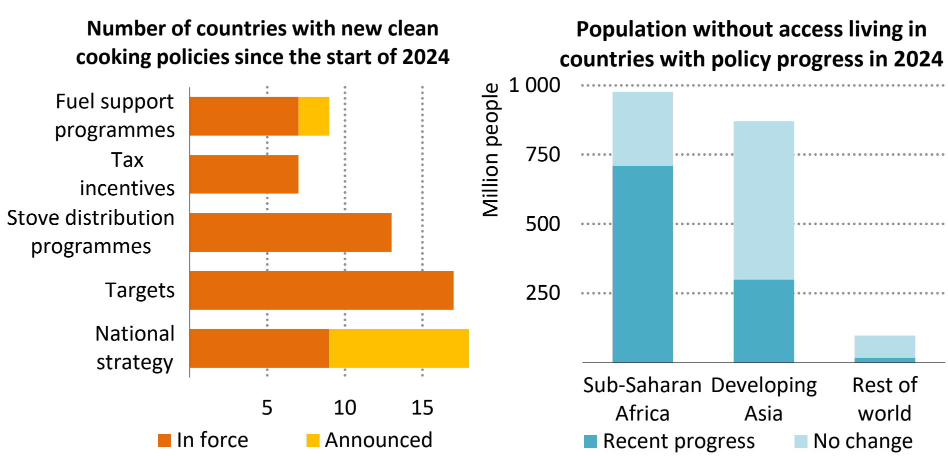
The pace of progress has slowed in recent years. Worldwide in 2019, around 120 million people gained access to clean cooking, while in 2023 just 100 million people gained access.

To some extent this slowdown reflects the major gains made in recent years in countries such as India and Indonesia; those still without access tend to be living in particularly remote areas. The spike in LPG prices following Russia's full-scale invasion of Ukraine in 2022 slowed progress. Some households reverted, at least temporarily, to cooking with biomass. Countries in developing Asia were particularly affected, given their strong reliance on LPG to expand access over the past decades. Preliminary indicators for 2024 indicate a further slowdown in developing Asia and stable progress in other regions.

LPG has fuelled progress to extend clean cooking access in the emerging market and developing economies. More than 75% of those gaining access to clean cooking between 2019 and 2023 did so with the uptake of LPG (Figure 6.2). Others did so by switching to natural gas (17%), and electricity (7%) or biogas. The use of natural gas to extend access was concentrated in countries with urban gas networks; China accounted for around 70% of the total.

In many parts of the world, almost everyone living in urban areas now has access to clean cooking options. In developing Asia and the LAC region, for example, urban access rates are around 95%, with remaining gaps concentrated in informal settlements on the urban fringe. As a result, most of the remaining global shortfall is in rural areas, where progress has been steady but uneven: rural access in the emerging market and developing economies rose from 44% in 2019 to 53% in 2023. However, sub-Saharan Africa remains an exception, with substantial clean cooking access deficits persisting in both urban (41% access rate) and rural areas (9% access rate).

Figure 6.3 ▷ Recent progress in clean cooking policies by region



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Over 50% of people without access to clean cooking live in countries that have introduced new clean cooking policies since the start of 2024

Notes: Tracking period is 1 January 2024 to 26 March 2025. Over 70% of the rest of world population without access is in Latin America and the Caribbean.

One hopeful indicator is that policy frameworks for clean cooking have recently been strengthened in a number of countries. The IEA tracks progress in the development of policy frameworks by looking at a range of policy measures, including national strategies, targets, government incentives, and delivery plans. Since the start of 2024, 64 new clean cooking policy initiatives have been adopted or announced in the emerging market and developing economies, and almost 55% of the population without clean cooking access live in a country that has adopted or announced at least one such initiative (Figure 6.3). Sub-Saharan Africa has seen a notable increase in policy coverage, where over 70% of those without access live in jurisdictions in which new policies have been implemented: 50 new clean cooking policies, including 17 new clean cooking targets, have been put in place since the beginning of 2024.

6.2.2 Outlook

Accelerating and maintaining progress in line with the fastest rates of progress witnessed globally would result in near-universal clean cooking access by around 2040, as projected in the ACCESS (Figure 6.4). On average, 130 million people gain access each year in the ACCESS, 1.4-times more than today. The rate of progress in the near term is much quicker, rising to a peak of about 190 million people per year around 2030. Sub-Saharan Africa sees faster acceleration than any other region, with the proportion of the population with access to clean cooking increasing at an average annual rate of 4.7 percentage points – a pace comparable to the best historical rate achieved in countries such as India, Indonesia and Cambodia. Urban areas generally reach full access about five years ahead of national averages, reflecting population density and the scope for making use of existing infrastructure.

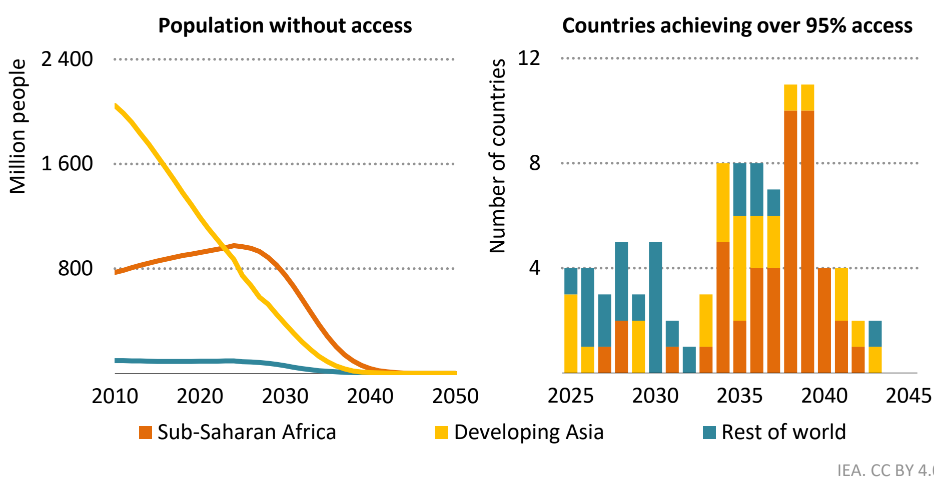
The timeline to achieve universal energy access to clean cooking differs significantly by region. The LAC region is on track to achieve over 95% clean cooking access by 2031, followed by developing Asia in 2033 and sub-Saharan Africa just before 2040. In the LAC region, the remaining challenge lies in reaching small, often remote or indigenous communities. In developing Asia, major access efforts are needed in countries such as Pakistan, Bangladesh and Mongolia, and a focus on last-mile connections in countries such as Indonesia and India that are approaching universal access. Sub-Saharan Africa is projected to be the last region to declare success in universal access, but it sees the sharpest acceleration in the ACCESS, with 80 million people gaining access each year – eight-times the current rate.

By 2030, 24 countries are expected to reach near-universal access in the ACCESS, covering around one-quarter of the global population that lack clean cooking solutions today. Most other countries are projected to achieve universal access between 2030 and 2040. While developing Asia and other regions move towards universal access sooner, sub-Saharan Africa lags behind. By 2038, nearly 80% of the remaining population without access to clean cooking is projected to be in Africa.

All types of clean cooking solutions contribute to progress. Geographic location, existing infrastructure and socioeconomic conditions all influence which options are likely to be adopted by communities, as do consumer preferences that reflect local cuisine and culture.

The IEA assesses the impact of these factors on the availability and affordability of different fuels by region in the modelling for the ACCESS. It takes account of new IEA spatial analysis that evaluates the delivered cost of various fuels at a very granular level to assess which options households are likely to favour, based on the assumption that they will select the most advantageous option within their financial means. The analysis also considers the scalability of supply chains, the scope for improvement in infrastructure and fuel availability over time, and broader considerations of energy security. While recognising that there are wider cultural and other non-financial factors that will also play a part in decisions about which cooking options to adopt, the IEA has not attempted to model these.

Figure 6.4 ▷ Clean cooking access by region in the ACCESS



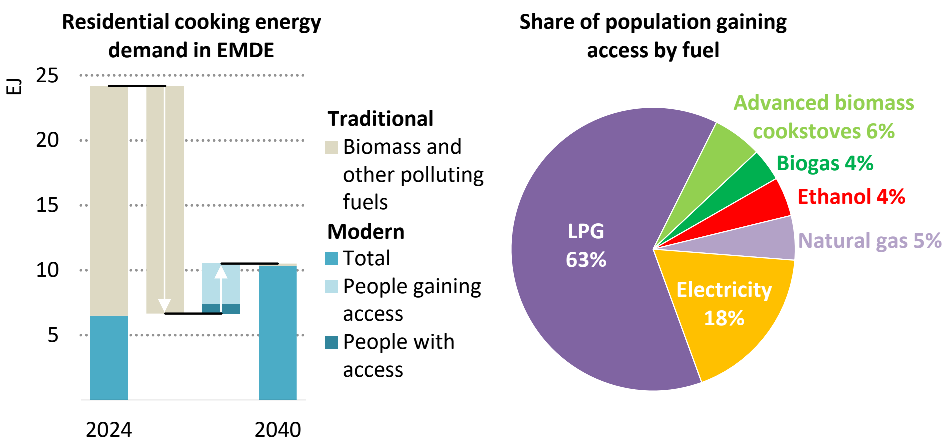
Developing Asia closes the clean cooking gap by maintaining today's pace of progress, while sub-Saharan Africa accelerates sharply in the ACCESS

Notes: Right chart shows 95 countries with an access gap, but excludes small countries which together represent less than 1% of the total access gap. Over 70% of the rest of world population without access is in Latin America and the Caribbean.

Source: IEA analysis based on World Health Organization Cooking fuels and technologies database (2025).

Based on this analysis, LPG remains the primary means of expanding clean cooking in the ACCESS, accounting for 63% of new clean cooking access (Figure 6.5). Its primacy reflects its affordability, relatively low infrastructure requirements, ease of transport and compatibility with traditional cooking practices. LPG plays a significant role in both urban and rural settings. Electric cooking provides 18% of new access, a larger share than observed over the past decade, driven by stronger policy support, increased efforts to take advantage of domestic electricity production, and declining technology costs. Electric cooking is a particularly favoured option in urban areas with a reliable electricity supply. Bioethanol and biogas each contribute around 4% of new access, with biogas mainly focused in agricultural areas with ample feedstock. Modern solid bioenergy accounts for a further 6%, and is adopted mainly in parts of Africa where affordability and underdeveloped distribution networks limit access to other clean fuels. Natural gas extends access to about 5% of households, primarily in urban areas where infrastructure exists and where supplies of domestically produced gas are readily available. Around two-thirds of the new natural gas connections are in developing Asia, often alongside housing development projects that target informal settlements.

Figure 6.5 ⊳ Residential energy demand for cooking and population gaining access by fuel in emerging market and developing economies in the ACCESS, 2024-2040



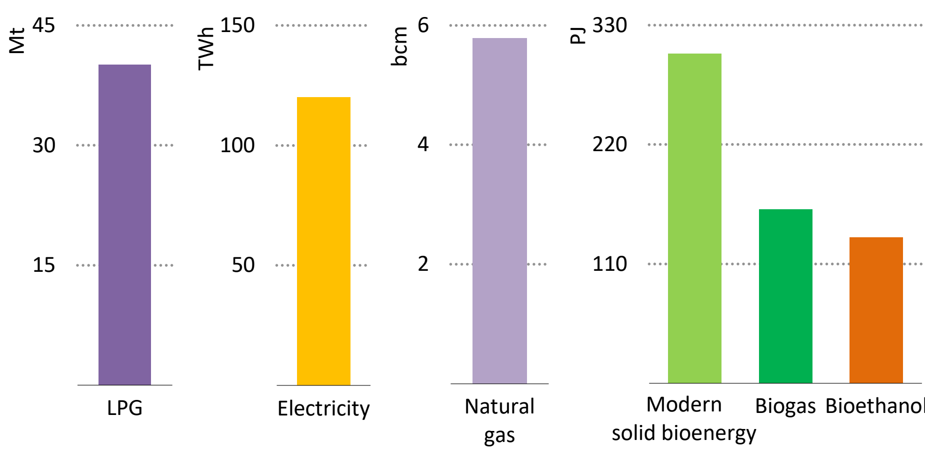
Most households that gain access to clean cooking access do so with the use of LPG (63%) or electricity (18%)

Notes: EMDE = emerging market and developing economies; EJ = exajoule; LPG = liquefied petroleum gas. Advanced biomass cookstoves only include clean advanced biomass cookstoves (Tier 4-5).

Demand for modern cooking fuels increases 1.5-times from today's level by 2040 in emerging market and developing economies in the ACCESS. While this is a significant shift – roughly equivalent to current total energy use in the United Arab Emirates – it accounts for a relatively small share of global energy demand growth. In sub-Saharan Africa, the transition to modern cooking fuels has a particularly pronounced impact, reshaping regional energy consumption patterns.

Global LPG use for residential cooking increases from 2.4 million barrels per day (mb/d) today to around 3.4 mb/d by 2040 in the ACCESS. In the near term, global LPG markets can supply this additional demand, but the increase in LPG demand for cooking may have implications for other users and for how the oil industry markets natural gas liquids. In the longer term, LPG supply is expected to increase through to 2040 as new liquefied natural gas and refining capacity comes online. Households gaining access to clean cooking via electricity increase demand by 120 terawatt-hours (TWh) in 2040 (Figure 6.6). The share of this increase in total electricity demand growth in the ACCESS varies by region, ranging from less than 1% in developing Asia to around 9% in sub-Saharan Africa. Expanding the use of electric cooking depends on improvements in grid reliability and upgrades to household wiring to accommodate the higher power needs of electric appliances. Bioethanol demand reaches 6.5 billion litres annually – around 6% of today's global fuel ethanol market – driven largely by growth in Africa, particularly East Africa. Biogas and modern solid biomass used for residential cooking also see strong growth, increasing twofold and 15-fold respectively over current levels in the emerging market and developing economies.

Figure 6.6 ▷ Demand for modern energy for clean cooking access by fuel in the ACCESS, 2024-2040



Modern energy use for cooking in emerging market and developing economies increases by a factor of 1.5 by 2040

Note: Mt = million tonne; TWh = terawatt-hour; bcm = billion cubic metre; PJ = petajoule; LPG = liquefied petroleum gas.

Adequate distribution infrastructure is much more of a challenge in most regions than fuel supply. Countries need to build distribution infrastructure to reach a broad array of consumers, including many in underserved regions and communities. This requires investment in logistics, retail networks, port infrastructure, storage, new manufacturing facilities and supply chain co-ordination.

Affordability persists as a significant challenge. Many low-income households cannot afford the upfront or recurring costs of clean cooking options. Bridging the gap requires a mix of measures such as tax and tariff reductions on clean cooking equipment and fuels, targeted subsidies, results-based financing and innovative business models such as pay-as-you-go systems or micro-purchases of fuel. The affordability challenge is particularly acute in sub-Saharan Africa, where IEA analysis shows that nearly 600 million people would need to spend more than 10% of their income to adopt and consistently use clean cooking solutions in the first year.

The transition to clean cooking presents other important policy considerations for governments. From an energy security perspective, increased reliance on imported fuels such as LPG, natural gas and ethanol risks increasing exposure to global price volatility and straining hard currency reserves. Governments can mitigate the risks by investing in local storage, diversifying fuel supply sources, and pursuing a broad mix of clean cooking solutions. Many governments are currently looking into reinforcing electric cooking and modern bioenergy options to make use of domestic energy resources such as surplus electricity and agricultural waste, and to create new income streams for farmers and utilities.

In addition, the shift away from traditional fuels will affect the livelihoods of workers in the firewood and charcoal supply chains. Supporting a just transition through retraining and integration into clean cooking markets could help to move these workers from the informal economy into formal employment. Their existing distribution networks and logistical experience means that many of them are likely to be good candidates for new roles in fuel delivery, appliance sales and servicing.

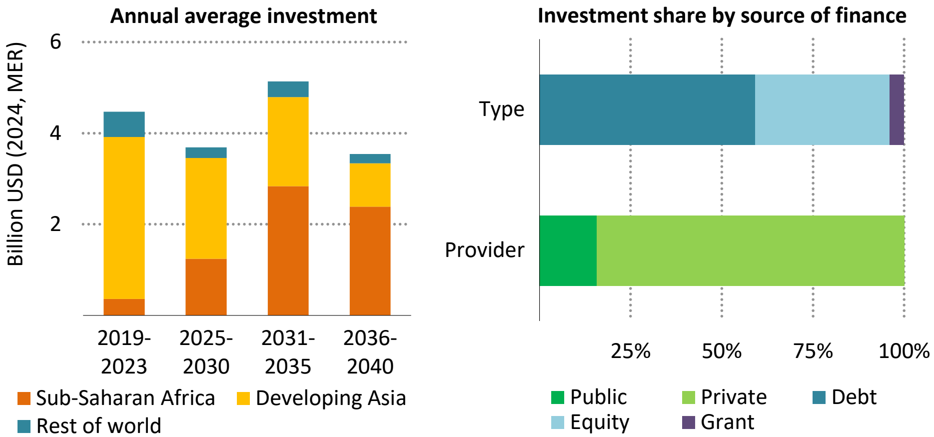
6.2.3 Investment

Global investment in stoves, end-user equipment and distribution infrastructure averaged USD 4.5 billion per year in the 2019-2023 period (Figure 6.7). LPG dominated at around USD 3 billion per year, largely financed by state-owned enterprises and the private sector, particularly oil and gas distribution companies leveraging on-balance sheet debt. Together electric cooking devices, natural gas, bioethanol, biogas and other cooking solutions attracted an average of nearly USD 1.5 billion in investment over the same period.

To reach universal access to clean cooking, total investment of around USD 65 billion is needed, with annual spending peaking in the first half of the 2030s at around USD 5 billion. While this annual average is largely in line with the levels of investment seen today, the ACCESS sees a shift from developing Asia, 80% of investment today, to sub-Saharan Africa with two-thirds of investment in 2036-2040. LPG continues to be the leading option, accounting for 60% of total investment over the period to 2040. The overall amounts remain modest compared with global energy investment, but could bring very high benefits (Box 6.1).

Scaling up investment in clean cooking requires action to expand the current range of finance providers and instruments, and to increase access to low cost, flexible debt to support working capital needs, especially for companies that are expanding their customer base but have yet to generate steady revenues from fuel sales or carbon credits. In the ACCESS, the share of debt in total financing for access to clean cooking rises from 35% today to around 60% toward 2040.

Figure 6.7 ▹ Investments in clean cooking access by type, 2019-2035, and by source of finance in the ACCESS, 2025-2040



IEA. CC BY 4.0.

Most of the USD 4 billion average annual investment needed for clean cooking comes from private investment, but public support is also crucial

Note: MER = market exchange rate. Over 70% of the rest of the world population without access is in Latin America and the Caribbean.

Financing requirements for clean cooking differ across regions. In developing Asia, support has largely come from state-owned enterprises or through concession-based models. In Latin America and the Caribbean, clean cooking programmes have primarily been administered by government bodies. In Africa, where financing for clean cooking is most needed, private capital is projected to account for 80% of total flows by 2040.

Private sector participation is constrained by structural barriers such as macroeconomic and political risk, and by the limited maturity of some markets. This an issue for small and medium enterprises in particular. Larger and more established clean cooking companies are increasingly able to secure financing from domestic and international banks, while major LPG distributors benefit from the ability to raise capital through their parent oil and gas companies, which are either public state-owned enterprises or overseas companies that can access debt in other markets, thereby avoiding the risk premiums typically applied to emerging market and developing economies. However, small and medium enterprises, especially those owned and operated by women, face persistent challenges. Many struggle to access finance or face high capital costs, despite playing a critical role in reaching underserved and remote communities where commercial players are unwilling to invest. As a result, many rely on off-balance sheet financing to fund operations, which inhibits their ability to scale up.

Affordability is another major hurdle. In many cases, clean cookstoves are replacing fuels such as firewood that were either free or low cost. For projects to be viable for price sensitive consumers, stove and fuel costs need to be low, which reduces the likelihood of private investment, unless it can be supplemented by public funding.

Viable business models are essential to address these challenges, mitigate repayment risk and unlock access to debt. Clean cooking companies are increasingly adopting innovative approaches such as pay-as-you-go, savings schemes, third-party financing and utility-led models. There is also an increasing focus on empowering women as users, entrepreneurs and employees. If these are seen to be successful, commercial banks are likely to perceive the models as less risky and to be willing to build on their growing experience with similar models for electricity access. This would lead to more favourable lending conditions, i.e. lower interest rates, reduced collateral requirements and longer loan periods, making it easier for companies to secure the financing needed to scale up. Carbon markets can also help close the financing gap, for example by facilitating the use of future carbon credit revenues as collateral to secure loans for their expansion. Carbon credit revenues already account for a significant proportion of the revenue stream for clean cooking companies operating in some regions, notably in Africa, where they represent over 10% of capital flows.

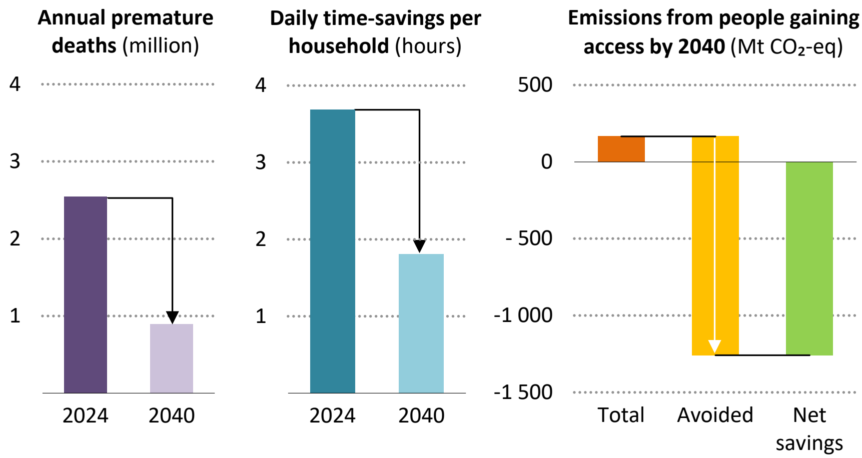
While private capital will remain the dominant source of finance, concessional public investment remains vital to extend access to commercially unattractive market segments and to catalyse private sector involvement. There are encouraging efforts to mobilise larger volumes of public finance to support clean cooking in underserved areas such as sub-Saharan Africa. USD 470 million has been disbursed following the USD 2.2 billion worth of new commitments made at the IEA Summit on Clean Cooking in Africa in 2024.

Domestic and international public financiers today offer a range of concessional instruments to de-risk investment. Many instruments are increasingly focused on crowding in private sector finance by offering guarantees, political risk insurance and currency hedging. Concessional capital providers can also help address the shortage of equity needed to unlock cost-effective debt at scale for medium-size enterprises with proven models seeking to attract angel investors, venture capital and private equity. In addition, technical assistance grants can help to support early stage business development, flexible grant instruments can help fill equity gaps for smaller firms, and access to flexible debt facilities on concessional financing terms, such as short-term or revolving debt facilities, can help cover fluctuations in cash flows and thus ease constraints on working capital and equity.

Box 6.1 ⊳ Benefits of extending access to clean cooking

Even when considering the costs of extending access to clean cooking, the benefits remain immense (Figure 6.8). Lack of access to clean cooking harms health, economic development, education and the environment. In the ACCESS, the impact of the transition to clean cooking solutions contributes to reducing premature deaths caused by household air pollution by almost two-thirds globally by 2040. The time saving benefits are also significant. In regions with a clean cooking access gap, women and girls in areas dependent on foraged firewood spend up to five hours a day gathering fuel and cooking, which cut short the time available for education or remunerated activities. In aggregate, the time saved by households switching to clean cooking solutions by 2040 is roughly equivalent to the total number of hours worked each year in Indonesia today.

Figure 6.8 ▷ Impacts of the ACCESS pathway in 2040



Benefits of extending clean cooking access are substantial in terms of health, productivity and the environment

Notes: Mt CO_2-eq = million tonnes of carbon-dioxide equivalent. Emissions are compared to a baseline scenario which assumes no further progress in access beyond 2024, with changes driven solely by population growth. Premature deaths refer to deaths caused by household air pollution.

Providing access to clean cooking cuts emissions too. Extending access to clean cooking generates approximately 165 million tonnes of carbon-dioxide equivalent (Mt CO_2-eq) of additional emissions through increased demand for electricity, LPG and natural gas. However, the transition away from biomass used in traditional cooking methods also reduces or avoids emissions by helping to prevent deforestation and by cutting methane emissions resulting from the incomplete combustion of biomass. This reduces greenhouse gas emissions from cooking and deforestation by around 1.4 gigatonnes of carbon-dioxide equivalent (Gt CO_2-eq) compared to a baseline in which there is no increase in access to clean cooking from the current level. Therefore, in net terms, actions to achieve universal clean cooking access in the ACCESS reduce greenhouse gas emissions by around 1.25 Gt CO_2-eq annually, equivalent to energy-related CO_2 emissions from international aviation and shipping.

6.3 Electricity access

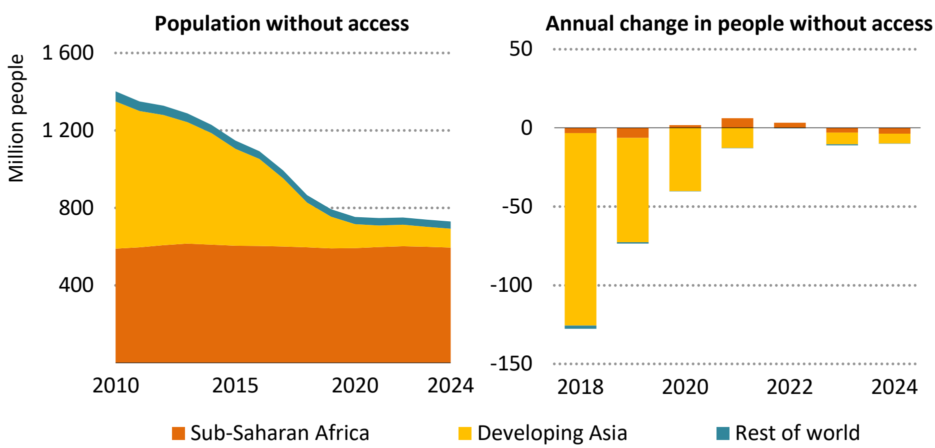
6.3.1 State of play

The world has witnessed substantial progress towards universal electricity access in the last two decades. The global access rate increased from 80% in 2010 to over 90% today, which means that 1 billion people have gained access to electricity over the past 15 years. Some countries have seen very significant progress. For example, Indonesia, India, and Bangladesh achieved universal access in 2020, 2021 and 2023 respectively, while access rates in Kenya and Rwanda have increased by around 30 and 40 percentage points since 2015 respectively.

Yet, successive crises in recent years, including the Covid-19 pandemic, have reversed progress. For the first time in decades, the number of people without access to electricity globally actually increased in 2022. While access levels then picked up, the pace of progress fell short of pre-pandemic trends and the global population without electricity access reduced by only 11 million between 2023 and 2024 (Figure 6.9). In some major economies, the pace of progress is slowing as they approach universal access, leaving only those most difficult to reach without access; in others, the slowdown reflects obstacles such as debt burdens after the Covid-19 pandemic and global energy crisis, and cuts in international aid.

6

Figure 6.9 ⊳ Population without electricity access by region, 2010-2024 and 2018-2024



IEA. CC BY 4.0.

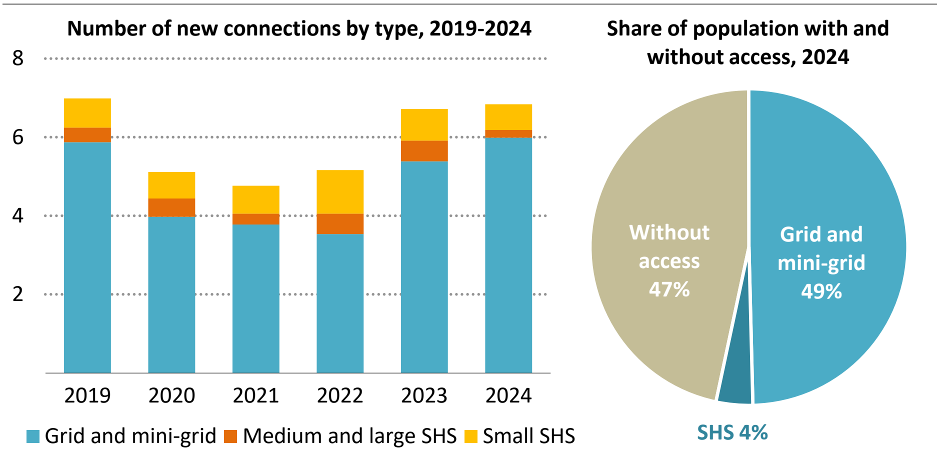
Number of people without access to electricity has declined more slowly since the pandemic; in sub-Saharan Africa it has been broadly flat since 2010

Note: Around 40% of the rest of the world population without access is in Latin America and the Caribbean.

Today, 730 million people still lack access to electricity. A persistent gap remains in sub-Saharan Africa, which accounts for 80% of the world's population that lack access. This population has hovered around 600 million since 2010. By contrast, most countries in developing Asia report access rates above 95%, with key exceptions in Pakistan, Afghanistan, Mongolia, Myanmar, and the Democratic People's Republic of Korea (North Korea). The LAC region has a regional access rate of 98%, though progress lags in Haiti, and connecting remote communities remains a complex task.

Grid expansion remains the main way of providing electricity access, but decentralised solutions such as mini-grids and solar home systems play an expanding role, particularly where grids are not available or lack reliability (Figure 6.10). Of the 27 million people that gained access to electricity globally in 2024, the vast majority of new connections were attributable to grid and mini-grid expansions. However, decentralised electricity systems played a particularly significant role in sub-Saharan Africa where over 4 million people – 12% of new connections – gained access to electricity through solar home systems in 2024. Around 4% of households in sub-Saharan Africa now get their electricity from solar home systems that meet the IEA threshold for electricity access (IEA, 2023).[4]

Figure 6.10 ▷ New electricity connections by type, 2019-2024, and population with and without access in 2024 in sub-Saharan Africa



New connections in sub-Saharan Africa picked up in 2024 mostly with grid-based solutions which accounted for the largest share of those with electricity access

Notes: SHS = solar home systems. Medium and large SHS have capacity of >50 Watt-peak (Wp). Small SHS have capacity of 10- 50 Wp. This figure does not include SHS less than 10 Wp, which are not large enough to support the power and demand thresholds in the IEA definition for electricity access. The IEA analysis takes account of a replacement rate that excludes systems sold as substitutes for existing units.

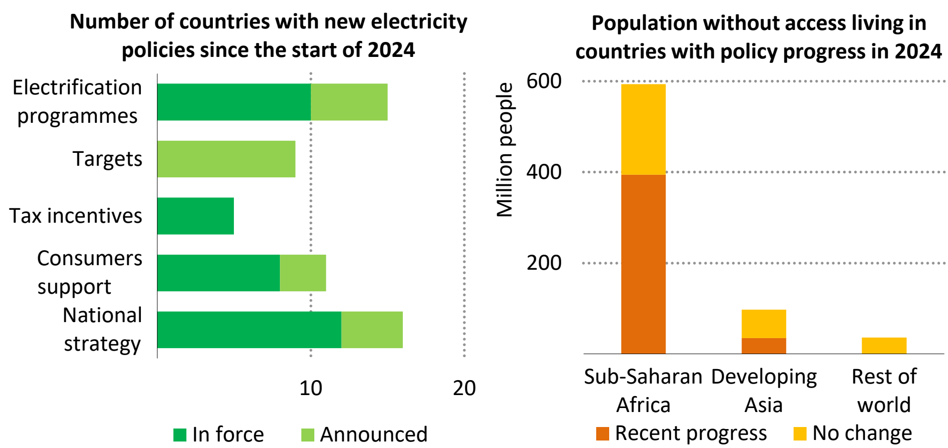
Source: IEA analysis based on the Global Off-Grid Lighting Association (GOGLA) (2025).

[4] The IEA defines solar home systems of 10 Wp and above as providing access to electricity.

Despite a challenging macroeconomic situation, sales of solar home systems in sub-Saharan Africa rose by 60% between 2019 and 2024, driven by continued market growth in East and West Africa (GOGLA, 2025). In developing Asia, solar home system sales have been more volatile over the same period, but recent data show a nearly 30% increase in 2024. In both regions, adoption has also been fuelled by increased demand for backup supply in areas with frequent grid disruptions. Innovative business models such as pay-as-you-go systems have helped overcome affordability barriers.

Electricity access policy frameworks have recently been enhanced in a number of countries with 56 new related policies implemented or announced since the start of 2024 (Figure 6.11). Examples include national electrification strategies, rural electrification or last-mile connection programmes, tax exemptions and consumer affordability support. Around 60% of the global population that lack electricity access live in the countries that have recently strengthened their access policy frameworks.

Figure 6.11 ⊳ Recent progress in electricity access policies by type and region



Around 60% of people lacking electricity access live in countries that have seen recent policy progress, with 56 new policies tracked since the start of 2024

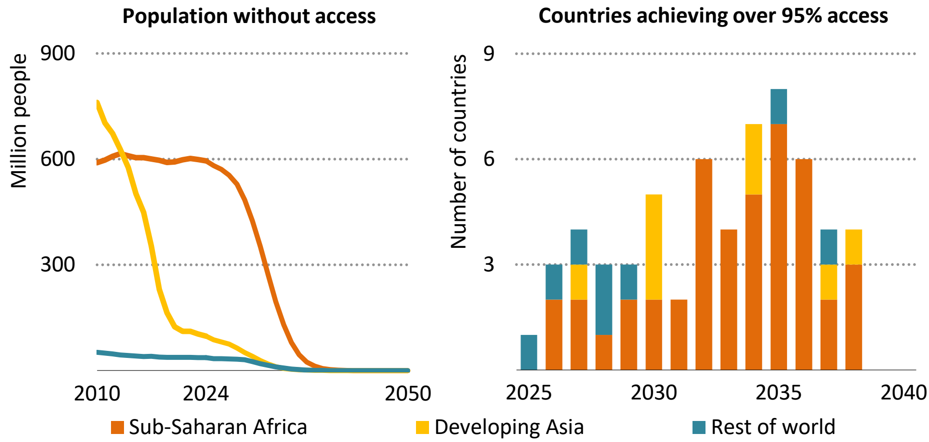
Note: Recent progress includes both policies that are in force and announced policies.

Most of these enhancements are in sub-Saharan Africa, where two-thirds of those without access live in countries with new policies, including Nigeria, Ethiopia, Kenya, Madagascar and Ghana. Policies include new targets laid out in Energy Compacts agreed by African countries at the African Energy Summit in Dar Es Salaam in 2025. In developing Asia, one-third of those without access live in countries with new policies, including Myanmar, Pakistan and the Philippines. In the LAC region, Bolivia and Paraguay have implemented major new policies.

6.3.2 Outlook

Universal access to electricity could be near by 2035 if global efforts were stepped up to rates equivalent to the best achieved so far. In the ACCESS, an average of 80 million people – more than a twofold increase compared to current rates – gain electricity access each year. Around 19 countries are expected to achieve near-universal access by 2030. Most other countries close their access gaps between 2030 and 2035, while a handful continue to extend last-mile connections through to 2038.

Figure 6.12 ▷ Electricity access by region in the ACCESS



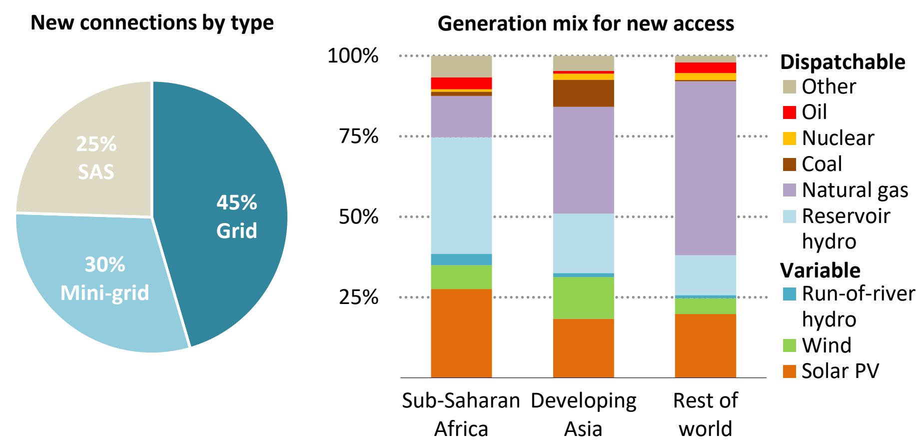
Most countries in developing Asia and the rest of the world close the last-mile gap before 2030 in the ACCESS, while most countries in sub-Saharan Africa need more time

Notes: Right chart shows 60 countries with an access gap but excludes small countries which together represent less than 1% of the total access gap. Around 40% of the rest of world population without access is in Latin America and the Caribbean.

The pathway to closing the electricity access gap varies significantly among countries. Some are on the final stretch to reach universal access, while others face a steep climb. In developing Asia and the LAC region, most countries have high penetration of electricity access and are now focused on reaching remote rural communities, which have historically been more difficult and expensive to connect. In the ACCESS, progress in these regions continues, but at a slower pace than previously, with around 10 million people gaining access each year. Sub-Saharan Africa, by contrast, still has large numbers of people without access in both urban and rural areas (Figure 6.12). This presents an opportunity for rapid gains in the ACCESS on the scale of those seen in India, Indonesia and China at the peak of their electrification drives. In the ACCESS, sub-Saharan Africa sees 70 million people gain access each year – almost a fourfold increase compared to today.

Electricity connections derive from three main sources: grid extensions, mini-grids or stand-alone systems. The type of electricity connection households receive in the ACCESS depends on several factors: proximity to existing infrastructure; population density of unelectrified areas; projected demand and ability to pay; and the speed at which new connections can be made. Allocations are informed by a geospatial, least-cost assessment that considers the cost of delivery alongside the projected demand profile, which in turn is closely linked to household income levels.

Figure 6.13 ▷ Global new electricity connections by type and associated generation mix by region in the ACCESS, 2024-2040



Almost half of households are connected via grids, while mini-grids connect 30% and stand-alone systems connect 25%

Note: SAS = stand-alone systems.

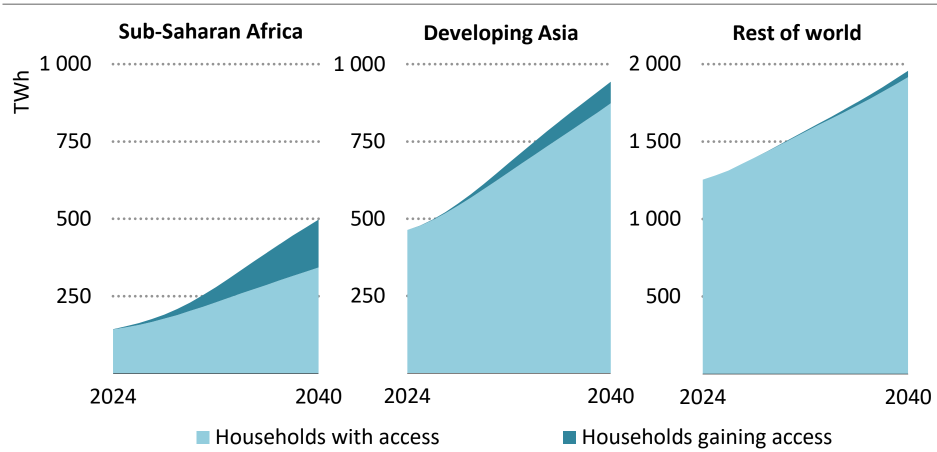
Grid expansion remains the dominant approach, accounting for 45% of new connections by 2040, mostly in regions which are relatively densely populated and where unelectrified communities lie close to existing transmission and distribution networks (Figure 6.13). In more remote but sizeable communities, i.e. especially those with schools, clinics, telecom towers, small-scale industry and local mining, mini-grids play a significant role and provide around 30% of new access. Stand-alone systems account for around 25% of new connections in the ACCESS. Stand-alone systems range from small solar home kits to larger set-ups including some with oil-based generators. They are typically deployed in dispersed, low demand areas where neither grid nor mini-grids are economically viable. Many of these systems power just a few basic appliances like lights, fans, radios and mobile phone chargers.

Although they are more expensive than grids on a per kilowatt-hour (kWh) basis, and are limited in the services they can provide, stand-alone systems play a crucial role to provide electricity for isolated households. Falling solar PV and battery storage costs mean that solar powered systems are becoming increasingly more common and accessible, particularly in sub-Saharan Africa, while pay-as-you-go and other innovative business models have improved affordability and increased uptake. Small "pico-solar" devices are also widely purchased and used today: while these may fall short of formal electricity access definition thresholds, they help meet the energy needs of those who cannot afford anything more.

When households are first connected, they typically consume only small amounts of electricity for lighting, phone charging and perhaps a fan, radio or television. This reflects affordability constraints and limited appliance ownership. Over time, demand tends to grow as incomes rise and households acquire more appliances, such as a refrigerator, washing machine or electric stove, but this process is gradual. Based on data in several African countries, the IEA has calculated that most newly connected households initially consume one-fifth of the regional average household energy use and even five years on, they consume 20% less than average households in those countries.

Despite low per household consumption at the outset, the sheer number of new connections means that demand growth from newly electrified homes is significant. By 2040, the incremental electricity demand arising from households gaining access reaches 270 TWh in the ACCESS, roughly the electricity consumption of Italy today. This increased demand has a marked effect in sub-Saharan Africa, where new access accounts for 45% of additional residential electricity demand from now to 2040, compared with 15% in developing Asia and 5% in other regions (Figure 6.14).

Figure 6.14 ▷ Residential electricity demand from connected households and those gaining access by region in the ACCESS by 2040



Extending electricity access contributes little to residential electricity demand growth to 2040 in most regions, but it accounts for over 40% of the total in sub-Saharan Africa

Notes: Rest of world = all regions with an access gap other than sub-Saharan Africa and developing Asia. Developing Asia in this figure excludes China, India and Indonesia, which have already reached universal electricity access.

New electricity demand is met by the most cost-effective generation sources that can ensure reliable service in the ACCESS. Hydropower and natural gas account for 30% and 25% of global electricity supplied to newly connected households. Solar PV meets a quarter of this demand and powers most off-grid systems. In mini-grids, especially those serving larger rural communities with schools, clinics or small businesses, solar is often combined with battery storage and oil-based backup generators to ensure reliability and continuous supply. The vast majority of stand-alone systems and small access solutions rely on solar and batteries. The total capacity needed to meet the additional demand from new connections through to 2040 is relatively limited.

Scaling up electricity access, particularly in areas with limited financial resources, requires efforts to identify and support productive uses of electricity. Local industries, agricultural activities and service providers can act as anchor customers for new access projects helping to stabilise demand and improve project economics. Such anchor consumers are often able to convert reliable electricity into increased productivity and income, improving their ability to pay for electricity services. For developers and financiers, this focus on productive uses is critical, as projects with strong commercial anchors are generally easier to finance and more sustainable.

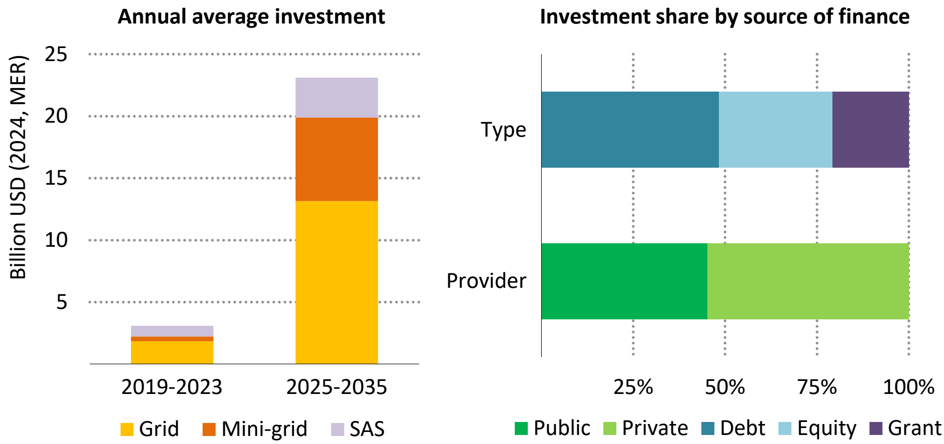
At the same time, expanding electricity access must be accompanied by efforts to improve reliability and affordability. Without dependable electricity, households and businesses cannot make full use of their connections, particularly for income generating activities. IEA analysis of satellite data on nighttime lighting in sub-Saharan Africa reveals that only about half of areas with access to electricity show signs of consistent electricity availability during peak evening hours. A number of countries in sub-Saharan Africa are beginning to strengthen regional power pools and improve co-ordination between rural electrification agencies and national utilities in order to boost reliability. These are important steps to ensure service quality keeps pace with access. Similar actions are underway in other regions too.

6.3.3 Investment

The IEA now tracks commitments from public and private financiers related to electricity access. Between 2019 and 2023, an average of USD 3 billion was committed annually to finance electricity access (Figure 6.15). Following a Covid-19 pandemic-related dip in 2020, finance commitments rebounded in 2021; total commitments are now around one-quarter higher than in 2019, at USD 3.4 billion. Finance flows have been heavily concentrated in a handful of countries: in Africa, six countries – South Africa, Mozambique, Kenya, Senegal, Angola and Nigeria – accounted for almost 50% of tracked financing on the continent over the five-year period. Funding has also been skewed towards urban and peri-urban areas, where higher population density and incomes made it easier to demonstrate bankability for projects.

Reaching universal access to electricity worldwide requires around USD 250 billion of investment between 2025 and 2035 to fund capital expenditure, including the cost of installing grid or mini-grid lines, and equipment costs for decentralised solutions. This translates into around USD 23 billion of spending per year between 2025 and 2035, which represents a sizeable portion of expected power sector investment outlays in the coming years and would mean a sevenfold increase in the current level of investment for electricity access.

Figure 6.15 ▷ Investment in electricity access by type, 2019-2035, and by source of finance in the ACCESS, 2025-2035



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Investment in access to electricity increases sevenfold in the period to 2035; of which around 55% is from private sources, with a notable increase in equity capital

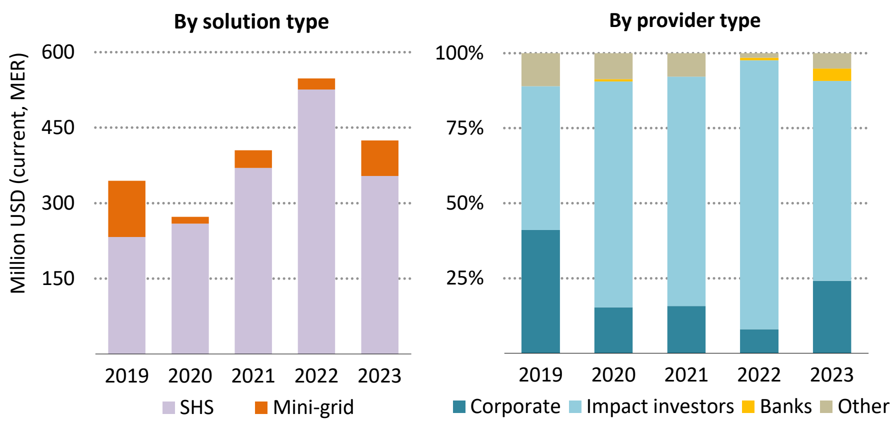
Notes: MER = market exchange rate; SAS = stand-alone systems. Investment in the 2019-2023 period is based only on countries that have not yet reached universal access in order to have an equal comparison to future investment needs. As such, countries such as India, Indonesia and Bangladesh that reached universal access in recent years are not included.

Mobilising more private finance is central to expand electricity access. The private sector accounts for roughly 60% of the investment needed in the ACCESS to reach universal electricity access. The level of private finance involvement varies across solution types: it accounts for 80% of investment in solar home systems, but that figure falls to 50% for grid connection projects, where state-owned utilities are the largest or only players in some markets (Box 6.2). Regulatory hurdles and exposure to financially struggling utilities (Box 6.3) can further hinder private investment in grid connection projects.

Box 6.2 ▷ Innovative financing solutions for off-grid access

Private sector investment in off-grid solutions has been increasing in recent years thanks to the development of new financing instruments, particularly off-balance sheet financing for solar home system (SHS) companies (Figure 6.16). Historically, SHS projects were financed through company balance sheets, but this can be restrictive for companies using a pay-as-you-go model because the liability for sold appliances remains on the balance sheet until it is fully paid off by the consumer. Since 2020, large SHS developers began using off-balance sheet transactions underpinned by the securitisation of company receivables – the future payments from customers as they pay back their SHS obligations – to attract a broader range of private investors, including commercial banks. This approach frees up the developer balance sheet while also limiting the risk exposure of investors (IEA, 2025b). In the ACCESS, the use of securitisation increases, including through the use of aggregation platforms that make such transactions viable for smaller developers.

Figure 6.16 ⊳ Private financing for decentralised electricity access in Africa by type of solution and investor, 2019-2023



Stand-alone systems and private sector finance contribute significantly to electricity access projects with large transactions in 2021 and 2022 boosting investment

Notes: SHS = solar home systems; impact investors = debt and equity funds with an impact mandate, including private equity and venture capital. Other = crowdfunding, family offices, foundations and angel investors. Data covers financing commitments in high impact countries which together account for about 80% of countries with significant levels of population without access to electricity.

Mini-grid companies, which have attracted lower shares of private investment compared to SHS, also expand their use of financing instruments in the ACCESS, including through green debt issuances. Mini-grid development is capital intensive, so access to cheap debt is essential to keep project costs manageable. Developers need longer term loans than are available from most commercial banks, but their transactions are generally too small for them to be able to raise capital in public capital markets. In Nigeria, a combination of concessional capital and local currency guarantees has been used to overcome this difficulty by enabling mini-grid developers to issue green bonds which have been purchased by private investors, including local pension funds. This model could be replicated in markets with clear mini-grid regulatory frameworks and strong financial markets.

Future private investment depends on the creation of favourable and stable regulatory frameworks, including provision for investment in grids, clear tariff design and targeted financial incentives. It also depends on an understanding of where private capital can feasibly be deployed, and of how public finance can be strategically disbursed to mobilise this investment. Concessional resources have fallen significantly below the levels envisaged in the ACCESS, but recently received a renewed push to increase them under Mission 300 – an initiative led by the World Bank and the African Development Bank to provide access to 300 million people by 2030 – and this could be invaluable.

One of the most significant changes in investment in the ACCESS concerns the structure of financing. As higher risk-taking capital, equity plays a pivotal role in attracting other forms of capital, notably low-cost debt that can help scale up projects to increase access to electricity. Difficulty in obtaining equity has so far held back growth, particularly in the start-up stage for solar home system developers and the growth stage for mini-grid developers. In the ACCESS, new sources of patient equity emerge, including local pension funds and the International Finance Corporation Zafiri Fund, which was announced in 2025 and is expected to scale up in coming years. As a result, the equity share of commitments to last-mile delivery rises in the ACCESS from the 20% level of in the last five years to over a third in the years ahead.

Box 6.3 ▷ Sustaining utility revenues while extending access

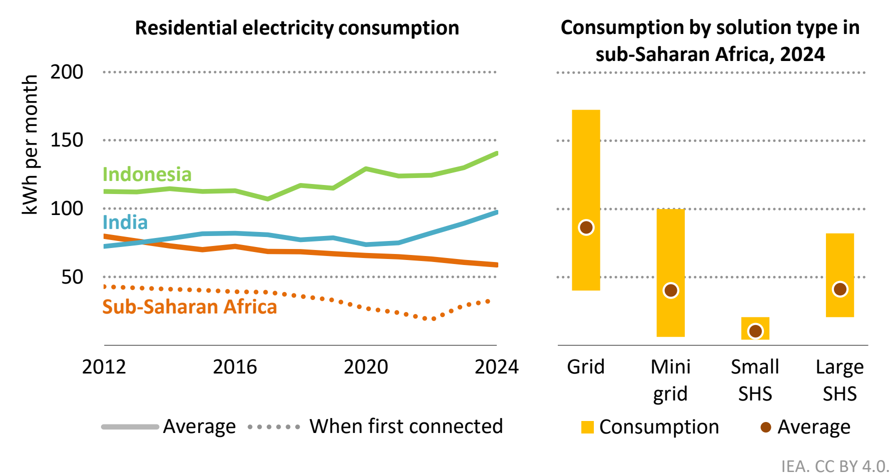
Extending electricity access requires significant upfront investment. This is rarely covered by the one-off connection fees paid by consumers: utilities typically recover these costs over time through tariffs. However, affordability challenges in many regions make this model difficult to sustain. Low and stagnant demand means utilities have to wait a long time to recoup their investment, which strains revenue and limits the liquidity they need to finance new connections.

This problem is particularly acute in sub-Saharan Africa. Newly electrified households in the region consume around 50% less electricity than their counterparts in countries like Indonesia and India, and average household electricity consumption in sub-Saharan Africa has declined by about 25% since 2012, while it has increased by a third in other emerging markets and developing economies (Figure 6.17). Expansion costs are also typically higher in sub-Saharan Africa, with dispersed populations and weak transmission networks pushing up the per connection cost of grid investment.

To strengthen the economic viability of electrification, utilities are increasingly promoting productive uses of electricity, such as irrigation, agri-processing, textile production and refrigerated supply chains. These uses consume more power than households, generate income that supports repayment, and stimulate broader economic development that, in turn, enables households to afford more energy services. They also support utility finances. In Kenya, for example, small and large industrial customers represent just 5% of connections but account for around 70% of electricity consumption and utility revenues (Kenya Power, 2024).

There is no estimate for how much suppressed demand for productive uses exists in Africa, though it may well be large, given that industrial, services, and agricultural electricity demand per unit of gross domestic product (GDP) in sub-Saharan Africa is around two-times lower than the average of the emerging market and developing economies grouping. Scaling up productive uses of energy could make a major contribution to the expansion of affordable access, while also contributing to economic development, food and water security.

Figure 6.17 ▷ Residential electricity consumption in sub-Saharan Africa and selected countries, 2012-2024, and by solution type, 2024



Average household electricity consumption in sub-Saharan Africa is low and has decreased by a quarter since 2012

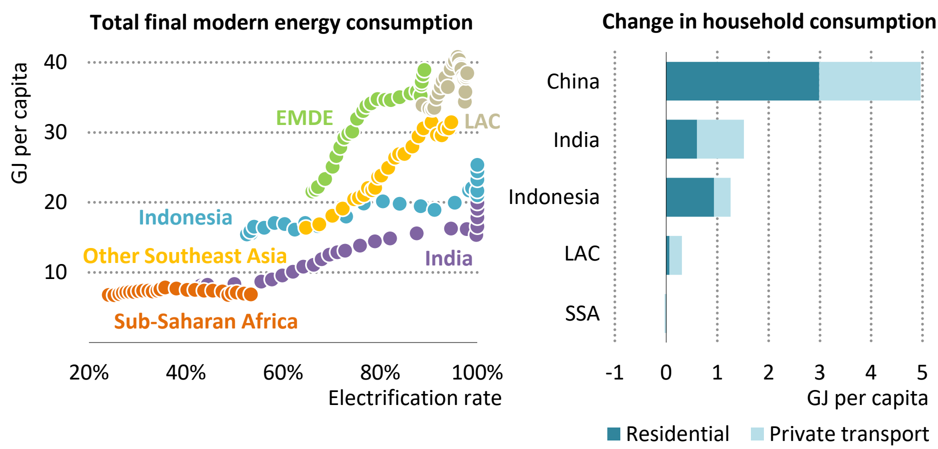
Notes: kWh = kilowatt-hour; SHS = solar home systems. Large SHS have capacity of >100 Watt-peak (Wp). Small SHS have capacity of 10-50 Wp. Sub-Saharan Africa excludes South Africa in this figure.

6.4 Moving beyond access

Many emerging market and developing economies stand to benefit immensely from expanded economic activities which are powered by constructive energy use. For example, making energy services available and affordable can help make the industry and agriculture sectors more productive, improve transportation logistics and enable refrigerated supply chains. Such opportunities are often untapped or underdeveloped by households and businesses that have only recently acquired access to energy services. Making energy more affordable and reliable could unlock this latent demand and help to deliver both economic and development goals. This section explores how energy demand has developed alongside energy access in the past and how it might evolve in the trajectory of the ACCESS.

Many major emerging market and developing economies have seen economy-wide energy demand per capita rise substantially in the last decade, often during periods in which they made major progress to extend energy access (Figure 6.18). For example, in China and India, residential energy demand rose alongside demand in the industry and services sectors, even as they registered fast reductions in energy intensity, comparable to rates seen in advanced economies. Other regions, however, have seen per capita modern energy use remain stagnant or fall. In sub-Saharan Africa, for example, per capita energy use has declined in recent years as efforts to energise economies and improve access to energy have lagged population growth.

Figure 6.18 ▷ Total final modern energy consumption per capita by region, 2000-2024, and change in household consumption and application by region, 2015-2024



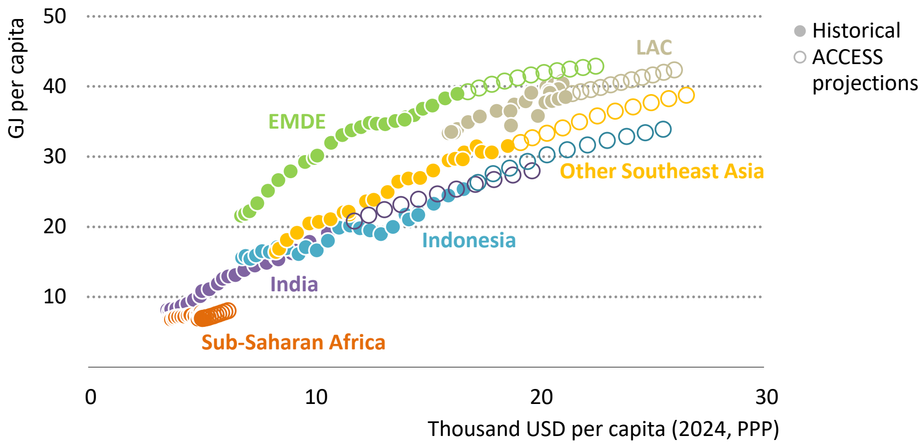
Modern energy consumption per capita has continued to rise in developing Asia over the past decade amid rising economic prosperity, while it has declined in other regions

Note: EMDE = emerging market and developing economies; LAC = Latin America and the Caribbean; SSA = sub-Saharan Africa; GJ = gigajoule.

In the ACCESS, regions where broader increases in energy-based services have stalled shift onto new trajectories that pair growth in energy demand rise with improved access to energy, similar to those witnessed in other emerging market and developing economies. Some regions that are closing their energy access gap, such as India and Indonesia, continue to advance along energy demand trajectories similar to those of advanced economies. In those regions, energy access rises alongside energy demand and GDP per capita (Figure 6.19). Total modern energy demand per capita rises in the ACCESS by around 15% per decade in developing Asia and sub-Saharan Africa, compared with 10% in the average of the overall group of emerging market and developing economies.

The overall level of energy demand per capita can vary between regions with similar levels of GDP, which reflects differences in industrial structure, climate, level of reliance on personal transport, prevalence of energy-efficient home appliances and the energy mix. Moreover, advances in energy efficiency mean that countries developing today will see lower increases in energy use per unit of GDP growth than economies that developed with less efficient options, while still achieving comparable levels of energy services. Increases in energy efficiency also play a key role to provide affordable options for households just gaining access.

Figure 6.19 ▹ Total final modern energy consumption per capita and GDP per capita for selected countries/regions in the ACCESS, 2010-2035



IEA. CC BY 4.0.

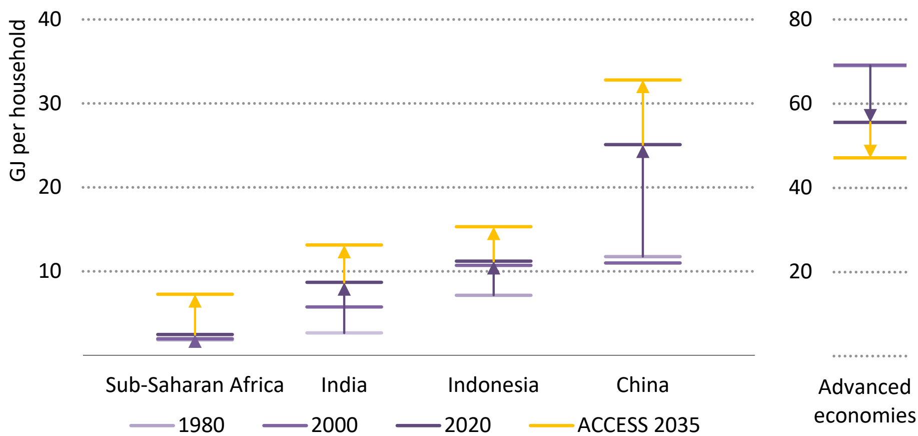
In developing regions, rising total final modern energy consumption accompanies improvements in energy access and increases in income levels

Note: LAC = Latin America and the Caribbean; PPP = purchasing power parity. EMDE = emerging market and developing economies

Despite recent improvements in energy access, the average household in emerging market and developing economies still consumes far less than in an advanced economy. Households in emerging market and developing economies today consume only 44% of the modern energy used in households in advanced economies (Figure 6.20). Even within emerging market and developing economies, the differences are striking: the average household in sub-Saharan Africa consumes just one-third of modern energy used by the average household in India, and one-tenth of the level in China.

Utility data in several African countries show modern energy demand in newly connected households significantly lagging national averages more than ten years after gaining access. This is reflected in the rates of household energy demand growth in the ACCESS. As incomes rise, household energy demand nevertheless increases in the ACCESS, doing so at a pace in line with what has been seen in other emerging market and developing economies, and reflecting expanding energy access, rising appliance ownership and improving living standards. Residential modern energy demand per household increases at different speeds in different regions: by around 15% over the 2025-2035 decade in China; around 20% in the rest of developing Asia; and more than doubling in sub-Saharan Africa. Among other things, the differences in speed reflect the variations in current levels of energy use and energy access in the regions concerned. Energy demand growth is somewhat faster through to 2035 than in later years, due to the rapid pace of access expansion during that period, but the growth of energy consumption per household with access is relatively constant over time.

Figure 6.20 ▷ Residential modern energy demand growth per household by region in the ACCESS, 1980-2035



IEA. CC BY 4.0.

Energy demand per household is set to continue rising in emerging market and developing economies as countries become wealthier and more people benefit from energy access

Note: GJ = gigajoule.

Energy access is not enough on its own to improve prosperity. Realising the full transformative potential of energy requires parallel efforts to connect households and companies with the equipment and services needed to turn energy access into improved livelihoods and economic opportunities. Possible initiatives might include: programmes to build refrigerated supply chains that allow farmers to bring more produce to market; to provide low-cost farming and manufacturing equipment to artisanal industries in order to enhance productivity; and to replace oil-based irrigation with efficient electric pumps. Efforts outside the energy sector could include improvements to transport and logistics infrastructure, and efforts to increase access to digital and financial services and tools.

The ACCESS presents a pathway to universal access which recognises that progress takes time and that affordability challenges will not be resolved overnight, but still illustrates the transformative potential of universal energy access and productive energy use. It also shows how proven models can be scaled up to address, once and for all, one of the most profound instances of energy insecurity that still persists in the world today.

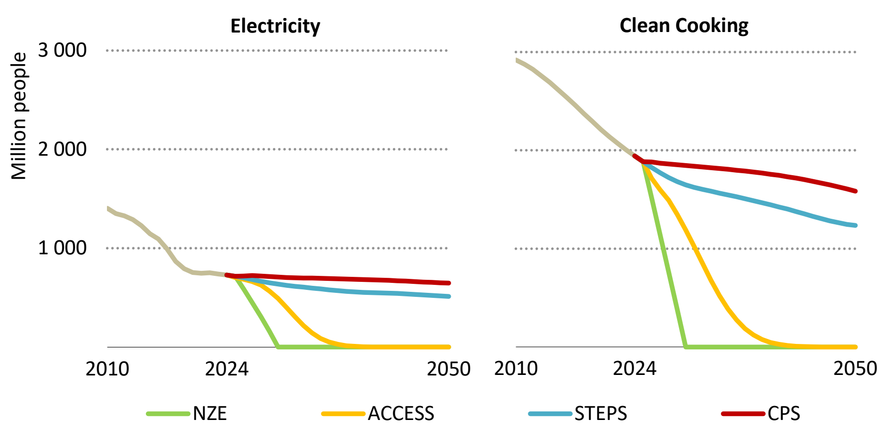
Box 6.4 ▹ Energy access in the *WEO* scenarios

As with all the scenarios in the *World Energy Outlook*, our energy access projections are not forecasts but rather an exploration of a range of possible outcomes under various sets of assumptions. The treatment of energy access progress is closely linked to how the wider energy sector is modelled (see Chapter 2).

In the **Current Policies Scenario** (CPS), only those access policies and programmes already in place are considered. In the **Stated Policies Scenario** (STEPS), we take into account also announced policies and programmes, although we do not assume that aspirational access targets are met. The **Accelerating Clean Cooking and Electricity Services Scenario** (ACCESS), introduced in this chapter, accelerates action to match the best historical progress observed in comparable country contexts. The **Net Zero Emissions by 2050 Scenario** (NZE) maps out a way to achieve the global Sustainable Development Goal 7 target to achieve universal access to electricity and clean cooking by 2030.

6

Figure 6.21 ▹ Global population lacking access to electricity and clean cooking by scenario, 2010-2050



Energy access slows in the CPS and STEPS as some countries reach universal access, leaving the bulk of those without access in countries with weak policy frameworks

Note: NZE = Net Zero Emissions by 2050 Scenario; ACCESS = Accelerating Clean Cooking and Electricity Services Scenario; STEPS = Stated Policies Scenario; CPS = Current Policies Scenario.

Outcomes related to modern energy access diverge sharply in these scenarios. In the CPS, progress slows as the countries making the strongest efforts achieve universal access, while leaving behind around 700 million people without electricity access and 1.8 billion without clean cooking by 2030, most of whom live in countries that have seen little progress in recent years under current policy settings (Figure 6.21). In the STEPS, the most recently announced policy measures lead to a modest acceleration of progress, though 1 650 million people remain without access to clean cooking in 2030. Electricity access also improves, but 640 million people without electricity access, mostly in sub-Saharan Africa. To achieve the targets of Sustainable Development Goal 7, the pace would need to rise dramatically in order to give around 150 million people access to electricity and nearly 400 million access to clean cooking each year to 2030 – a rate of progress never previously achieved.

Chapter 7

Net Zero Emissions by 2050

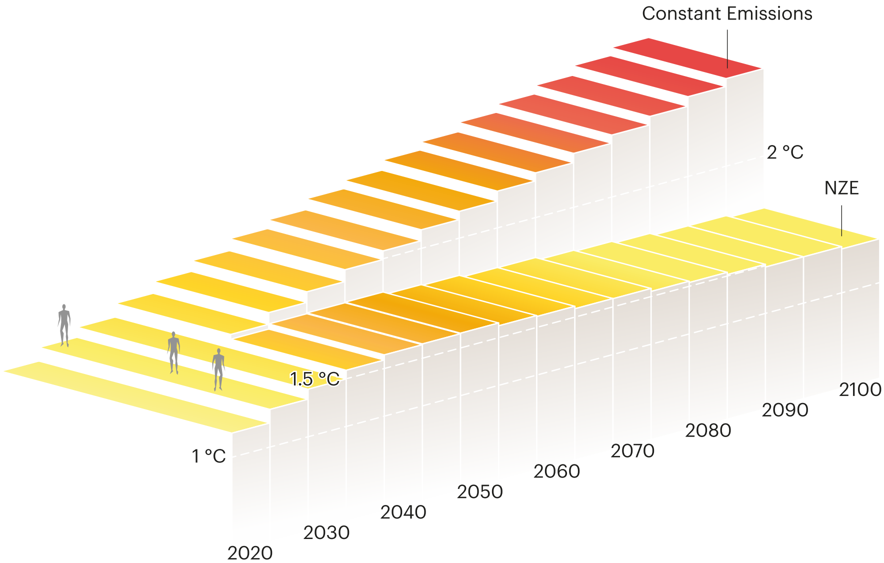
Acting now to limit overshoot

S U M M A R Y

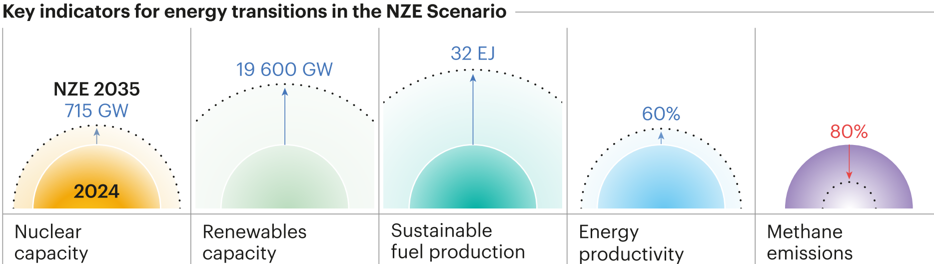
- The Paris Agreement set the global goal of limiting warming to well below 2 °C and pursuing efforts to limit it to 1.5 °C. The IEA Net Zero Emissions by 2050 (NZE) Scenario translates the 1.5 °C goal into a global pathway for the energy sector. The updated NZE Scenario presented here takes account of the most recent data and trends. Each country will tailor its own path to net zero emissions. The updated NZE Scenario is based on four central pillars that are widely applicable: clean energy electrification, energy efficiency, low-emissions fuels and methane abatement.
- The installed capacity of renewables increases nearly fourfold from today's level by 2035 in the NZE Scenario: nuclear and other low-emissions technologies increasingly contribute as electricity demand grows to account for one-third of all energy consumption. Energy efficiency increases by about 4% per year by 2035, double the rate of 2022. Sustainable fuels – including liquid biofuels, biogases, low-emissions hydrogen and hydrogen-based fuels – are widely deployed: their use more than quadruples by 2035 from current levels. Methane emissions are cut by more than 80% by 2035.
- Global energy-related carbon dioxide (CO_2) emissions were 38 gigatonnes (Gt) in 2024. In the NZE Scenario, emissions fall by nearly 55% by 2035 to around 18 Gt. Yet, the increase in long-term global average temperature exceeds 1.5 °C around 2030 and peaks at around 1.65 °C about 2050. The NZE Scenario achieves the COP28 goals of doubling efficiency and tripling renewables capacity by 2030, and it meets the Paris Agreement goal of holding warming well below 2 °C throughout the 21st Century.
- The updated NZE Scenario reflects the fact that exceeding 1.5 °C is now inevitable, and some reliance on technologies to remove CO_2 from the atmosphere is unavoidable to return warming to below 1.5 °C. Such technologies are expensive and unproven at scale: immediate action to reduce emissions can limit the scale of the removals needed. In the NZE Scenario, the global average temperature increase falls back below 1.5 °C by 2100.
- Energy investment in the NZE Scenario increases to around USD 4.8 trillion per year over the next decade, from USD 3.3 trillion today. As these upfront investments are made, savings from lower fuel prices together with efficiency gains mean that households face costs for energy services comparable to those of today through to 2035, and lower still in the longer term. Fuel importers benefit too as import bills are cut by about two-thirds. Electricity takes on a bigger role to meet energy demand, underlining the significance of electricity security, and the need for secure and diversified supply chains for critical minerals and energy technologies.

A pathway to return temperature rise below 1.5 °C

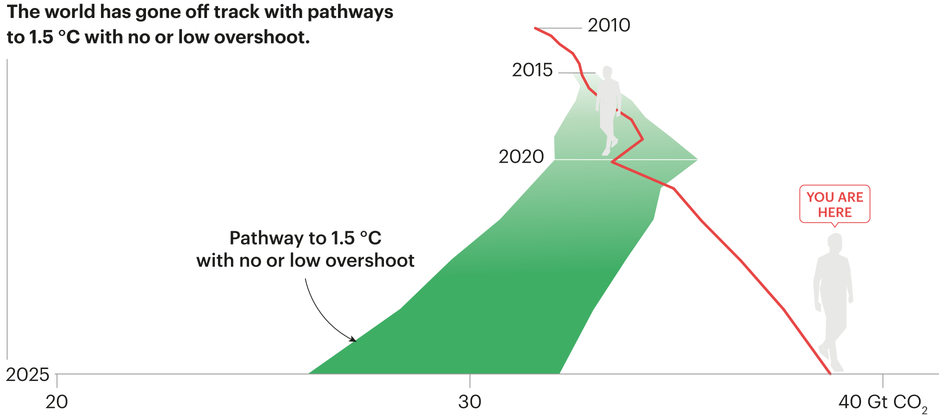
The NZE scenario sees temperatures rise by around 1.65 °C above pre-industrial levels before falling back to 1.5 °C by 2100. Returning warming to below 1.5 °C requires immediate emissions reductions and carbon dioxide removal.



Key indicators for energy transitions in the NZE Scenario



The world has gone off track with pathways to 1.5 °C with no or low overshoot.



7.1 Context

Background to the NZE Scenario

In 2015, the Paris Agreement set the overarching goal of holding the increase in the global average temperature to well below 2 degrees Celsius (°C) above pre-industrial levels and pursuing efforts to limit the temperature rise to 1.5 °C. Subsequent meetings under the United Nations Framework Convention on Climate Change (UNFCCC) of the Parties to the Paris Agreement strengthened the focus on limiting warming to 1.5 °C, building on the findings of the Intergovernmental Panel on Climate Change (IPCC) Special Report on 1.5 °C (IPCC, 2018). The outcome of the UNFCCC Conference of the Parties (COP) 28 in 2023 recognised that limiting the temperature increase to 1.5 °C required countries to reach net zero emissions from the energy sector by mid-century. It identified key milestones for the global energy sector, including tripling the installed capacity of renewables and doubling the rate of increase in energy efficiency improvements by 2030.

The International Energy Agency (IEA) was asked by the COP26 Presidency in 2021 to give an indication of what achieving the 1.5 °C goal would mean for the energy sector. Responding to this request, the Net Zero Emissions by 2050 Scenario (NZE Scenario) was developed. It represents a global pathway towards the goal of limiting global warming to 1.5 °C. The IEA has always been clear that there are various paths to reach this objective and that each country will have its own route. Since 2021, the IEA has updated its NZE Scenario each year, in line with changes in real world investment, technology developments and greenhouse gas (GHG) emissions.

Three inter-related trends have marked the last several years:

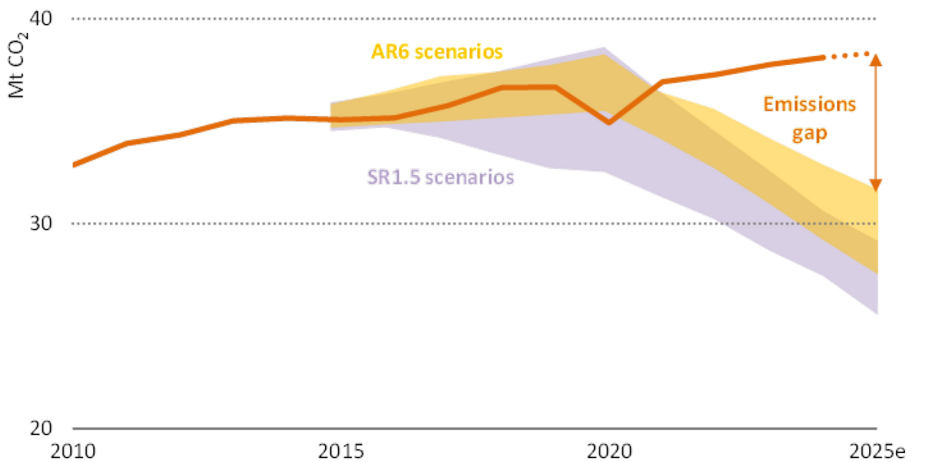
- Energy sector emissions have continued to set record highs.
- Progress in deploying low-emissions technologies and increasing energy efficiency has been very rapid in some cases but is uneven across sectors and countries.
- The context in which governments and energy companies are operating remains complex and challenging, marked by features such as increasing geopolitical fragmentation, high government debt burdens, and rising levels of concern about energy security and affordability after the global energy crisis.

With these in mind, we have revisited several aspects of the design of the NZE Scenario in this *Outlook*, while maintaining the end point of net zero energy-related CO_2 emissions by 2050, in order to provide an up-to-date analysis of the current state of efforts to meet the Paris Agreement target of 1.5 °C and additional efforts needed to achieve it in the current context. The updated NZE Scenario is presented in this chapter.

A limited overshoot pathway to 1.5 °C has slipped out of reach

Pathways assessed by the IPCC which limit the increase in the global average temperature to below 1.5 °C by 2100 with no or limited overshoot assumed immediate and rapid emissions reductions from 2015 or 2020.[1] Global energy-related carbon dioxide (CO_2) emissions, however, have continued to rise, increasing by 1% in 2024 to an all-time high of 38.2 gigatonnes (Gt). Current emissions levels are therefore moving the world increasingly away from these IPCC pathways (Figure 7.1).

Figure 7.1 ▷ Energy-related CO_2 emissions and emissions pathways in scenarios assessed by the IPCC consistent with no or limited overshoot of 1.5 °C, 2010-2025



Energy-related emissions are increasingly diverging from pathways assessed by the IPCC which limit warming to 1.5 °C with no or limited overshoot

Notes: Mt CO_2 = million tonnes of carbon dioxide. 2025e = estimated values for 2025. The ranges for scenarios assessed by the IPCC represents the 25th and 75th percentile. SR1.5 scenarios refers to scenarios assessed in the IPCC Special Report: Global Warming of 1.5 °C (IPCC, 2018). AR6 scenarios refers to C1 scenarios assessed by the IPCC in the Sixth Assessment Report (IPCC, 2022a).

Sources: IEA analysis based on IIASA (2022a; 2022b).

Because of the delay in reducing emissions, each edition of the *World Energy Outlook (WEO)* has updated the NZE Scenario to factor in higher cumulative emissions and higher peak warming. In the *WEO-2024* version of the NZE Scenario, peak warming reached just below 1.6 °C around 2040 before subsequently declining to below 1.5 °C by 2100. Therefore, our NZE Scenario in the *WEO-2024* came very close to exceeding the threshold of limited overshoot of about 0.1 °C as defined by the IPCC.

[1] Limited overshoot 1.5 °C pathways are defined by the IPCC as those that keep the temperature rise below 1.5 °C with a 33% chance or greater, and which hold the temperature rise in 2100 below 1.5 °C with a 50% chance or greater, and which exceed the 1.5 °C limit by "up to several decades". This is equivalent to a 50% chance or greater of exceeding 1.5 °C by up to about 0.1 °C (IPCC, 2022).

The level of long-term warming today stands at around 1.4 °C. Given continued high levels of emissions and recent investments in emissions-intensive infrastructure, temporarily exceeding the 1.5 °C threshold is virtually certain. Even pathways that limit this overshoot to less than about 0.1 °C, i.e. IPCC limited overshoot pathways, have slipped out of reach. They would require global CO_2 emissions to reach net zero in the mid- to late-2030s. This would mean a fall in emissions of around 3.5 Gt CO_2 per year – twice the drop seen in 2020 related to the Covid-19 pandemic – which would have to continue every year for at least the next decade.

Deployment of some low-emissions technologies is in line with what is needed, but progress is uneven

IEA scenarios are not predictions. Nonetheless, it is useful to compare real world data and trends with scenario projections in order to assess the extent to which they are aligned with what is needed to achieve climate goals. In several areas, clean energy deployment is broadly in line with or even above the levels seen in the NZE Scenario in the *WEO-2021*: solar photovoltaics (PV) and electric vehicles (EVs) are the best examples (Figure 7.2). In other areas, deployment has been slower: carbon capture, utilisation and storage (CCUS), hydrogen and hydrogen-based fuels, and energy efficiency have all made slower progress than in the *WEO-2021* NZE Scenario. Improvements in energy efficiency from 2021 to 2024 averaged 1.6% per year, which is slower than the long-term average during the 2010s, and far below the levels modelled in our original NZE Scenario in 2021. Deployment of clean energy technologies has been highly concentrated geographically. In the 2021-2024 period, advanced economies and China accounted for 80% of all clean energy investment.

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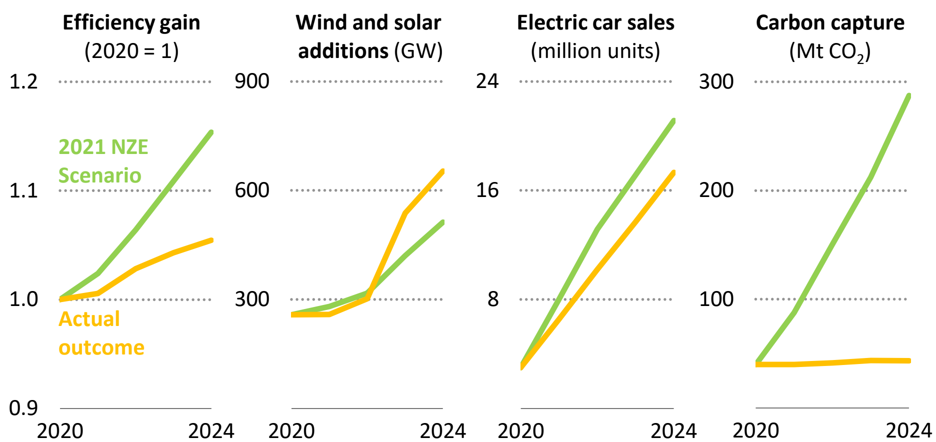
Figure 7.2 ⊳ Key indicators of energy transition in the NZE Scenario in the *WEO-2021* versus actual outcomes, 2020-2024



Technology deployment has been uneven: some areas are tracking ahead of or in line with a path towards 1.5 °C, while others are lagging

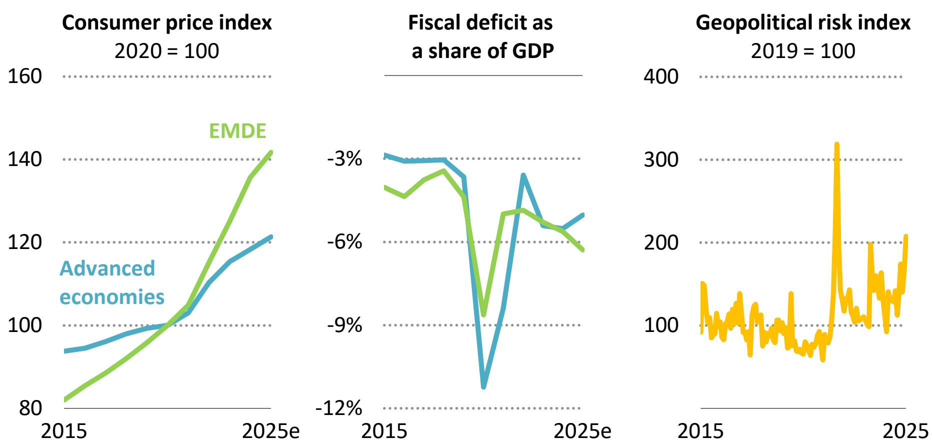
Note: GW = gigawatt; Mt CO_2 = million tonnes of carbon dioxide.

Policies face a complex context

Three issues are creating a complex international context for climate policies.

First, the global economy is just coming out of the worst bout of inflation since the 1970s, which was exacerbated by the 2022 global energy crisis triggered by the Russian invasion of Ukraine. In many countries, consumer prices rose substantially faster in the post-Covid period than before. Inflationary pressures in the energy sector were worsened by high global fossil fuel prices, in particular for natural gas, leading to widespread concerns about energy affordability (Figure 7.3).

Figure 7.3 ▷ Global monetary, fiscal and geopolitical indicators in the pre- and post-Covid periods, 2015-2025



Affordability, fiscal and geopolitical headwinds have sharpened in the post-Covid period

Note: EMDE = emerging market and developing economies. 2025e = estimated values for 2025.

Sources: IEA analysis based on data from Oxford Economics (2025); IMF (2025); Caldara and Iacoviello (2021).

Second, clean energy technologies are typically more capital intensive than incumbent technologies, and rapid energy transitions require high levels of investment (section 7.4.1). At present, many households, businesses and governments are facing high interest rates and many governments around the world are grappling with challenging fiscal outlooks: in 2025, fiscal deficits in both advanced and emerging market and developing economies are projected to be around 60% larger than on average during the pre-Covid period. Low-emissions energy systems can provide hedges against volatility in fossil fuel markets, but raising the investment needed to achieve energy transitions is made more difficult by tighter financing conditions.

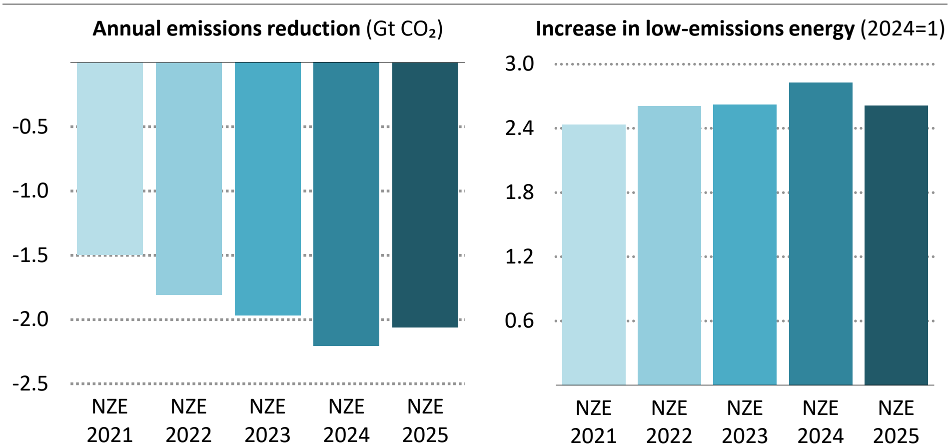
Third, governments face a challenging and increasingly fragmented geopolitical environment. Large-scale armed conflict has broken out in multiple regions of the world, economic frictions have increased, trust between countries has eroded, and multilateralism is struggling to provide solutions to problems like climate change which require global co-operation.

NZE Scenario

As countries prepare to consider the next round of Nationally Determined Contributions (NDCs) under the Paris Agreement, this updated NZE Scenario pathway aims to provide a pragmatic but ambitious vision of what would it take for the world to pursue efforts to limit warming to 1.5 °C, given recent data on energy, technology, and emissions.

As in previous editions, this updated pathway keeps the goal of net zero global CO_2 emissions by 2050. However, it also factors in the reality of recent high emissions, recent emissions-intensive investment, and the slow progress being made in taking forward some options for emissions reductions. Consequently, while it still achieves the COP28 energy goals of doubling the pace of annual efficiency improvements and tripling the installed capacity of renewables, it sees a slightly less rapid transition, with higher emissions in the near term than in previous *WEO* editions. Warming exceeds 1.5 °C degrees for several decades, and returning to below 1.5 °C by 2100 is only possible with the deployment in the second half of this century of carbon dioxide removal technologies that are currently unproven at large scale. This updated NZE Scenario nevertheless remains a highly ambitious and challenging pathway (Figure 7.4). Critically, it remains below the upper limit enshrined in the Paris Agreement of holding warming to well below 2 °C above pre-industrial levels throughout the 21st Century and meets internationally agreed energy goals.

Figure 7.4 ▷ Average annual emissions reductions from peak year to 2035, and scale up of low-emissions energy supply to 2035 in various editions of the NZE Scenario



The NZE Scenario 2025 retains an ambitious outlook for emissions reductions and scaling up low-emissions energy supply

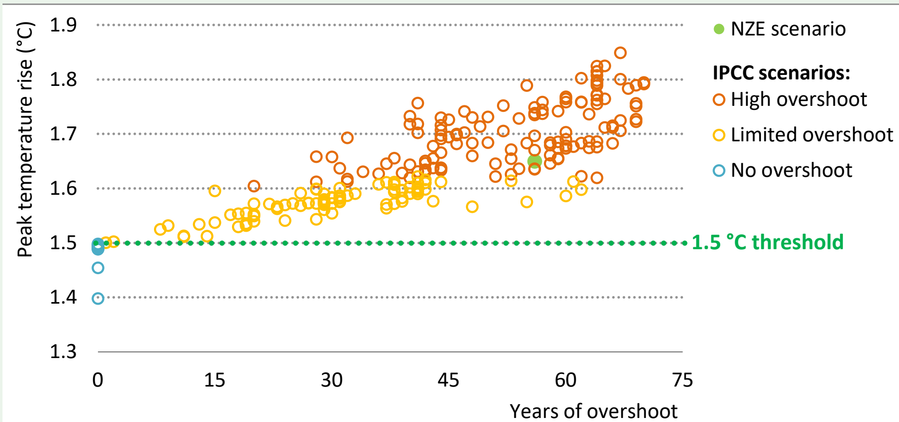
Note: Gt = gigatonne; NZE = Net Zero Emissions by 2050 Scenario.

Box 7.1 ⊳ Interpreting the 1.5 °C goal of the Paris Agreement

The 1.5 °C goal enshrined in Article 2 of the Paris Agreement forms the basis of the target to reach net zero emissions by 2050 which has been adopted as a domestic policy goal by over 90 countries. However, the wording of the Paris Agreement does not specify several key aspects of the 1.5 °C goal. The most important of these are how the increase in temperatures should be defined and measured; whether it incorporates a temporary exceedance of 1.5 °C; and, if so, how long the period above 1.5 °C may be allowed to last.

A scientific and policy consensus on these issues has emerged, shaped to a large extent by subsequent clarifications made by the UNFCCC as well as by assessments of the 1.5 °C target made by the IPCC (UNFCCC, 2022; IPCC, 2021). On the question of how to measure warming, the UNFCCC has specified that warming should be anthropogenic in origin, i.e. for example the effects of volcanic activity should not be taken into account, and that it should be measured "over decades" to smooth out the effects of short-term climate variability, caused for example by the El Nino Southern Oscillation.[2] This decadal average results in a long-term temperature rise which can differ from the measured temperature rise in a given year by up to around 0.2 °C. In 2024, for instance, the best estimates of the long-term temperature rise were between 1.34 °C and 1.41 °C, whereas the measured annual average temperature rise was a record-breaking 1.55 °C (Forster, Smith and Walsh, 2025; WMO, 2025).

Figure 7.5 ⊳ Peak temperature rise and years of overshoot in the NZE Scenario and IPCC 1.5 °C scenarios



Only 4% of scenarios assessed by the IPCC avoid overshoot of the 1.5 °C threshold, and more than half exceed 1.5 °C for at least 40 years

Note: Figure shows the C1 and C2 scenarios from IPCC's Sixth Assessment Report (IPCC, 2022a).

[2] The IPCC used the middle year of a 20-year average to define the point in time when a certain average global surface temperature level is reached and used the period 1850-1900 as an approximation of the pre-industrial period specified as a baseline in the Paris Agreement (IPCC, 2021a).

The IPCC classification of scenarios compatible with 1.5 °C warming also sheds light on the question of overshoot (Figure 7.5). Only 4% of these scenarios avoided overshooting the 1.5 °C threshold; 40% have a peak temperature rise of up to around 1.6 °C (limited overshoot), and the remainder have a peak temperature rise of up to 1.8 °C (high overshoot). Most of the scenarios involve overshoots lasting between 35 and 65 years. The updated NZE Scenario presented in this chapter has a peak temperature rise of around 1.65 °C and overshoots 1.5 °C for around 55 years (section 7.2.2).

7.2 Pathways for emissions and temperature

7.2.1 Emissions

In 2024, global energy-related GHG emissions[3] reached 42.6 gigatonnes of carbon-dioxide equivalent (Gt CO_2-eq). CO_2 emissions accounted for 38.2 Gt of this total – an all-time high. In the NZE Scenario, GHG emissions fall around 50% to 2035, and CO_2 emissions by almost 55% to around 18 Gt (Figure 7.6). Emissions from electricity generation, which today make up about 40% of total energy-related CO_2 emissions, decline particularly fast: they drop to around one-quarter of today's levels by 2035. By 2050, remaining energy-related CO_2 emissions of around 2.1 Gt are mainly from industry (0.45 Gt), aviation and shipping (0.4 Gt) and road freight (0.32 Gt), and are balanced by removals of the same magnitude, without any reliance on removals from land-use measures.

7

The NZE Scenario also sees rapid reductions in GHG emissions and climate forcers other than CO_2, including short-lived climate forcers (SLCFs), which exert a large warming effect but have short atmospheric lifetimes. Cutting emissions from SLCFs has a key role to limit global warming in the decades around mid-century (section 7.2.3). Important energy-related SLCFs include methane and black carbon[4], emissions of which drop by more than 80% in 2035 from today's level (section 7.3.4). As many SLCFs are air pollutants, curbing their emissions also has significant benefits for public health.

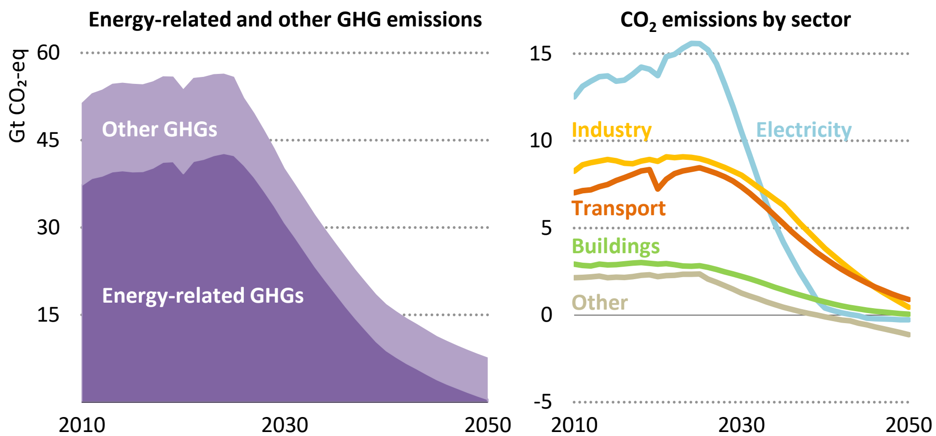
Reducing or limiting the growth in non-energy-related GHG emisions also plays a valuable part in minimising the rise in global temperatures. For example, in the NZE Scenario CO_2 emissions associated with deforestation fall almost 50% by 2050, with the result that net CO_2 emissions from land use and forestry, i.e. including the effects of afforestation, fall from over 4 Gt today to net zero in the mid-2040s. In a similar vein, efficiency gains in crop management which reduce reliance on fertiliser mean that nitrous dioxide emissions from agriculture in 2050 are close to current levels, despite a 75% increase in crop production for food and

[3] Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) from fossil fuel combustion, flaring and fugitive CO_2 and industrial processes.

[4] The warming effects of black carbon remain highly uncertain due to its complex interactions with clouds and surface albedo, especially in snow- and ice-covered regions (IPCC, 2021b).

bioenergy by that time. Despite these measures, it remains hard to eliminate all non-energy-related GHG emissions by 2050, particularly those from agriculture and from F-gases used as refrigerants and in industrial processes. Emissions of non-energy-related GHGs fall by 45% between 2024 and 2050.

Figure 7.6 ▷ Energy-related and other GHG emissions, and energy-related CO_2 emissions by sector in the NZE Scenario, 2010-2050



Global energy-related GHG emissions fall by around 55% by 2035, led by rapid reductions in the electricity sector and in methane emissions

Note: GHG = greenhouse gases; CO_2-eq = carbon-dioxide equivalent. Other includes agriculture, forestry and other land use (AFOLU) and waste.

Sources: AFOLU emissions based on IEA modelling and Land-Use Analytic.

Implications for emissions and atmospheric carbon dioxide removals after 2050

Bringing the global increase in average temperature back down to below 1.5 °C requires scaling up CO_2 removal from the atmosphere. The NZE Scenario assumes that this occurs predominantly through bioenergy with carbon capture and storage (BECCS) and direct air capture and storage (DACS), although other removal strategies exist outside the energy sector (Box 7.2). Annual CO_2 removal using these technologies in the NZE Scenario reaches 2.1 Gt CO_2 in 2050 and 3.8 Gt CO_2 by 2100 (Figure 7.8). This would mean removing the current annual energy-related CO_2 emissions of India and Indonesia combined from the atmosphere by 2100. CO_2 removal on this scale has obvious economic and resource implications. The earth system response to net zero emissions and to net removals from the atmosphere is also highly uncertain.

Box 7.2 ▷ The critical importance of cutting gross emissions

Removing CO_2 from the atmosphere is very challenging. The scale of CO_2 removals needed to return warming to below 1.5 °C depends not just on the degree of temperature overshoot but also on the size of residual gross emissions. Some sectors, such as aviation, may struggle to reach net zero emissions if low-emissions technologies such as sustainable aviation fuels cannot be scaled up sufficiently (section 7.3.3). If this is the case, some atmospheric removals will be needed to achieve net zero emissions.

In the NZE Scenario, gross annual emissions are reduced to around 2.1 Gt by 2050 and decline further to just under 1 Gt by 2100. Comparable high overshoot 1.5 °C scenarios assessed by the IPCC assume much lower potential to reduce gross emissions. In these scenarios, even after net zero is reached, gross emissions average nearly 7 Gt per year out to 2100 (Figure 7.7). This is more than the total emissions today from hard-to-abate sectors such as international transport, iron and steel and cement.

Figure 7.7 ▷ Average annual emissions and removals from applications of BECCS and DACS in high overshoot 1.5 °C scenarios assessed by the IPCC

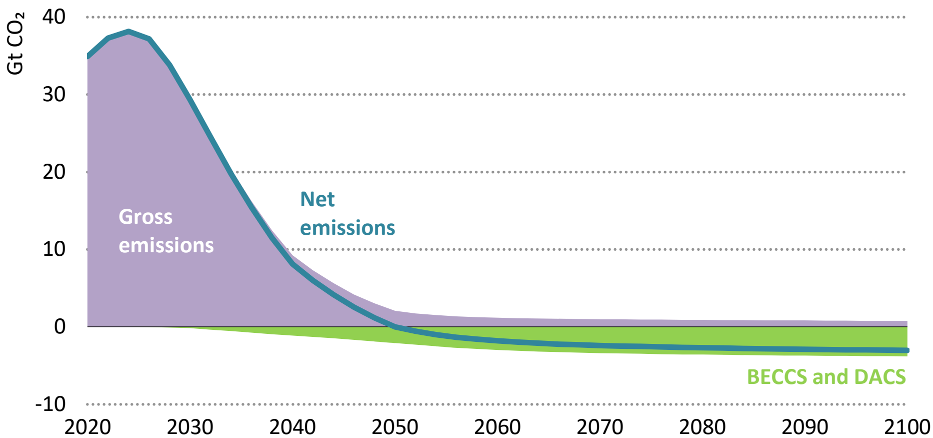
In scenarios assessed by the IPCC, continued high levels of gross emissions lead to a large reliance on removal technologies which are unproven at scale today

Note: Annual average is measured from the year energy sector emissions reach net zero to 2100.

Source: IEA analysis based on data from IIASA (2022).

Limiting reliance on removal technologies, which are unproven at scale today, means acting now to reduce peak warming as much as possible, for example by cutting emissions of short-lived-climate forcers and maximising the deployment of clean energy technologies across the entire energy system. Achieving this in sectors such as energy-intensive industries and long-distance transport will require innovation.

Figure 7.8 ▻ Global gross and net energy-related CO_2 emissions in the NZE Scenario, 2020-2100



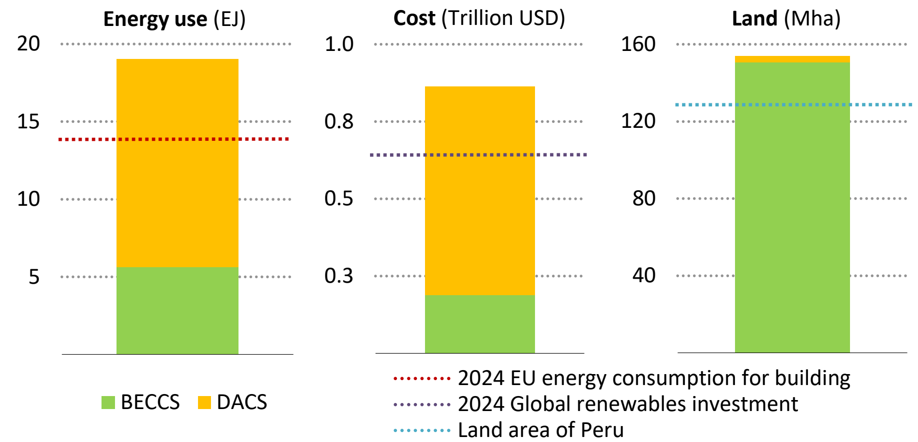
Around 3.8 Gt per year of CO_2 removals via BECCS and DACS would be needed to bring the temperature rise to below 1.5 °C by 2100

Note: Gt CO_2 = gigatonne of carbon dioxide; BECCS = bioenergy equipped with CCUS; DACS = direct air capture and storage.

By 2050, around 1.1 Gt CO_2 is removed from the atmosphere through BECCS in the NZE Scenario, and this rises to around 2 Gt by 2100. The extent to which BECCS can be increased is constrained by limits on sustainable bioenergy supply, as well as by the economic and logistical challenges of deploying infrastructure to connect widely dispersed bioenergy facilities with large-scale CO_2 storage sites. Removing 2 Gt CO_2 per year would require gathering, processing, combusting, capturing, transporting and storing the emissions from bioenergy produced on roughly 150 million hectares (Mha) of land, around 15% more than the total land area of Peru (Figure 7.9).

While the deployment of DACS is not restricted by the availability of feedstock or suitable sites, the low concentration of CO_2 in the atmosphere means that DACS is currently much more energy-intensive and costly than BECCS. By 2050 around 1 Gt of CO_2 is removed by DACS in the NZE Scenario, and this grows to about 1.8 Gt by 2100 to make up the remaining removals. This level of DACS would require just over 13 exajoules (EJ) per year by 2100, roughly equivalent to the energy requirements for buildings in the European Union today. If the energy required for the deployment of DACS were provided by solar PV, this would require around 3.3 Mha of land - slightly more than the land area of Belgium. While this is orders of magnitude lower than the land and water footprints typically associated with bioenergy production, it would put further strains on an already resource-constrained energy system.

Figure 7.9 ▷ Global annual energy use, costs and land-use requirements for CO_2 removal technologies in the NZE Scenario, 2100



BECCS and DACS required in the NZE Scenario would require enormous amounts of energy, money and land

Note: EJ = exajoule; Mha = million hectares; BECCS = bioenergy equipped with carbon capture and storage; DACS = direct air capture and storage; EU = European Union.

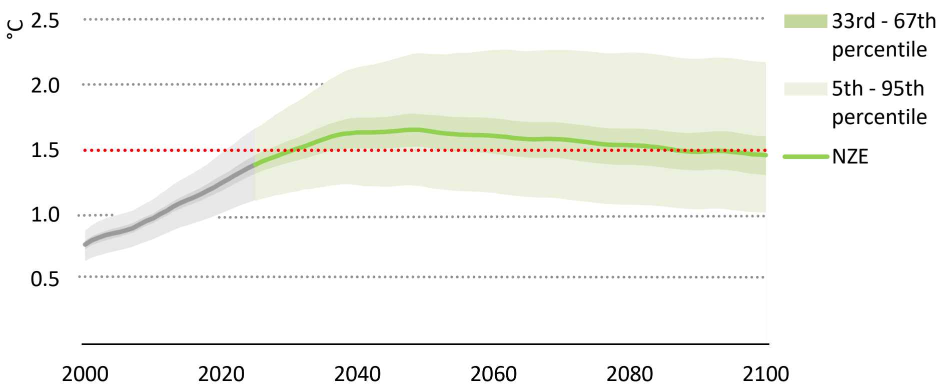
Today, total CO_2 removal capacity stands at around 1 Mt CO_2 per year, mostly in the form of BECCS. While recent company announcements suggest that BECCS and DACS capacity may increase more than 80-fold by 2035 from current levels, this is still far below the annual removal of 660 Mt CO_2 needed by 2035 in the NZE Scenario. Reaching the levels needed would take huge, concerted efforts to support innovation, increase efficiencies, and promote durable, measurable and verifiable removals. It would also require a huge amount of money: removing 2 Gt with BECCS and 1.8 Gt with DACS each year by the end of the century would cost just over USD 850 billion per year, or around one-third more than was spent on global renewables investment in 2024. Organising this scale of resource mobilisation would be a major challenge requiring close international co-operation. The difficulties involved in large-scale removal of CO_2 from the atmosphere very strongly underline the case for ensuring that everything possible is done to minimise the need for it.

7.2.2 Climate outcomes

The long-term global average rise in temperatures above pre-industrial levels was around 1.4 °C in 2024 (Forster, Smith and Walsh, 2025; WMO, 2025). In the NZE Scenario, this increases to above 1.5 °C around 2030 and peaks at around 1.65 °C in about 2050 (Figure 7.10). It then gradually declines by 0.04 °C per decade to below 1.5 °C in 2100. The reduction in warming after 2050 reflects in part natural processes whereby land and oceans absorb atmospheric carbon and reduce its warming effect, the steep drop in emissions of

SLCFs such as methane in the preceding decades, and a small additional uptake of CO_2 from afforestation. However, these factors alone would not be sufficient to reduce the temperature rise below 1.5 °C: this outcome is only achieved through the large-scale deployment of CO_2 removal technologies.

Figure 7.10 ▷ Temperature rise in the NZE Scenario, 2000-2100



Temperature rise peaks close to 1.65 °C around 2050 and falls back below 1.5 °C by 2100; however, significantly higher levels of warming cannot be ruled out

Note: Figure shows the long-term global mean temperature rise equal to the mid-point of a 20-year average of the combined land and marine near-surface temperature anomaly relative to 1850-1900, corresponding to IPCC Sixth Assessment Report definition of warming of 0.85 °C between 1995-2014.

Sources: IEA analysis based on the outputs of MAGICC 7.5.3, IPCC (2021).

In the NZE Scenario, global warming rises above 1.6 °C for almost 30 years and above 1.5 °C for around 55 years. This prolonged temperature overshoot presents significant consequences for vulnerable populations, ecosystems and the stability of critical climate tipping elements. This is in part because overshooting 1.5 °C intensifies extreme weather events, e.g. heatwaves, droughts and floods, which disproportionately impact vulnerable populations and regions, especially in low-income countries with limited adaptive capacity. Weather extremes can also adversely affect the functioning of energy systems with associated costs arising from climate impacts and the necessity to build more climate resilient infrastructure (see Chapter 5).

The IPCC Reasons for Concern framework notes that increased warming brings extra risks for unique and threatened systems, such as glaciers and biodiversity hotspots, and is likely to mean more frequent and damaging extreme weather events and raises the risk of large-scale singular events, such as abrupt shifts in ocean circulations. The level of additional impact and risk due to climate change grows markedly as warming progresses beyond 1.5 °C, with multiple risks becoming high or very high between 1.5 °C and 2 °C (IPCC, 2022b). Threats to biodiversity and ecosystem integrity are expected to persist for decades beyond the period of peak warming. In over one-quarter of surveyed global regions, the likelihood that animal and plant species can fully recover to pre-overshoot conditions is either highly uncertain or effectively negligible (Meyer et al., 2022). Some effects of global warming are also known to be irreversible as temperatures fall back down. For example, sea levels will continue to rise for centuries to millennia even if long-term temperatures decline, and regional changes in climate are likely to persist after global mean temperatures decline (Schleussner, 2024).

Inherent uncertainties in how the earth responds to future warming, GHG emissions, and the engineered removal of CO_2 from the atmosphere mean that significantly higher levels of warming cannot be ruled out. We calculate that, even if the NZE Scenario were to be achieved in full, there would still be about a 20% chance of future warming exceeding 2 °C, and about a 45% chance of not reducing warming below 1.5 °C by 2100. In addition to exacerbating extreme weather and other physical hazards associated with climate change, higher levels of warming might lead to various tipping points being reached, e.g. melting of the Greenland Ice Sheet or the rapid dieback of the Amazon rainforest, which would not reverse even if warming were subsequently brought down below 1.5 °C. Reaching these kinds of tipping points would have consequences for the long-term habitability of the planet (Wunderling et al., 2022). The risks associated with rising temperatures are much more acute in the STEPS and CPS.

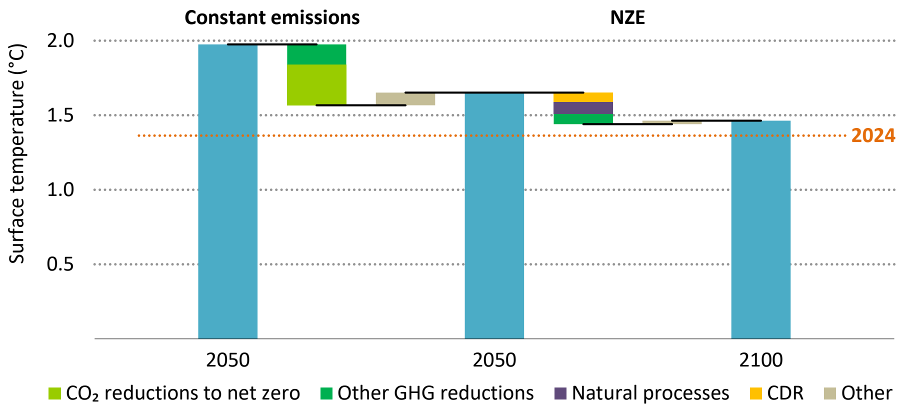
SPOTLIGHT

How the NZE Scenario limits peak warming and then cools the planet

If economy-wide GHG emissions were to continue at 2024 levels then the temperature rise – which today stands at around 1.4 °C – would reach just under 2 °C by 2050. In the NZE Scenario, however, the temperature rise reaches a peak of around 1.65 °C in 2050 and then starts to decline. Around two-thirds of the avoided warming in the NZE Scenario results from rapidly reducing economy-wide CO_2 emissions to net zero around 2050, with the almost all the remainder of avoided warming due to declining methane and N_2O emissions. Other effects in the NZE Scenario, including cuts to emissions of aerosols and fluorinated gases, lead in aggregate to a small warming effect, raising temperatures in 2050 by around 0.1 °C above what their level would have been otherwise (Figure 7.11).

After 2050 the temperature rise reduces steadily to around 1.45 °C in 2100 in the NZE Scenario. About 30% of this cooling happens because of removals of CO_2 from the atmosphere, mainly via BECCS and DACS, and a further 30% of cooling stems from reductions in methane and N_2O emissions – both as a lagged response to reductions that happen prior to 2050 and because of continuing reductions in emissions of these GHG after 2050. A final 40% of cooling is associated with natural processes that reduce global surface temperatures in the decades after net zero CO_2 emissions are achieved. There is also a small temperature rebound from other effects.

Figure 7.11 ▷ Global warming avoided in the NZE Scenario relative to constant emissions in 2050 and cooling 2050 to 2100 by lever



Reducing CO_2 emissions to net zero contributes most to warming avoided in the NZE Scenario in 2050; after 2050 cooling from natural processes plays a key role

Notes: Constant emissions = all GHG emissions held at 2024 levels between 2024-2050; Other GHG reductions = methane and N_2O reductions; CDR = carbon dioxide removals; Other = reduced emissions of aerosols, aerosol precursors and Montreal gases (including fluorinated gases) and the lagged temperature response to prior emissions due to physio-chemical interactions between GHGs in the atmosphere. Analysis based on global anthropogenic emissions, not only energy-related emissions.

Source: IEA analysis based on Climate Resource and MAGICC 7.5.3.

Predicting the level of warming associated with future GHG emissions is inherently uncertain, meaning that significantly higher warming than happens in the NZE Scenario cannot be ruled out. Much of the uncertainty stems from physical and biogeochemical feedback effects as the earth warms such as changes to cloud cover and the rate at which the land and oceans draw down atmospheric CO_2. Nonetheless there is a well-established near linear relationship between cumulative CO_2 emissions and the short-term temperature rise.

However, there is currently a weaker scientific understanding of the extent to which removing CO_2 from the atmosphere will cool the climate (Zickfeld, 2021). Much of this is due to uncertainty in the "Zero Emissions Commitment" (ZEC) – the change in global average surface temperatures due to natural processes in the decades after reaching net zero CO_2 emissions. For example, the MAGICC climate model used by the IEA for this assessment estimates a ZEC corresponding to around 0.1 °C of cooling in the 50 years after net zero is reached, but other climate models find between around 0.4 °C of cooling to 0.3 °C of warming under similar conditions (Palazzo Corner S, 2023).

Achieving the climate outcomes of the NZE Scenario if natural processes fail to lower surface temperatures after 2050 would present major implications for the energy sector. Emissions of methane and N_2O in aggregate drop by around 20% between 2050 – 2100; speeding up this rate of reduction by 50%, which would be extremely difficult given the scarcity of options to further cut emissions, could reduce temperatures in 2100 by around 0.02 °C – around one-quarter of what would be needed to compensate for the absence of cooling from natural processes. The remaining cooling would need to be achieved via CO_2 removals from the atmosphere, which would need to increase to around 8 Gt per year by 2100 – around twice the level in the NZE Scenario. It is possible that some of this could happen because of increased afforestation, but it is likely that technological removals via BECCS and DACS would need to reach much higher levels than in the NZE Scenario, with stark consequences for land use, energy requirements and cost.

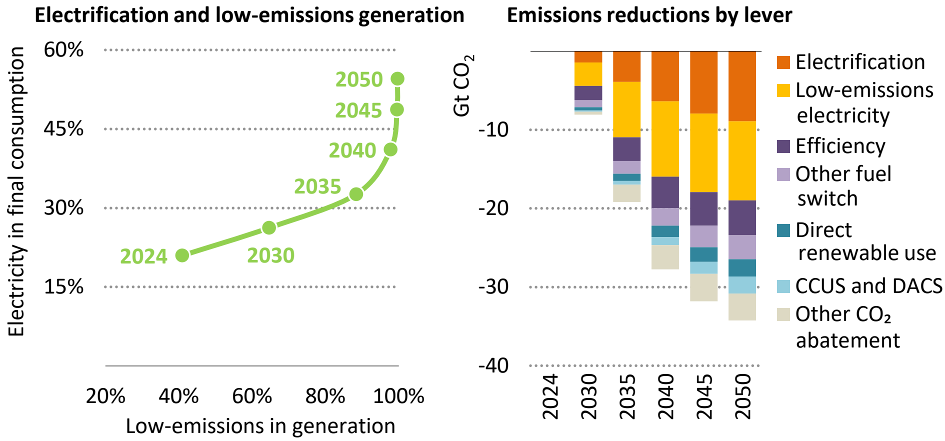
7.3 Energy pathways in the NZE Scenario

The NZE Scenario illustrates a possible global path to the goal of net zero emissions by 2050. Each country will have its own pathway, depending on their circumstances. The energy transition set out in the NZE Scenario has four main pillars: deployment of low-emissions sources of electricity and electrification to reduce emissions in end-uses; improvements in energy efficiency; use of low-emissions fuels such as hydrogen, biofuels, and CCUS; and reductions in methane emissions. These strategies rapidly reduce emissions and drive a demand-led transition away from fossil fuels in this scenario.

7.3.1 Clean electrification

Today, the power sector accounts for about 40% of global energy-related emissions. Shifting electricity generation to low-emissions sources and increasing the deployment of low-emissions electricity in existing and new end-uses are central to the NZE Scenario: these strategies give rise to around two-thirds of the emissions reductions to 2035 (Figure 7.12). In the NZE Scenario, low-emissions sources provide nearly all electricity generation by 2040, while electricity increases its share in total final consumption to around 40% by 2040 and 55% by 2050. The expanding role of electricity in total final consumption and the increase in electricity supply from variable renewable sources underline the importance of electricity security in the NZE Scenario.

Figure 7.12 ▷ Low-emissions share of generation relative to electricity in final consumption and levers employed to cut emissions in the NZE Scenario, 2024-2050



Clean electrification, which includes shifting generation to low-emissions sources and maximising electricity end-use, provides around two-thirds of emissions reductions achieved by 2035

Note: Gt CO_2 = gigatonnes of carbon dioxide; CCUS = carbon capture, utilisation and storage; DACS = direct air capture and storage.

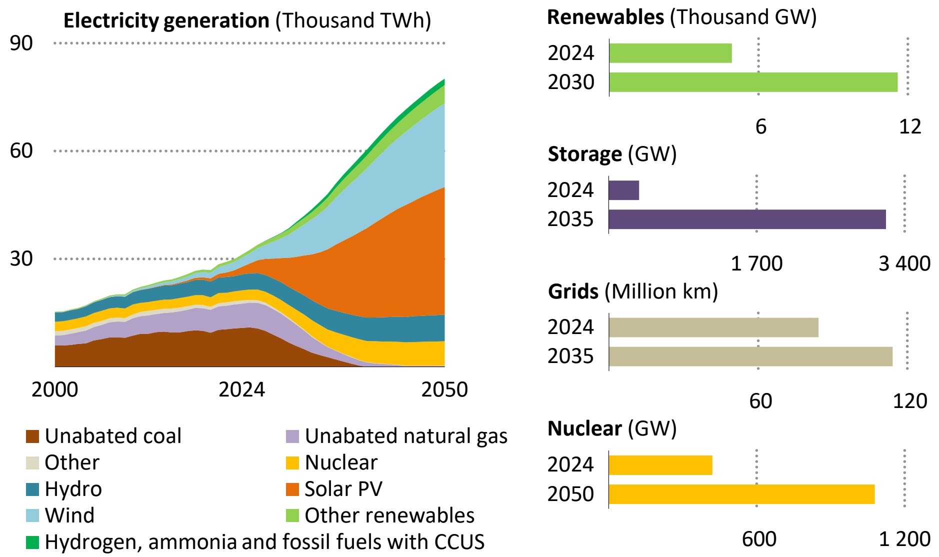
Generating electricity with low-emissions sources

Low-emissions sources of electricity – renewables, nuclear, fossil fuels with CCUS, hydrogen and ammonia – accounted for just over 40% of global electricity generation in 2024, up from around 30% a decade ago. Renewables were responsible for 32% of power generation worldwide, and nuclear for around 9%: there was also a very small contribution of less than 0.003% from fossil fuels equipped with CCUS.

Global installed capacity of renewables triples to 2030 from a 2022 baseline in the NZE Scenario, building on the strong momentum already seen in the power sector, and meeting the goal set at COP28 in 2023 (Figure 7.13). As a result, renewables expand from around one-third of total generation today to around three-quarters by 2035. Achieving this while maintaining electricity security means ensuring that investment in electricity system flexibility keeps pace. Having surged by over 80% in 2024, the installed capacity of stationary batteries increases 17-fold to 2035, average of 30% per year, reaching almost 2 900 gigawatts (GW) in capacity terms and more than 8 400 gigawatt-hours (GWh) in energy terms. In the NZE Scenario, investment surges in grid infrastructure, and around 30 million kilometres (km) of new transmission and distribution lines are added by 2035.

As variable renewables such as solar PV and wind account for a rising share of generation, dispatchable capacity plays a critical role to ensure electricity security. Long lead-times for nuclear limits its role in the near term, but installed nuclear capacity in the NZE Scenario increases 70% by 2035 from the current level, and by 2050 it is two-and-a-half times higher. By the 2030s, the nuclear industry delivers annual additions of around 40 GW per year (Box 7.3). Hydropower capacity also expands strongly, with generation increasing more than 1.5-times by 2050. Unabated fossil fuel plants are operated increasingly for flexibility and capacity adequacy, and consequently their installed capacity falls more slowly than their output across the *Outlook* period. Fossil fuel plants equipped with CCUS and plants fired with hydrogen or ammonia are also deployed, providing additional low-emissions dispatchable capacity.

Figure 7.13 ▷ Electricity generation and key pillars for the power sector in the NZE Scenario, 2000-2050



Rapid growth in all low-emissions sources enables the electricity sector to reach net zero by the early 2040s, supported by investment in grids, storage and dispatchable capacity

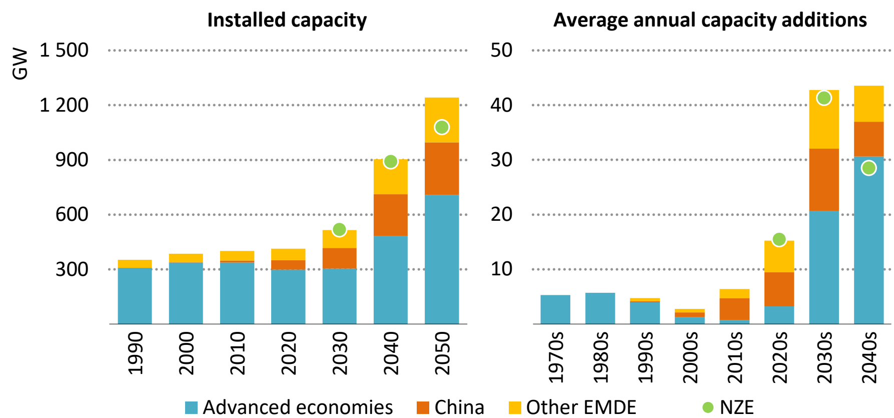
Notes: TWh = terawatt-hour; GW = gigawatt; CCUS = carbon capture, utilisation and storage. The goal to triple renewables capacity set at COP28 refers to a baseline of installed capacity as of 2022.

Box 7.3 ▷ What would it take to meet the pledge of tripling installed nuclear capacity?

At the COP28 in December 2023, more than 20 countries, representing 70% of current installed nuclear capacity, pledged to triple global nuclear power capacity by 2050. Six additional countries signed the pledge at the COP29 in 2024. If fully realised, this commitment would increase global nuclear capacity from 413 GW in 2020 to 1 240 GW by mid-century, which would exceed the level in the NZE Scenario by 160 GW.

Reaching the tripling target by 2050 would require immediate efforts to scale up the nuclear industry in the 2020s to accelerate deployment in the 2030s and beyond, with annual deployment rates rising quickly in the 2030s to around 40 GW and being maintained throughout that decade and the 2040s. According to our analysis, this would lead to levels of global nuclear capacity additions never achieved before (Figure 7.14). This expansion would support a wide range of applications. Beyond its traditional role in the power sector, nuclear energy could contribute to water desalination and to low-emissions hydrogen production, for example. In the NZE Scenario, the pace of nuclear capacity additions is expected to slow after the mid-2030s, in line with other low-emissions technologies, as most electricity systems become largely decarbonised by then: as a result, capacity rises 2.5-times from the current level rather than tripling.

Figure 7.14 ▷ Global nuclear installed capacity and capacity additions to reach the tripling target by 2050 relative to the NZE Scenario



Achieving the tripling of global nuclear capacity requires capacity additions of some 40 GW annually through the 2030s and 2040s, primarily driven by advanced economies

Note: Other EMDE = emerging market and developing economies other than China; NZE = Net Zero Emissions by 2050 Scenario.

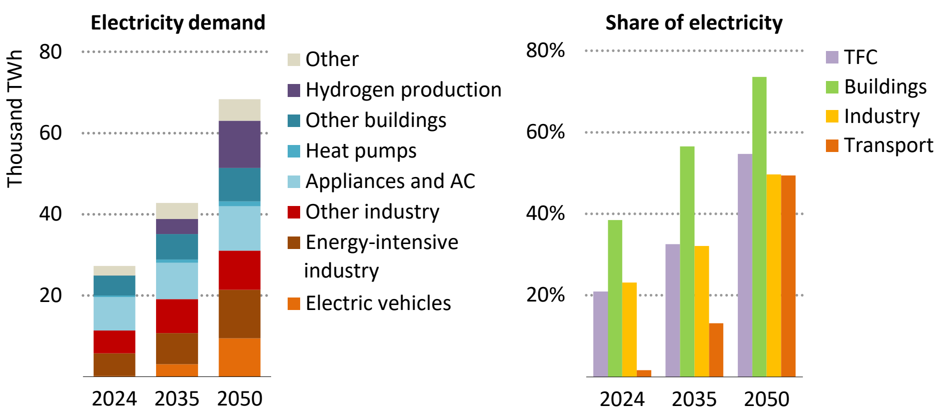
Achieving this tripling of nuclear capacity would require a significant increase in investment. Annual investment spending would need to rise from over USD 70 billion today to a peak of about USD 210 billion around 2035 before plateauing at around USD 160 billion through the 2040s. Investment would need to be on average 50% higher throughout the 2040s than in the NZE Scenario, resulting in an additional USD 900 billion of spending by 2050. This scaling up would be heavily dependent on robust supply chains, skilled labour and long-term policy support.

The United States could play a central role in this global effort. An Executive Order issued in May 2025 to reform the US Nuclear Regulatory Commission aims to revitalise the domestic nuclear industry and sets a goal of adding 300 GW of new capacity by 2050. It is reinforced by the One Big Beautiful Bill Act, which makes continued tax credits available to the nuclear industry. Countries in the European Union, Middle East, Africa, East Asia and North and Central America are also showing renewed interest in nuclear power as part of their decarbonisation strategies.

Electrifying final consumption

Electrification is one of the key levers in the NZE Scenario to reduce CO_2 emissions in the end-use sectors, i.e. industry, transport and buildings. Direct emissions from end-use sectors currently account for more than half of total energy-related CO_2 emissions. Electrification provides almost 40% of the emissions reductions from end-uses by 2050.

Figure 7.15 ⊳ Electricity demand by use and in total final consumption by end-use sector in the NZE Scenario, 2024-2050



Industrial demand and electric vehicles drive up the share of electricity over half of total final consumption by 2050

Notes: TWh = terawatt-hour; AC = air conditioning; TFC = total final consumption. Hydrogen production excludes onsite production which is covered in energy-intensive industries.

Rising demand in existing end-uses and the electrification of new end-uses in the NZE Scenario led to significant growth in electricity demand, which increases by 4.1% on average per year until 2035, adding an average of 1 400 terawatt-hours (TWh) each year. By 2035, a third of the energy used in end-use sectors comes from electricity, up from one-fifth today. This rises to over half of total final consumption by 2050 (Figure 7.15). The share is higher in the buildings sector and lower in the transport and industry sectors, where bioenergy, CCUS, hydrogen and hydrogen-based fuels and some residual fossil fuels account for a higher share of the total. In these sectors, low-emissions fuels are required to meet demands for energy that are difficult to electrify, notably in some energy-intensive industries and in aviation and shipping (section 7.3.3).

EVs are one of the most important contributors to electricity demand growth. They are central to the decarbonisation of the transport sector, reducing its CO_2 emissions by 2.4 Gt by 2035. Heat pumps are the key technology for decarbonisation of buildings through electrification of space heating: their share in space heating increases from around 12% today to 45% by 2050. Heat pumps are also an important technology for decarbonising the industry sector, particularly in non-energy-intensive industries with low temperature heat needs: the share of electricity in non-energy-intensive industries rises from around 40% today to over 50% by 2035. After 2035, technologies currently under development accelerate the electrification of energy-intensive industries (Box 7.4).

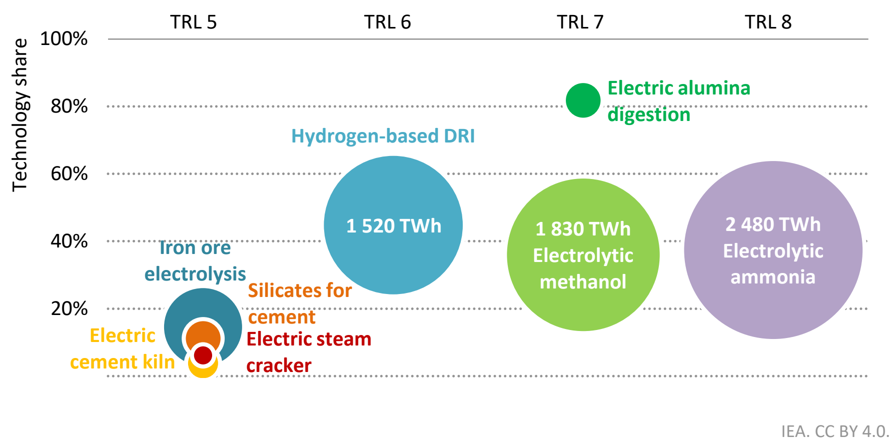
Box 7.4 ▷ Emerging technology focus: Direct electrification of energy-intensive industries

Direct electrification of processes in energy-intensive industries is challenging because most of them require high temperatures and specific materials for reactions. As a result, the share of electrification in steel, cement and primary chemicals production is well below 15% today. However, there are several technologies under development that could electrify these processes, in some cases directly and in others indirectly, notably by using electricity to produce onsite low-emissions hydrogen. While first demonstration plants for processes such as electrolytic ammonia and methanol or hydrogen-based steel making are already online or under construction, technologies such as iron ore electrolysis or electric steam crackers are at the prototype stage.

Integrating these technologies is vital if energy-intensive industries are to be decarbonised. Their use avoids 2.2 Gt CO_2 of emissions by 2050 in the NZE Scenario, contributing around a third of combustion emissions reductions in the industry sector. Technologies that are more mature today reach market shares of 30-50% in their respective industries in the NZE Scenario, and electric alumina digestion attains a market share of over 80% by 2050 (Figure 7.16). Technologies at the prototype level today are not deployed as extensively in the NZE Scenario, so there is potential upside if they prove to be feasible in larger demonstration projects.

The deployment of electrification technologies in the NZE Scenario has important implications for the electricity system. The electricity demand of all technologies analysed reaches nearly 6 700 TWh by 2050: this is more than twice the electricity consumption of energy-intensive industries today, and accounts for about 10% of total electricity demand in 2050.

Figure 7.16 ▷ Current readiness, deployment and electricity demand of electrification technologies in energy-intensive industry in the NZE Scenario in 2050



Technologies that electrify energy-intensive industries account for around 10% of total electricity demand by 2050, and this could rise if their deployment potential increases

Note: TRL = technology readiness level; TWh = terawatt-hour; DRI = direct reduced iron.
Source: TRL is based on IEA (2025a).

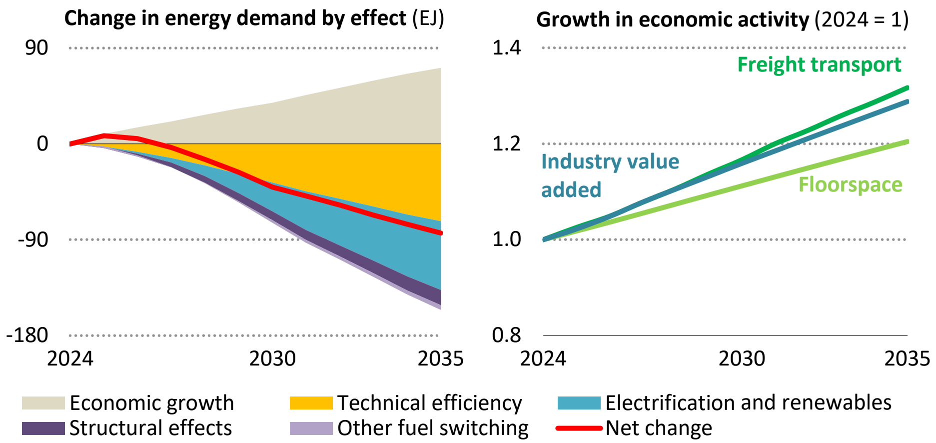
7.3.2 Energy efficiency

Energy efficiency plays a critical role to boost economic competitiveness, increase affordability of energy and lower overall energy demand. Many efficiency measures have short payback periods and offer attractive opportunities to reduce energy spending and CO_2 emissions. Annual global gross domestic product (GDP) growth averaged 3% in the 2015-2024 period, while total energy demand increased by 1.6% annually, indicating a relative decoupling of energy demand from economic growth at the global level. At national level, some 40 countries that make up about 30% of total global energy demand are seeing a decline in energy demand even while their GDP continues to grow, indicating a long-term absolute decoupling of energy demand from economic growth.[5]

In the NZE Scenario, the annual rate of improvement in energy intensity – defined as the energy demand needed to produce a dollar of economic output – steadily rises to reach 4% on average in the period to 2030. This meets the goal of doubling the rate of annual energy efficiency improvement.

[5] Relative decoupling refers to GDP increasing faster than energy demand. Absolute decoupling refers to an absolute decline in energy demand even while GDP continues to grow.

Figure 7.17 ▷ Energy demand by effect and selected economic activity indicators in the NZE Scenario, 2024-2035



Energy efficiency plays an important part in reducing energy demand even as the global economy expands

Note: Energy demand in this figure refers to total primary energy demand, also known as total energy supply.

In the NZE Scenario, the annual rate of improvement in energy intensity – defined as the energy demand needed to produce a dollar of economic output – steadily rises to reach 4% on average in the period to 2030. This meets the goal of doubling the rate of annual energy efficiency improvement.

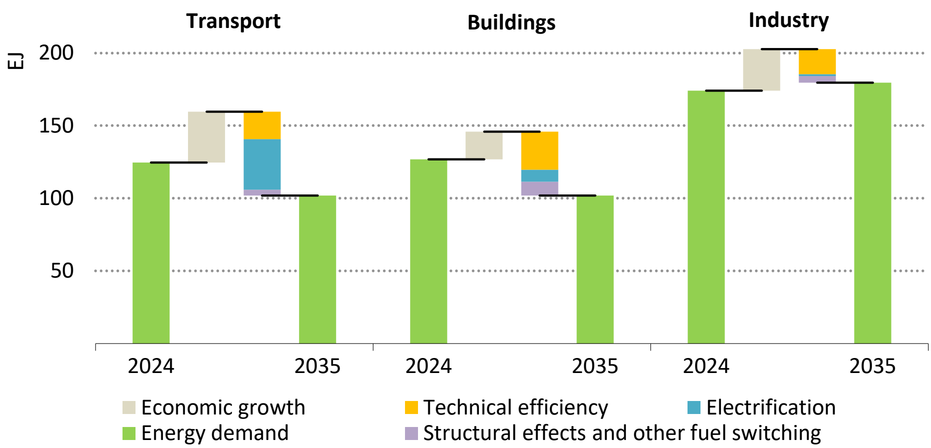
In the NZE Scenario, energy efficiency is achieved through:

- Technical efficiency improvements in equipment and buildings.
- Switching from other fuels to electricity in end-uses where feasible, as electricity is much more efficient as an energy carrier than other fuels.
- Structural effects such as material efficiency and modal switching.
- Shifting to more efficient sources of energy where electrification is not feasible or where those sources are being used to generate electricity, for example when renewables are used in place of less efficient fuels to generate electricity.

Together these elements enable energy efficiency to play an important part to reduce energy demand (Figure 7.17). However, the importance of each element varies from sector to sector (Figure 7.18).

In the buildings sector, minimum energy performance standards for appliances and energy codes for new construction are combined with policies that boost retrofit rates in the NZE Scenario. By 2035, new space cooling equipment in all markets reaches the performance levels of today's best available technologies in their respective regions, and there is progress toward global best-in-class standards thereafter. Continued electrification of space and water heating equipment also increases efficiency in the buildings sector. Moving to more efficient cooking fuels such as liquefied petroleum gas and electricity reduces energy demand by up to 85% compared to traditional cooking.

Figure 7.18 ⊳ Energy consumption by effect in end-use sectors in the NZE Scenario, 2024-2035



Continued energy efficiency gains allow economic growth to go hand-in-hand with reductions in energy consumption

In the transport sector, the switch from internal combustion engine (ICE) vehicles to EVs reduces energy consumption because of the higher efficiency of electric motors, regenerative braking and simpler drivetrains: an EV uses 70-80% less energy than a comparable ICE vehicle to travel the same distance. Modal shifts and vehicle downsizing can help to ensure more efficient use of batteries to meet transport needs. For instance, sport utility vehicles today require ten-times more battery capacity per passenger-kilometre than electric buses, and almost three-times more than a small battery electric car. Fuel economy improvements across all types of drive trains and increasing sales of EVs together lead to an absolute reduction in road transport energy consumption even as demand for transport continues to expand.

In the industry sector, material efficiency measures such as light weighting products, extension of product lifetimes and enhanced recycling help to reduce the use of energy-intensive materials, while providing consumers with the same level of service. Increases in technical efficiency in industrial motors, drives and processes also contribute. The increasing deployment of artificial intelligence offers scope to bring about further increases in energy efficiency across energy-intensive and non-energy-intensive industries (see Chapter 1).

7.3.3 Filling up on low-emissions fuels

Although electrification plays a major role to increase efficiency and lower emissions in the NZE Scenario, it cannot fully decarbonise some key end-use sectors. As a result, low-emissions molecules, i.e. hydrogen, hydrogen-based fuels and bioenergy, have a vital role to play to supplement electricity on the path to net zero emissions. In the NZE Scenario, such low-emissions fuels supply around 10% of total final consumption in 2035 and around 20% in 2050, up from 5% today. In the short and medium term, low-emissions molecules have a role to play as drop-in fuels for decarbonising conventional energy technologies; in the long term, they play a significant role in the decarbonisation of some hard-to-abate sectors.

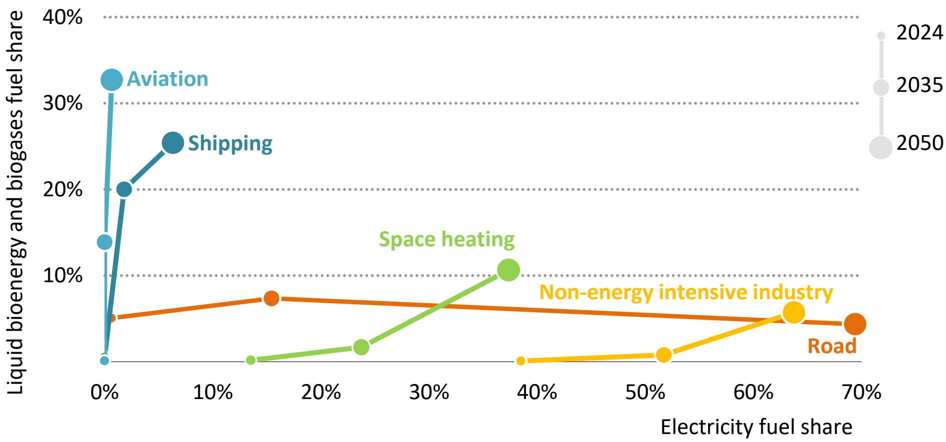
Biofuels

Liquid biofuel consumption today is dominated by road transport. In the NZE Scenario, EVs are the main route to decarbonise passenger road transport, and continued growth for liquid bioenergy comes from other end-use sectors which rely on energy-dense liquid fuels. These include shipping and aviation, which together account for around 25% of liquid and gaseous bioenergy consumption by 2035 (Figure 7.19). In aviation, biofuels play an important role in the next decade as the primary means of producing sustainable aviation fuels (SAF) that can be directly substituted for conventional fossil-based jet fuel. In 2035, around 80% of SAF are biofuels, more than 85% of which are produced from biomass that does not compete with food production. It is not until the 2040s that fuels synthesised from hydrogen and CO_2 captured from point sources or the atmosphere become an important source of SAF in the NZE scenario.

The use of heat pumps brings about a shift to electricity for much of space heating and many non-energy-intensive industrial processes, but some buildings and non-energy-intensive industrial processes are difficult or costly to electrify, notably those processes that require high-temperature heat. Bioenergy plays a role to reduce emissions in these cases, especially for buildings and industries that remain connected to natural gas infrastructure. Emerging market and developing economies are the largest source of expansion, with blended biomethane playing an important role to decarbonise gas networks that supply domestic heating and non-energy-intensive industries, meeting around 10% and 7% respectively of those energy demands by 2050.

This increase in blending leads to significant growth in biogas demand compared to liquid biofuels. Biogases can be deployed in hard-to-abate sectors using existing infrastructure. They also tend to score well on energy security metrics because they are usually consumed close to the sites where they are produced, and because they can be stored more cheaply than electricity. The IEA 2025 update to the *Outlook for Biogas and Biomethane* used geospatial analysis to demonstrate that almost 25% of today's natural gas demand could be met sustainably by biogases (IEA, 2025b). The NZE Scenario does not rely on all this potential being tapped: it envisages biogas demand reaching 15 EJ in 2050, or around 10% of current demand for natural gas.

Figure 7.19 ▷ Fuel demand met by liquid bioenergy and biogases relative to electricity for key end-uses in the NZE Scenario, 2024-2050



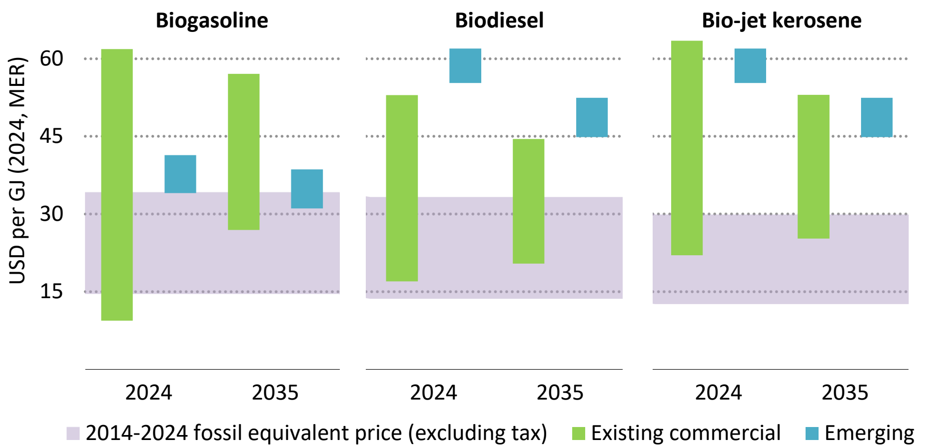
Energy demand that is hard to electrify relies heavily on low-emissions molecules to decarbonise

Notes: Liquid bioenergy includes biogasoline, biodiesel, biomethanol and bio-jet kerosene, i.e. biogenic SAF; biogases include biogas and biomethane. Solid biofuel, including modern and traditional use of biomass, is not shown.

Biofuels depend on land use for their production. Expanding the use of biofuels is constrained by competition for other land uses, e.g. forest conservation and forest restoration. Total bioenergy and waste consumption in the NZE Scenario is just over 100 EJ in 2050, which is approximately equivalent to conservative estimates for its sustainable global production potential (Creutzig, 2014). In contrast with current production, which relies mainly on constrained supplies of food crops and waste vegetable oil, the NZE Scenario sees increasing amounts of liquid biofuels produced from short rotation woody biomass crops, which can be grown on marginal land but still produce twice as much bioenergy per hectare as existing bioenergy crops. Woody biomass is also used as solid bioenergy with minimal processing in several sectors, particularly power, energy-intensive industries and space heating. Converting these crops into drop-in liquid fuels requires advanced technologies, of which the NZE Scenario sees production rise from low levels today to nearly 5 EJ by 2035.

Adoption of biofuels is influenced by costs as well as supply limitations. The main cost driver for existing commercial biofuels is feedstock, which accounts for more than 80% of the total cost of production. These production costs vary significantly over time and between regions: at times they have fallen below the equivalent fossil fuel price. Looking forward, increasing competition for biofuels reduces the incidence of very low prices and increases the lowest prices at which existing commercial biofuels can be produced (Figure 7.20). The share of feedstocks in the cost of emerging biofuel technologies is lower than for existing commercial options, reflecting the high capital and operating costs of the biofuel conversion processes. However, these conversion costs decline slightly over time, reducing the costs of emerging biofuel technologies and bringing them closer to those of existing commercial biofuels: in the case of biogasoline, it brings costs into the historical range of fossil end-user prices.

Figure 7.20 ▷ Existing commercial and emerging liquid biofuel costs relative to fossil equivalent prices, 2024 and 2035



IEA. CC BY 4.0.

Biofuel costs are highly uncertain, but can be competitive with fossil alternatives; emerging biofuel technologies become more competitive over time as processing costs fall

Notes: GJ = gigajoule; MER = market exchange rate. Historical and projected feedstock prices for existing commercial biofuels are taken from OECD-FAO (2025), the variation in which underpins the range in cost estimates.

Box 7.5 ▷ Emerging technology focus: What next for bioethanol?

More than half of liquid biofuels in use today are based on bioethanol produced from food crops. Bioethanol plays an important role in decarbonising the road sector, particularly in regions where it is already widely deployed, but growth opportunities are limited because of the widespread electrification of vehicles. Continued expansion therefore depends on the extent to which other applications are found, particularly in the heavy-duty transport sector, where there is a higher level of uncertainty about the lowest cost routes to decarbonisation.

In the aviation sector, alcohol-to-jet (AtJ) pathways are a promising option for upgrading bioethanol, and demonstration projects are under way in both Europe and the United States. In the NZE Scenario, these pathways account for over 10% of SAF production in 2035. Because bioethanol can be produced from a range of feedstocks, AtJ pathways have much higher SAF production potential than today's dominant hydrotreated esters and fatty acids pathway which produces fuels from vegetable oils, waste oils and fats. However, the ability of AtJ to compete with more established technologies for alternative fuel production like the Fischer-Tropsch process has yet to be demonstrated.

In the shipping sector, bioethanol does not currently meet the requirements for consideration as a sustainable fuel by the FuelEU Maritime regulation if produced from a food crop. As a result, its future use depends to a considerable extent on whether it can be produced affordably using waste material. If this hurdle can be overcome, it could be a competitive option, since it is denser and less toxic than some other biofuels like biomethanol. In regions with established production and robust regulatory frameworks for sustainable production chains, bioethanol may offer an option for near-term emissions reductions where existing infrastructure could be used to make it available for bunkering before other types of sustainable fuel are viable.

Hydrogen and hydrogen-based fuels

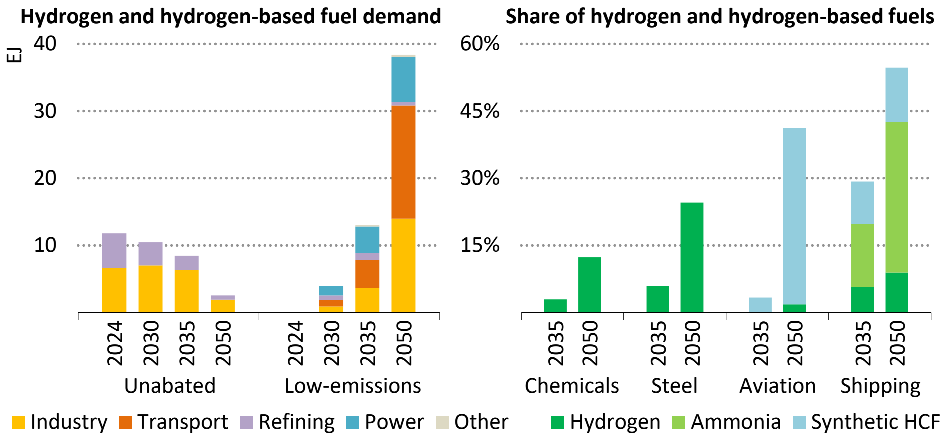
In addition to biofuels, low-emissions hydrogen and hydrogen-based fuels can support decarbonisation in parts of the energy sector where other mitigation measures are more difficult or costly. In the NZE Scenario, low-emissions hydrogen and hydrogen-based fuels account for 2% of total final consumption by 2035, increasing to almost 10% by 2050. However, their share is much higher in sectors such as aviation and shipping. Low-emissions hydrogen and ammonia are also used as fuels for electricity generation.

Around 100 million tonnes of hydrogen (Mt H_2) were used in the energy sector in 2024, of which around 55% was in industry, mostly to produce ammonia and methanol, and around 45% was in refineries for hydrocracking and desulphurisation processes (Figure 7.21). Today, hydrogen is almost entirely produced from unabated fossil fuels, resulting in CO_2 emissions of 980 Mt CO_2. Low-emissions hydrogen meets less than 1% of global hydrogen demand.

Low-emissions hydrogen production rapidly scales up in the NZE Scenario, and over 35% of all hydrogen used in the industry sector by 2035 comes from low-emissions sources. The two largest electrolyser projects in the world that have received a final investment decision (FID) are in Saudi Arabia (2.2 GW) and India (1.3 GW): both will use low-emissions hydrogen to produce ammonia. In refineries, low-emissions hydrogen meets around 30% of hydrogen demand by 2035. The iron and steel sub-sectors start to make use of low-emissions hydrogen: several projects that plan to use low-emissions hydrogen in the direct reduced iron (DRI) are under development, and eight projects with an electrolyser capacity at or above 100 megawatts (MW) have received FID approvals, the largest of which is being built in Sweden with an electrolyser capacity of 800 MW.

In the transport sector, hydrogen is already used in road transport, but it plays a minor role, with only 100 000 fuel cell vehicles on the road worldwide and 1 300 hydrogen refuelling stations in operation in 2024. In the NZE Scenario, the role of hydrogen in road transport remains limited. However, the use of hydrogen and hydrogen-based fuels expands in other parts of the transport sector where the direct use of electricity is more difficult. In the shipping industry, more than 65 methanol-powered vessels were in operation as of October 2025, running on methanol derived from fossil fuels, and an additional 300 ships are on the order books of shipping companies. In the NZE Scenario, low-emissions ammonia, synthetic methanol and hydrogen rapidly displace other fuels, and between them they meet around 30% of the energy needs for shipping in the NZE Scenario by 2035. In the aviation sector, synthetic kerosene, from a power-to-liquid process, is not being used today, though mandates for its future use have been put into force in the European Union and the United Kingdom. By 2035, it meets 3% of global aviation fuel demand in the NZE Scenario, and this share rises rapidly in later years.

Figure 7.21 ▷ Hydrogen demand by sector to 2050, and hydrogen fuel use in selected sub-sectors, 2035 and 2050, in the NZE Scenario



Low-emissions hydrogen replaces hydrogen from unabated fossil fuels in refining and industry and takes an increasing share in shipping, aviation and electricity generation

Notes: HCF = hydrocarbon fuels. Other includes buildings and agriculture. The share of low-emissions hydrogen and hydrogen-based fuel use refers to the share of these fuels in energy consumption in the sub-sector. For chemicals and steel, the total energy consumption includes the energy use for onsite low-emissions hydrogen production.

Low-emissions hydrogen and ammonia are not used in electricity generation today, but they could help to reduce emissions from existing plants while also providing flexibility for the electricity system. In the longer term, power plants running entirely on hydrogen or ammonia and combined with hydrogen storage could become a seasonal electricity storage option. In the NZE Scenario, low-emissions hydrogen and ammonia meet around 1.5% of the total fuel needs in the global power sector by 2035.

Box 7.6 ▷ Emerging technology focus: Geological hydrogen

Geological hydrogen can be broadly grouped into two categories: natural hydrogen and stimulated geological hydrogen. Natural hydrogen refers to hydrogen that has accumulated in subsurface reservoirs. The only documented well producing natural hydrogen is in Bourakébougou, Mali, with a production rate of about 5 tonnes of hydrogen per year. Stimulated geological hydrogen is produced by artificially accelerating the natural hydrogen generating reaction in iron-rich rocks using chemical, physical or biological stimulation. Stimulating the production of geologic production is still at an early development stage and has been demonstrated so far only in the laboratory.

Natural hydrogen exploration activities are now underway in more than ten countries. In the United States, for example, the US Geological Survey released a map for the first time in 2024 showing likely areas to explore for hydrogen. In France, two natural hydrogen deposits were discovered in 2023 and 2025; the size of the earlier discovery has been estimated at 46 Mt (Ruffine et al., 2025). The Philippines launched the world's first natural hydrogen exploration auction in 2024 covering 230 000 ha near Manila. Venture capital is investing in geological hydrogen: start-up companies attracted USD 300 million in 2024. Over 40 companies are searching for natural hydrogen deposits commercially, and some developers have announced that they expect to be able to extract natural hydrogen at estimated costs of around USD 1 per kilogramme of hydrogen. However, commercial development remains uncertain due to limited understanding of reservoir behaviour and replenishment rates, and to the lack of demonstration of sustained production at scale.

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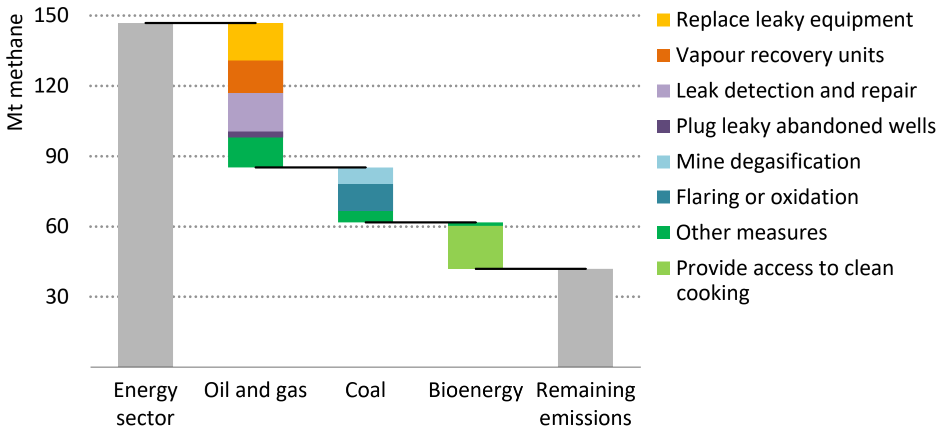
7.3.4 Cutting energy-related methane emissions

Methane is responsible for around 30% of the rise in global temperatures that has taken place since the industrial revolution (IPCC, 2021a). Rapid and sustained reductions in methane emissions are key to limit near-term global warming and to improve air quality. Methane has a much shorter atmospheric lifetime than CO_2, around 12 years for methane versus centuries for CO_2, but it absorbs much more energy while it remains in the atmosphere.

Today the concentration of methane in the atmosphere is over two-and-a-half times above pre-industrial levels. Atmospheric records show that, in relative terms, methane concentrations have been rising more quickly than those of all other major GHGs, and at a rate faster than in any period since recordkeeping began. The energy sector, including oil, natural gas, coal and bioenergy, accounts for more than 35% of methane emissions from human activity.

The fossil fuel sector offers significant potential for rapid and low-cost reductions in methane emissions. In the NZE Scenario, methane emissions from the energy sector fall by more than 80% by 2035 as all available mitigation measures are deployed across energy supply chains (Figure 7.22).

Figure 7.22 ▷ Opportunities to reduce methane emissions in the energy sector, 2024



Measures to reduce methane emissions are available across the value chains of all fuels

Note: Mt = million tonne.

Nearly half of global oil and gas production is covered by corporate near zero methane targets. Measures to lower methane emissions from fossil fuels to near zero already exist and could be deployed today at little cost. Around 30% of total methane emissions from oil, gas and coal could be avoided at no net cost, based on 2024 average energy prices. This is because the required outlays for abatement measures are less than the market value of the additional methane gas captured and used or sold.

There are many reasons why companies may fail to invest in methane abatement despite positive rates of return. Companies could be unaware of the scale of the problem or the available solutions or may not have identified an effective route or business case to bring captured methane to productive use. There may be higher profile opportunities competing for resources, or contractual arrangements may fail to incentivise methane savings. It may also be difficult to secure the capital required for upfront investment, especially in developing economies.

The implementation of tried and tested policy measures, such as leak detection and repair (LDAR) requirements and a ban on routine flaring and venting, could cut global oil and gas emissions of methane by more than half. Additional measures, for example establishing emissions pricing, financing instruments and performance standards, could lead to an 85% reduction by 2035. Almost all these abatement measures would be cost effective to deploy with a GHG emissions price of about USD 20 per tonne of carbon-dioxide equivalent.

Novel applications of technologies for associated gas utilisation, continuous LDAR systems and process improvements offer ways to go further to reduce oil and gas emissions. These applications include the use of methane monitoring towers equipped with specialised sensors, use of artificial intelligence for predictive maintenance, and use of automated air-fuel controls to increase combustion efficiencies. Tests are underway to deploy methane oxidation catalyst systems that tackle methane emissions from incomplete combustion, which are also known as methane slips, from marine LNG engines.

In the coal sector, methane emissions could be halved through effective methane utilisation in mines, or by deploying flaring or oxidation technologies when energy recovery is not viable. Drainage systems could be used to direct coal mine methane to power generation, heating or processing ahead of pipeline injection. Net costs to deploy these solutions globally at scale would amount to less than USD 5 billion per year.

In the bioenergy sector, accelerating access to clean cooking and modern heating would eliminate most methane emissions from the incomplete combustion of bioenergy (see Chapter 6), while the application of best available technologies, e.g. gastight digestate (a byproduct of anaerobic digestion) storage at biogas plants, would minimise emissions from modern bioenergy supply. Biogas production could also help reduce methane emissions from waste and agriculture.

Existing high-level pledges on methane, including the Global Methane Pledge, cover around 80% of global fossil fuel production. There is scope for importing countries to help drive significant cuts in methane emissions in exporting countries through economic incentives or trade measures, such as the import standards referenced by the European Union Methane Regulation, and for investors to contribute by promoting performance standards and pushing for verifiable methane reductions together with transparent and comparable disclosures on measured emissions.

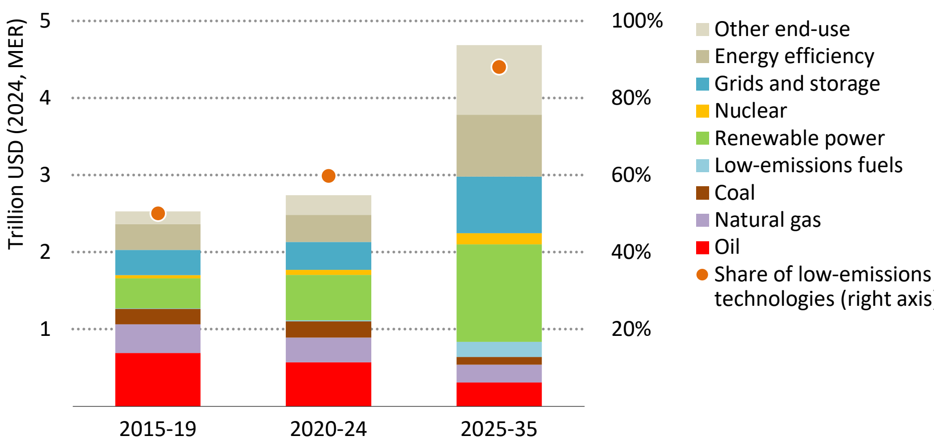
7.4 Implications

7.4.1 Investment

Transformation of the energy sector in the NZE Scenario involves the roll out of technologies with high capital costs, but generally low operating costs, across the energy system. Reflecting this, total annual energy sector investment increases, reaching USD 4.8 trillion on average in the next decade, and rising to USD 5.6 trillion in 2035. This latter figure is around 70% higher than today's level and over 50% higher than in the Stated Policies Scenario (STEPS).

Clean electrification is a key driver of emissions reductions in the NZE Scenario, and annual global investment in the power sector reaches over USD 2.5 trillion by 2035, almost double today's level. Low-emissions power generation and grid infrastructure account for nearly 90% of investment in the power sector since 2020, and this share increases to almost 100% by 2035. Investment in renewable sources of electricity dominates power sector investment, nearly doubling to reach almost USD 1.3 trillion on average in the next decade. Between 2025 and 2035, annual spending on grids and storage rises to USD 800 billion, and annual spending on nuclear power to USD 150 billion. In both instances, this is double the level of annual investment from 2020-2024.

Figure 7.23 ▷ Annual energy sector investment by sector, 2015-2024, and in the NZE Scenario to 2035



Spending on renewables, grids and storage, energy efficiency and electrification accelerate rapidly over the next decade

Note: MER = market exchange rate; NZE = Net Zero Emissions by 2050 Scenario.

On the demand side, the NZE Scenario sees rapid electrification of final energy use across the buildings, transport and industry sectors, driven by the swift deployment of EVs and heat pumps. This translates into average spending on electrification of over USD 900 billion each year to 2035 – a tripling from current levels. Average annual investment in energy efficiency in the buildings sector alone approaches USD 600 billion per year over the next decade. Annual average investment in efficiency in transport and industry also nearly doubles, though from a smaller base, reaching about USD 160 billion and USD 70 billion respectively.

The scale up in investment in low-emissions technologies and energy efficiency in the NZE Scenario brings down the investment requirement in fossil fuels. Compared to an annual average spending of around USD 1 trillion in fossil fuel supply in recent years, investment in the NZE Scenario falls to an average of less than USD 350 billion per year in 2035. As in previous editions of the NZE Scenario, upstream investment is directed towards maintaining the output of existing fields, as – in the absence of such investment – their natural decline rates would exceed the rate of decline of fossil fuel demand in the NZE Scenario. By 2050, the energy system still consumes some fossil fuels, with emissions from unabated fossil fuels offset by BECCS and DACS or fossil fuel emissions abated with CCUS. This means that fossil fuel supply investment does not drop to zero even by 2050, but it falls 90% compared to today.

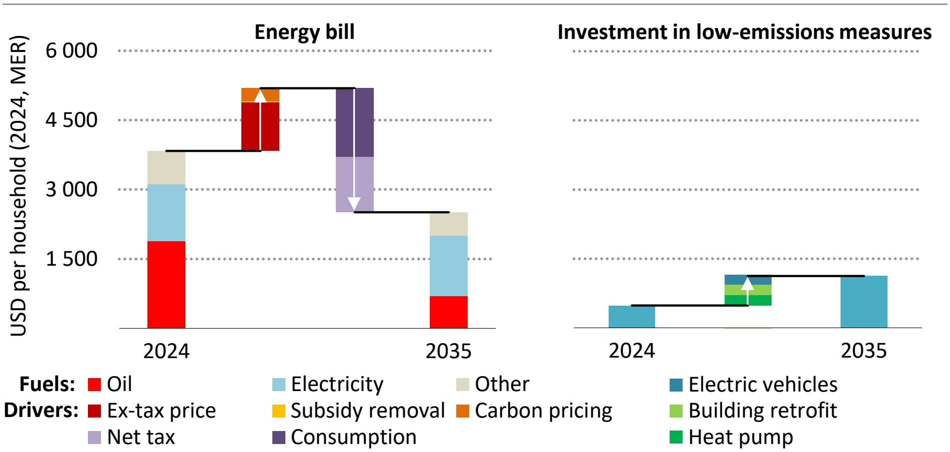
7.4.2 Social inclusion

Affordability for households

How changes in investment, fuel prices and operating costs ultimately impact the affordability of energy for end-users is a key issue in all our scenarios. The IEA has extensively explored the implications of transitions to net zero emissions such as the NZE Scenario on overall affordability. Here, we focus on household energy consumption, including both residential and transport energy use. There are three main dynamics at play: a large increase in upfront spending on clean energy equipment; a shift away from spending on direct fossil fuels like gasoline and towards electricity; and regulatory interventions that add CO_2 costs, remove fossil fuel subsidies and provide incentives for the uptake of low-emissions technologies.

The most immediate implication of the NZE Scenario for households is a large increase in spending on EVs, building retrofits and appliances, especially heating and cooling equipment. This increase means that households in advanced economies spend on average around USD 650 per year more on these technologies than they do today. This figure considers that many households will spread payments for large purchases such as EVs, heat pumps or building renovations over a number of years.

Figure 7.24 ▻ Average annual household energy expenditure in advanced economies in the NZE Scenario, 2024-2035



In advanced economies, increased household investment in low-emissions equipment is offset by lower spending on energy bills over time

Notes: MER = market exchange rate. Spending on clean energy options only reflects the share which is borne by households, minus any public subsidies or fiscal incentives.

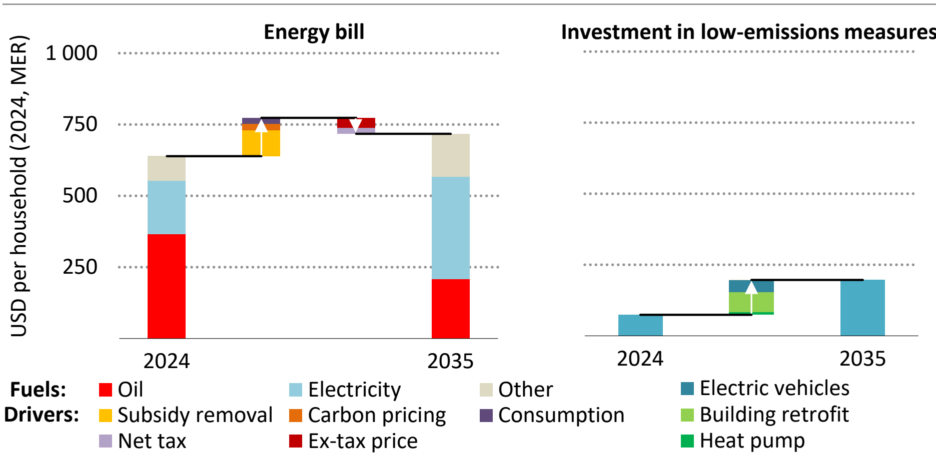
Over time, households in advanced economies see a sharp reduction in expenditure on gasoline and diesel as more of their energy needs are met with low-emissions electricity. By

2035, average household spending on oil products falls to around USD 700 per year in the NZE Scenario, down from about USD 2 000/year today. Over the same period, electricity expenditure increases only slightly from around USD 1 200/year to USD 1 300/year. As a result, overall household energy bills are lower. This reduction is driven by the widespread electrification of end-uses – most notably the uptake of EVs and electrification of heating – alongside efficiency gains from building retrofits and appliances. In general, electrification enables households to consume less energy for the same level of service, thanks to the superior efficiency of electric technologies.

Additional household investment in low-emissions technologies on average lead to larger energy savings, reducing total energy expenditure by households in advanced economies by around 15%. These gains particularly benefit lower income households, which tend to need to spend a higher proportion of their income on energy than wealthier households. For instance, some households in the lowest income decile currently spend over 30% of disposable income on energy services: this share declines to less than 20% in 2035 in the NZE Scenario. Though these gains depend on lower income households being able to fund the upfront purchase costs of low-emissions technologies, and this may only be possible if subsidies or other support measures are available.

The other major implication of the NZE Scenario for households is that a set of changes in regulations and policies affects the costs of different energy services, notably through the introduction of CO_2 pricing, the removal of untargeted fossil fuel subsidies, and an increase in financial support for the adoption of clean energy technologies.

Figure 7.25 ▷ Average annual household energy expenditure in emerging market and developing economies in the NZE Scenario, 2024-2035



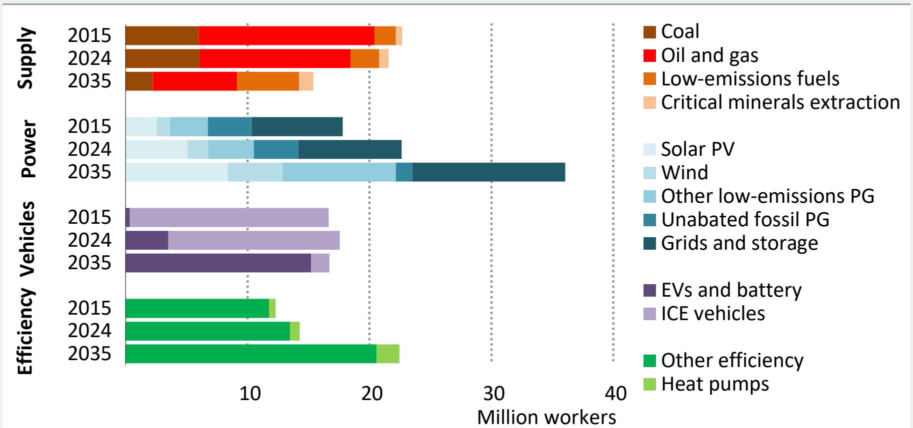
Carbon pricing and subsidy removal increase energy prices in emerging market and developing economies, but also generate new revenues streams for governments

Managing the removal of fossil fuel subsidies while protecting low-income households and keeping fiscal budgets balanced would be a major challenge for some emerging market and developing economies and could be especially difficult for major producer economies whose revenues from fossil fuel exports decline in the NZE Scenario. However, the removal of untargeted subsidies and introduction of CO_2 pricing in the NZE Scenario also create new revenue streams and reduce fiscal burdens. These new revenues could be used to provide extra assistance for low-income households, for example through payments to reduce energy bills or to help them invest in low-emissions energy equipment.

Box 7.7 ▷ Energy employment in the NZE Scenario

Global energy employment expands by more than 14.5 million jobs by 2035 in the NZE Scenario, an 20% increase from 2024 compared with increases of 4% in the Current Policies Scenario and 6% in the Stated Policies Scenario. Most of the growth comes in the power sector, where the number of jobs rises to 36 million, driven by a doubling of low-emissions jobs related to electricity generation and a 50% expansion in the electricity grids workforce. Vehicle manufacturing also undergoes a major shift, with EVs projected to account for 90% of vehicle industry employment by 2035. Employment in the fossil fuels sectors contracts in the NZE Scenario, with coal declining by 60% and oil and gas by 45%, underscoring the importance of just transition policies to support affected workers.

Figure 7.26 ▷ Energy employment by technology, 2015 and 2024, and in the NZE Scenario in 2035



Global energy employment expands by more than 14.5 million jobs by 2035 in the NZE Scenario, though labour market constraints may slow the pace of the transition

Note: NZE = Net Zero Emissions by 2050 Scenario; PG = power generation; ICE = internal combustion engine.

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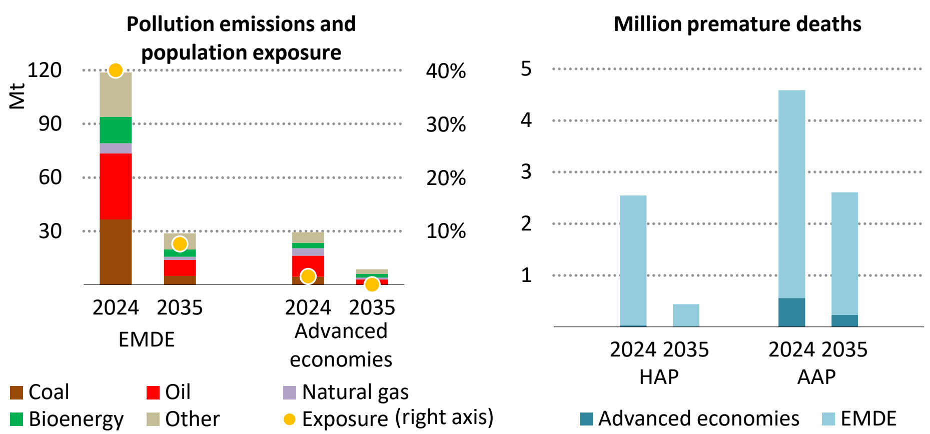
Yet even if the direction is clear, the speed of transition may be constrained by labour market realities. Skilled labour shortages, already a challenge in today's energy sector, would intensify in the NZE Scenario. Trades workers, such as electricians, welders, and line workers, are expected to remain the largest occupational group in the energy sector, with more than 5.8 million additional workers needed between 2024 and 2035. At the same time, acquiring new skills to address the growing importance of digitalisation, automation and AI will require large-scale reskilling and upskilling.

Air pollution

Ambient (outdoor) air pollution caused about 4.5 million premature deaths in 2024, and there were about 2.5 million premature deaths related to household air pollution, mainly smoke from burning fuelwood for cooking. Over 90% of the premature deaths occurred in emerging market and developing economies, where forty percent of people breathe heavily polluted air daily which adversely impacts human health and economic productivity.

Figure 7.27 ▷ Volume and share of population exposure to heavy air pollution by source, and premature deaths by economic grouping in 2024 and in 2035 in the NZE Scenario



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Exposure to heavy air pollution drops by 80% in the NZE Scenario, resulting in 4 million fewer premature deaths per year by 2035 relative to 2024

Notes: Mt = million tonnes; NZE = Net Zero Emissions by 2050 Scenario; EMDE = emerging market and developing economies. HAP = household air pollution; AAP = ambient air pollution. Air pollution emissions include the sum of SO_2, NO_X, and $PM_{2.5}$ with concentrations ≥ 35 microgrammes per cubic metre.

Over the past decade, less use of coal for electricity generation, tighter fuel standards and early progress to broaden access to clean cooking options have helped to reduce air pollution emissions in some regions, yet progress has been uneven around the world. The NZE

Scenario leads to rapid cuts in all pollutants in all regions. By 2035, emissions of fine particulate matter ($PM_{2.5}$), sulphur dioxide (SO_2) and nitrogen oxides (NO_X) in aggregate fall by 70% in advanced economies, driven largely by less oil use in road transport, and almost 80% in emerging market and developing economies, driven by less use of coal in power generation. The benefits by 2035 include that the number of people exposed to heavily polluted air falls to essentially zero in advanced economies and drops fivefold in emerging market and developing economies compared to the current level.

These emissions cuts deliver public health benefits. By 2035, around 2 fewer million people per year die prematurely from ambient air pollution compared to today; 85% of these avoided deaths are in emerging market and developing economies. Universal access to clean cooking avoids around 2.1 million deaths per year from household air pollution, a drop of 85%.

7.4.3 Energy security

The NZE Scenario presents a complex set of opportunities and challenges for energy security, requiring careful attention from policy makers. This section addresses various issues related to energy security along the path to net zero emissions.

Fuel security

As investment in low-emissions energy supply and energy efficiency is scaled up in the NZE Scenario, investments in the supply of fossil fuels and in the construction and maintenance of related infrastructure are scaled back. However, they do not drop to zero. Continued investment is required to counteract the effect of natural decline rates in oil and gas fields (IEA, 2025c), and some infrastructure, such as natural gas networks, import terminals or natural gas peaking plants, are needed for some time to provide buffers for the energy system. The transition will therefore require careful sequencing of the scaling up of low-emissions energy supply; continued operations, maintenance and possible repurposing of critical fuel supply infrastructure; and eventual safe decommissioning.

As low-emissions energy meets an ever-growing share of demand in the NZE Scenario, the production of oil and natural gas becomes concentrated in low-cost suppliers. In the NZE Scenario, the share of the Organization of Petroleum Exporting Countries + (OPEC+) in oil supply increases to around 55% by 2035. Governments will need to decide whether to seek to preserve domestic production and/or stockholding capacity for oil and gas to provide a counterweight to this increasing geographical concentration.

In the NZE Scenario, prices in international fuel markets fall in line with declining demand. This has beneficial effects for fuel importers, which see fuel import bills cut by more than two-thirds by 2035. However, lower revenues for producer economies in the NZE Scenario imply significant macroeconomic and fiscal challenges, given the reliance of these economies on revenues from the sale of fuels in international markets, and a consequent need for proactive economic diversification policies.

Electricity security

The NZE Scenario implies sharper challenges for electricity security. As electricity comes to provide over half of the energy consumed around the world by 2050 in the NZE Scenario, the economic consequences of potential disruptions increase. The electricity sector becomes more complex in the NZE Scenario, with growing supply from variable sources of generation and increasing consumption from a wide range of end-uses such as EVs and heat pumps. Maintaining electricity security will require a diverse portfolio of measures.

Dispatchable capacity will be critical to balance the power systems and particularly to meet seasonal flexibility needs. In the NZE Scenario, total installed dispatchable capacity, excluding batteries, is maintained broadly at current levels through to 2035, even as variable sources of generation take an increasing share of generation. Dispatchable renewables such as hydropower, geothermal and bioenergy play a role here, as does nuclear power. As their costs fall sharply, batteries come to play an increasingly important role to absorb surplus renewables and meet peak demand. The installed capacity of batteries reaches around 2 900 GW by 2035, an 11-fold increase from the current level; this is in line with the scaling up of the installed capacity of solar PV over the past decade. While batteries are well-suited today to provide short-term flexibility needs for durations of several hours, other forms of longer duration storage, such as pumped hydro, are also needed.

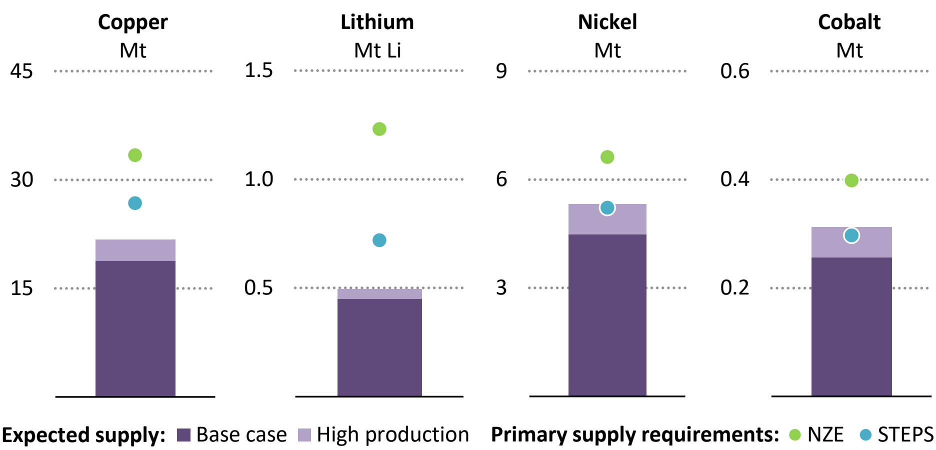
Demand-response measures offer significant but still underutilised potential to make electricity systems more flexible and secure. Tapping this potential will require incentives and market structures that value demand response, infrastructure such as smart controls, and the innovative use of technology to manage controllable loads efficiently and securely. Overbuilding of renewables projects and curtailment of surplus generation can contribute to cost-effective strategies to ensure electricity security in systems with high penetration of renewables. Electricity grids see high levels of investment in the NZE Scenario, reflecting the need for expansion and modernisation to ensure the timely connection of generation and load projects, and the need to ensure that the grid can play a crucial role in electricity security.

Critical minerals security

Demand for critical minerals rises much faster in the NZE Scenario than in other scenarios. For example, demand for copper – fundamental to all electrical applications – is around 25% higher in 2035 than in the STEPS. Lithium demand is 70% higher. Nickel, cobalt and graphite demand is 30-50% higher. While concerns around supply concentration remain crucial, additional volume challenges emerge in the NZE Scenario (Figure 7.28).

In the STEPS, recent project announcements have narrowed expected supply gaps for many minerals, however, copper is a notable exception. In the NZE Scenario, most minerals still require additional projects, further innovation and expanded recycling to bridge the gap between supply and demand. For example, expected copper supply from existing and announced projects in 2035 falls short of projected demand by over 40%, compared with around 30% in the STEPS. For nickel and cobalt, announced projects are broadly sufficient to meet demand growth in the STEPS, but shortfalls remain in the NZE Scenario.

Figure 7.28 ▷ Critical mineral primary supply requirements and expected supply from existing and announced projects by scenario, 2035



Additional supply, further innovation and expanded recycling are required to bridge the gap between critical mineral supply and demand in the NZE Scenario

Note: Mt = million tonne; Mt Li = million tonnes of lithium metal content; NZE = Net Zero Emissions by 2050 Scenario; STEPS = Stated Policies Scenario.

Unreliable supply of critical minerals could significantly affect both the pace of progress and the cost of achieving the goals in the NZE Scenario. Some minerals account for a large share of total energy technology costs, so price spikes would inevitably have implications for manufacturing costs and ultimately for consumer prices (see Chapter 5). Supply disruptions could also derail efforts to diversify energy technology manufacturing, concentrating supply chains further and affecting industrial development and jobs. Action is needed both in the near term to strengthen preparedness for potential disruptions, and in the medium term to diversify supply chains and mitigate structural risks. Securing reliable critical mineral supplies is essential not only for energy security but also to ensure an orderly, affordable energy transition consistent with the 1.5 °C goal.

7.4.4 Implications for the next ten years

By 2035, the NZE Scenario sees global energy-related emissions fall by around 50% from 2024 levels, and electricity use rise to account for one-third of total final consumption. The installed capacity of renewables reaches around 19 600 GW, increasing fourfold from 2024. Other low-emissions sources such as nuclear also see rapid growth, enabling deep cuts to be made in electricity sector emissions. The average annual increase in energy efficiency is maintained at around 4% per year through to 2035, compared with 2% in 2022. Deep cuts in energy sector methane emissions help to lower peak warming, avoiding an even higher overshoot of the 1.5 °C goal. By 2035, energy sector methane emissions are 80% lower than today.

Deployment of options that have a critical role to cut emissions in the longer term start to accelerate by 2035 in the NZE Scenario. Total CO_2 capture increases to around 2 260 Mt, a more than 50-fold increase over today's levels (Table 7.1). Of this, around 660 Mt is removed from the atmosphere, up from near zero today. Removals are indispensable not only to reach net zero emissions by 2050 but also to achieve net negative emissions in the second-half of the century and thus bringing warming back below 1.5 °C by 2100. Hydrogen and hydrogen-based fuels, new nuclear reactor designs, advanced geothermal, novel storage technologies and other innovative technologies also start to be widely deployed. Low-emissions hydrogen production, for example, rises from less than 1 Mt today to around 125 Mt by 2035.

Table 7.1 ▷ Key indicators of the energy transition in the NZE Scenario, 2024-2035

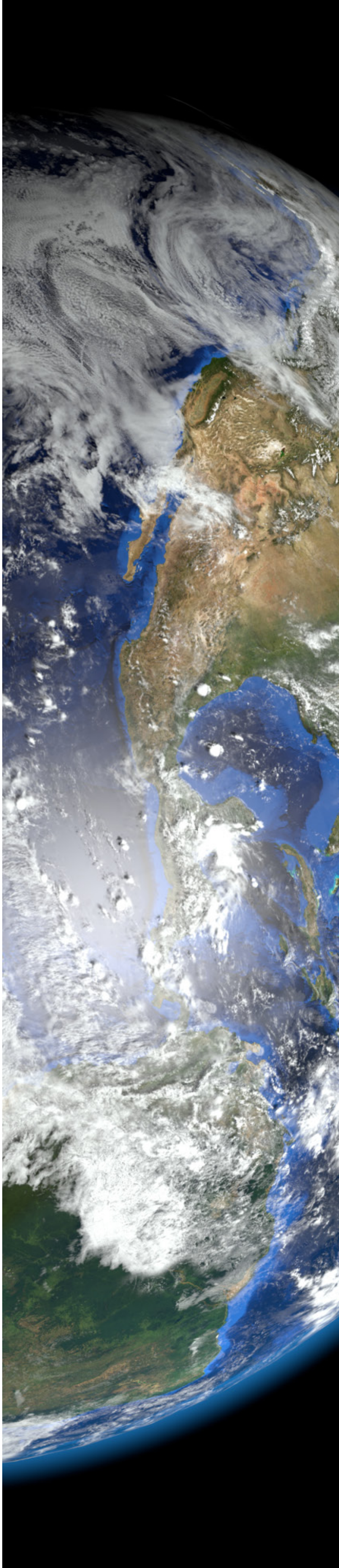
	2024	2030	2035
Energy-related CO_2 emissions (Gt CO_2)	38.2	29.4	17.6
Installed renewables capacity (GW)	4 900	11 600	19 600
Installed nuclear capacity (GW)	420	520	710
Energy intensity improvement per year	1.1%	4.0%	4.0%
Share of electricity in final consumption	21%	26%	33%
Total CO_2 captured (Mt CO_2)	45	690	2 260
Total CO_2 removed (Mt CO_2)	<1	180	660
Liquid biofuel supply (mboe/d)	2.5	4.2	5.4
Low-emissions hydrogen production (Mt)	1	35	125
Energy sector methane emissions (Gt CO_2-eq)	4.4	1.3	0.9

Note: Gt CO_2 = gigatonne of carbon dioxide; GW = gigawatt; Mt CO_2 = million tonne of carbon dioxide; mboe/d = million barrels of oil equivalent per day; Mt = million tonne; Gt CO_2-eq = gigatonne of carbon-dioxide equivalent.

PART D
REGIONAL INSIGHTS

Part D of the *World Energy Outlook* explores future energy supply and consumption by region.

Chapter 8 examines the diverse energy sector trends and priorities in ten countries and regions that cumulatively account for over 90% of the world's population, GDP and energy demand. It also includes analysis of a specific topic for each region that is relevant to its future energy requirements.



Regional insights

Diverse priorities, diverse pathways

SUMMARY

- This chapter explores energy sector trends and priorities in countries and regions that cumulatively account for around 90% of the world's population, GDP and energy demand. Priorities, objectives and national circumstances vary widely between and within regions, but two trends that are visible in most parts of the world are a rise in the electrification of end-uses, and a rise in the share of renewables in electricity generation.
- Energy trends in advanced economies are shaped by the structure of their economies, and by high average incomes and rates of vehicle and appliance ownership. Overall energy demand typically has peaked, although electricity use continues to increase, with electric vehicles and data centres adding to demand.
- Energy demand per capita is generally lower in emerging market and developing economies. Many of these countries are still developing their industries, some suffer from a lack of universal access to energy, and most have lower average incomes and levels of ownership of energy consuming equipment than advanced economies. However, the picture is a dynamic one: many countries are undergoing rapid urbanisation, building infrastructure, making swift progress on access to modern energy, and seeing their economies and their demand for energy grow strongly.
- Energy security is a key determinant of energy policies. While energy security is a broad term that includes affordability and supply chain resilience, an often cited metric is import dependence on fuels, notably oil, natural gas and coal. Several large economies are net importers of energy. These include Japan, Korea, European Union, India and China. Others, notably the Middle East, Eurasia, Africa and the United States, are net exporters of energy. A high level of import dependence can act as a spur to boost renewable and nuclear energy, diversify sources of supply and improve energy efficiency.
- This chapter explores energy pathways in different countries and regions. It also includes a deep dive into a pertinent topic for each region. For the United States, Latin America and Africa, we explore themes that focus on the development of domestic resources. For India, Southeast Asia and the Middle East, we explore the strategies and policies being deployed to manage energy demand growth in ways that are aligned with country and regional priorities. For the European Union, Japan and Korea, we explore themes of competitiveness and energy security. We also explore the future of coal demand in China, and prospects for natural gas exports from Russia.

Centre of gravity of energy shifts over time

1972 2024 2050

The infographic traces how select indicators have shifted using the concept of a "centre of gravity", the weighted geographic midpoint of the variables considered. In simple terms, it's the average point on Earth where an activity is centred.

Air conditioner stock

Before 2012, the US led in air conditioner installations; now China leads, with India and the Middle East rising fast.

Total energy demand

The US and EU were the top energy consumers until overtaken by China in 2009. India and Southeast Asia now lead in energy demand growth.

Renewables share in electricity generation

For six decades, Latin America – notably Brazil – led in renewable electricity. The EU is now among the largest, with China and India growing fast.

Oil production

Middle East and Eurasia have historically dominated oil production. The US has surged in recent years to become the leading producer today.

Lack of access to electricity

Until the 2000s, India had most people without electricity; now the challenge lies in Sub-Saharan Africa, notably Nigeria, DR Congo, and Ethiopia.

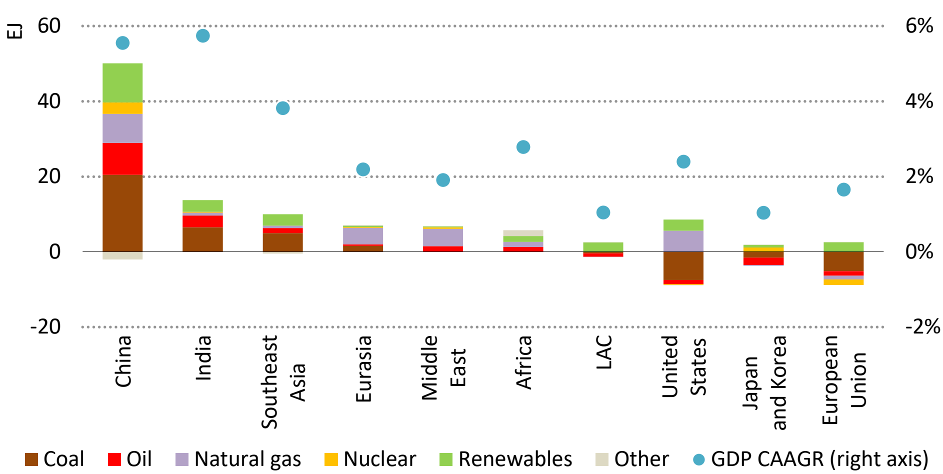
8.1 Introduction

This chapter explores energy sector pathways for countries and regions that together account for nearly 90% of the world's population, gross domestic product (GDP) and energy demand. Key economic, demographic and energy sector metrics vary widely between these regions, reflecting their diverse histories and shaping their future policy priorities. Our analysis traces how regional trends have evolved over time by examining the changes that have taken place across a range of indicators.

China, followed by India, Southeast Asia and the Middle East have been the main engines of growth over the past decade – accounting for over 90% of the increase in global energy demand and nearly 60% of global GDP growth (Figure 8.1). The rise in their energy demand has been driven by increasing industrialisation and urbanisation, plus expanding ownership of appliances and vehicles. There has been a gradual move toward less energy-intensive economic activities in some other regions, along with a focus on improving efficiency. These trends are particularly pronounced in advanced economies, where energy needs have begun to plateau or even decline. For example, energy demand in the European Union in 2024 was about 10% lower than in 2015, even though its economy grew by nearly 20% in this period. There are also lingering impacts from the Covid-19 pandemic, as some sectors – notably industry – did not rebound in some regions.

8

Figure 8.1 ▻ Change in energy demand by fuel and average annual GDP growth rate by region/country, 2015-2024

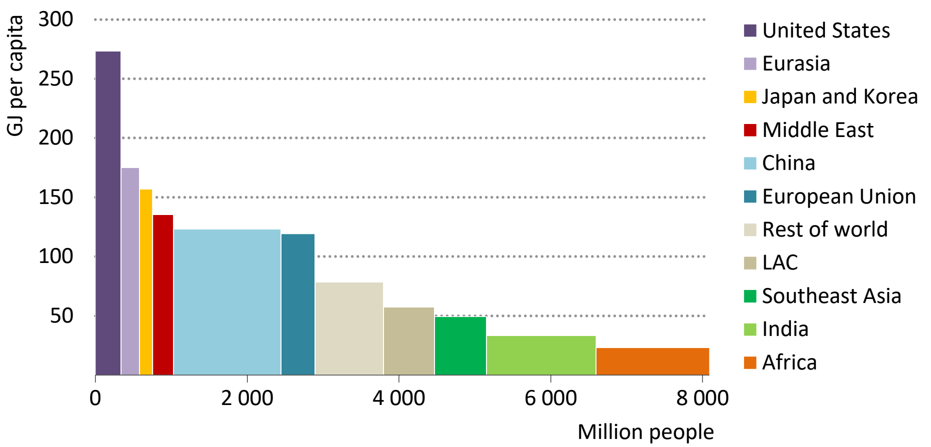


In recent years, energy demand in fast-growing regions – China outpacing all others – was met through a mix of fuels, while advanced economies saw demand stabilise or decline

Notes: EJ = exajoule. LAC = Latin America and the Caribbean. GDP CAAGR = gross domestic product compound average annual growth rate, calculated in year-2024 US dollars at purchasing power parity terms.

The energy landscape looks markedly different when considering per capita energy demand (Figure 8.2). Countries and regions including the United States, parts of Eurasia, advanced Asian economies, and the Middle East have relatively high per capita energy demand as a result of a combination of factors including higher incomes, significant heating or cooling needs, the presence of a large industrial base, and in some cases fossil fuel subsidies. At the other end of the spectrum, per capita demand in Africa remains very low, not least because almost one billion people still lack access to clean cooking and almost 600 million people lack access to electricity, mainly in rural sub-Saharan Africa.

Figure 8.2 ▷ Energy demand per capita and population by region/country, 2024



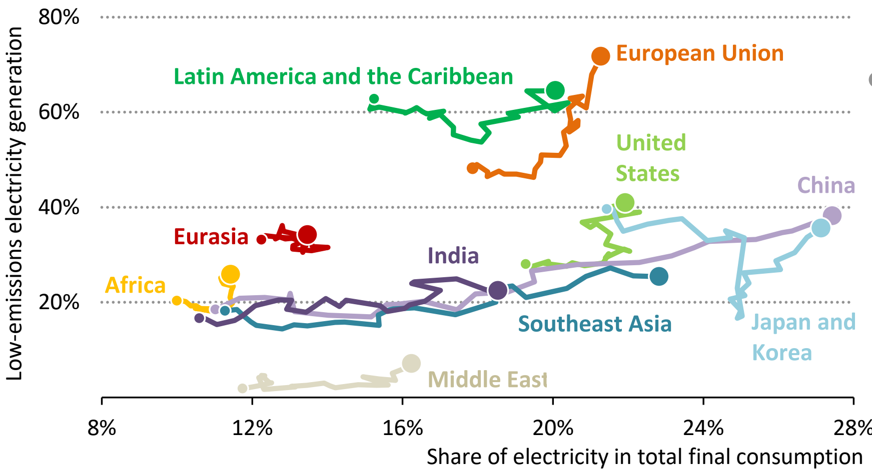
There are wide variations in per capita energy demand across countries and regions

Note: GJ = gigajoule; LAC = Latin America and the Caribbean. Energy demand per capita corresponds to the ratio of total energy demand to population.

Another metric that reveals significant variations across regions is the share of electricity generation accounted for by low-emissions sources, which accounted for 41% of global electricity generation in 2024, of which 32% is from renewables and 9% from nuclear. The European Union (EU) sources over 70% of its electricity from low-emissions sources, of which 48% is renewables and 23% is nuclear. Latin America and the Caribbean (LAC) report an even higher renewable share at 63%, which is mostly hydropower, but nuclear has a much smaller share. At the other end of the scale, today low-emissions sources have a very small share in power generation in the Middle East, where natural gas and oil dominate the generation mix.

The share of electricity in total final consumption is another important metric (Figure 8.3). Japan and Korea long led in this regard, and are now joined by China as the most electrified regions, reflecting the rapid uptake of electricity use in industry, increasing appliance ownership, expanding demand for space cooling and growing electromobility. Similar rapid growth has also been observed in Southeast Asia and India, while shares of electricity are lowest in Africa and Eurasia, where such trends are only beginning to emerge and advancing more gradually.

Figure 8.3 ▷ Electricity in total final consumption and low-emissions sources in electricity generation by region, 2000-2024



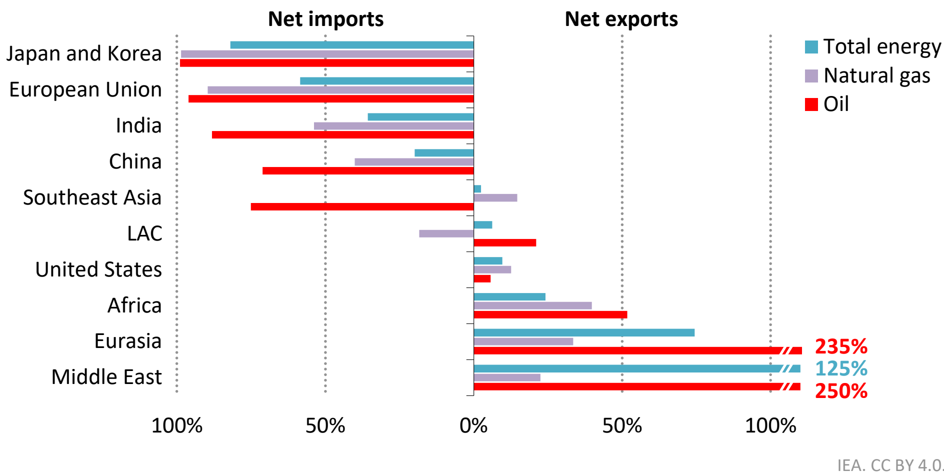
Renewables and nuclear electricity have evolved unevenly across regions since 2000, end-use electrification also varied, growing particularly rapidly in Asian economies

Stark differences in fossil fuel import dependence – often cited as an indicator of energy security – are apparent across the various regions. Today, well over 80% of oil demand in Japan, Korea, European Union and India is met by imports, and the same goes for over 40% of natural gas demand in these regions and China (Figure 8.4). A high level of dependence on imported fossil fuels can spur efforts to boost renewables and nuclear energy, diversify sources of supply and improve energy efficiency.

New national climate commitments known as Nationally Determined Contributions (NDCs) are due in 2025 from the signatories of the Paris Agreement. As of 5 November 2025, 74 parties representing about 55% of global energy-related greenhouse gas (GHG) emissions had submitted new NDCs to the United Nations Framework Convention on Climate Change (UNFCCC) secretariat (Table 8.1). A further 50 countries are due to communicate their NDC before or at the UNFCCC Conference of the Parties (COP) COP30 in Belém, Brazil. The full impact of new NDCs will be reflected in future analysis.

The rest of this chapter takes a closer look at different regions. It explores their outlooks for energy supply and demand, and includes a deep dive for each on a pertinent topic.

Figure 8.4 ▷ Net trade as a share of energy demand by region/country, 2024



Major economies rely on imports for over half of their use of key fuels

Notes: LAC = Latin America and the Caribbean. Intra-regional trade flows are not included in net trade.

Table 8.1 ▷ New Nationally Determined Contributions submitted to the UNFCCC by selected countries

Region/country	Updated commitments
Latin America and the Caribbean	• Brazil aims to reduce its GHG emissions to 0.85-1.05 Gt CO_2-eq in 2035. • Chile aims to cap its GHG emissions at 90 Mt CO_2-eq by 2035.
European Union	• The European Union aims to reduce its GHG emissions to between 66.25% and 72.5% below 1990 levels by 2035.
Africa	• Nigeria aims to reduce its GHG emissions to 29.3% below 2018 levels by 2030 and 32.2% by 2035. • South Africa aims to limit its GHG emissions to 320-380 Mt CO_2-eq by 2035.
Middle East	• United Arab Emirates aims to reduce its GHG emissions to 47% below 2019 levels by 2035.
Eurasia	• Russia aims to limit its GHG emissions to 65-67% of 1990 levels by 2035.
China	• China aims to reduce economy-wide GHG emissions to 7-10% below peak level by 2035, increase the share of non-fossil fuels in primary energy consumption to more than 30% by 2035 and increase its total installed capacity of wind and solar power sixfold above 2020 levels.
Japan	• Japan aims to reduce its GHG emissions by 60% below 2013 levels by 2035 and by 73% by 2040.
Southeast Asia	• Indonesia aims to achieve its peak in GHG emissions by 2030 and reach 1.3-1.5 Gt CO_2-eq in 2035.

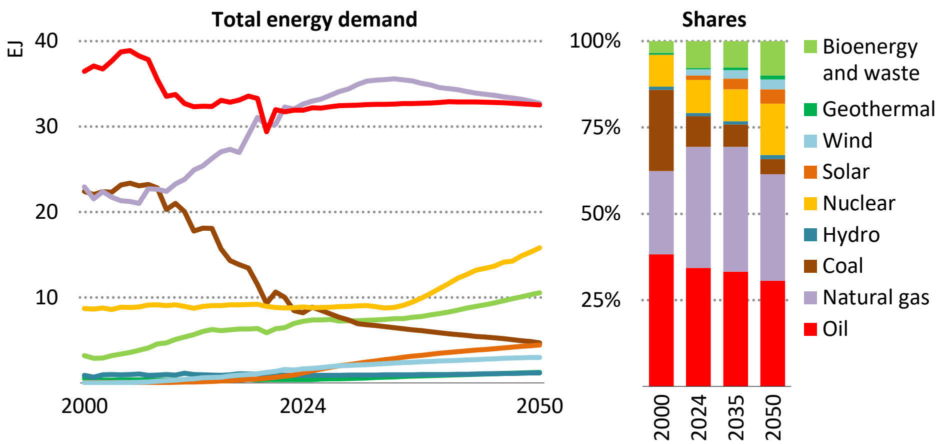
Note: GHG = greenhouse gas; Gt = gigatonnes; CO_2-eq = carbon dioxide-equivalent; Mt = million tonnes.

8.2 United States

8.2.1 Key energy trends

The US energy policy landscape is undergoing significant change. The passage of the One Big Beautiful Bill Act (OBBBA) in 2025 signals a renewed emphasis on domestic energy production – notably coal, nuclear, geothermal, oil and natural gas – and energy infrastructure development. The OBBBA mandates oil and gas lease sales on federal lands and offshore areas; reinstates tax deductions for drilling; and maintains, extends or enhances tax credits for carbon capture technologies, nuclear power, geothermal energy, bioenergy and battery storage. It also accelerates the phase-out of tax credits for wind, solar photovoltaics (PV) and electric vehicles (EVs). These policy changes, along with a series of regulatory, federal staffing, and public funding and financing changes, are re-shaping the US energy landscape.

Figure 8.5 ▷ Total energy demand by source in the United States in the CPS, 2000-2050



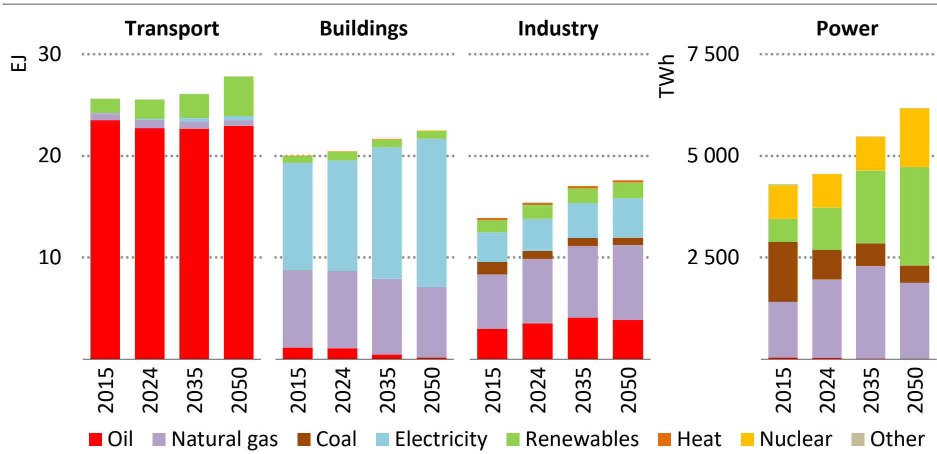
Natural gas demand continues to increase into the 2030s and then declines slightly, coal demand gradually falls, nuclear capacity increases significantly

Note: EJ = exajoule.

In the Current Policies Scenario (CPS), total energy demand in the United States is projected to rise by 0.5% per year to 2035, marking a return to growth after broadly stable demand over the past two decades. Natural gas sees significant growth in demand to 2035 and remains the largest US energy source through to 2050 (Figure 8.5). Oil demand continues to slowly increase in the medium and plateaus in the long term, while coal steadily declines to 2050. Nuclear power remains stable in the near term before a new wave of large reactors and small modular reactors being developed today come online in the 2030s, backed by supportive policies and strong interest from technology firms. This nuclear comeback depends on continuing efforts to develop the workforce and supply chains for construction and fuels. Bioenergy remains the largest renewable energy source through to 2050, while solar PV and wind power continue to expand, albeit more slowly than in recent years.

The power sector and the various end-use sectors in the United States each have a distinct energy mix, but they all see rising energy demand in the CPS (Figure 8.6). In transport, oil remains dominant, accounting for over 80% of total transport energy use each year to 2050. In the buildings sector, electricity continues to play a central role, meeting nearly all new demand and gradually displacing oil use, while natural gas consumption remains broadly stable. However, natural gas does meet the largest share of new demand for data centres (Box 8.1). Industry maintains a diverse fuel mix, with natural gas meeting half of new demand, while oil and electricity use also increase. In the power sector, natural gas demand continues to rise to 2035, and it remains the largest source of electricity generation through to 2050. Demand also increases for a broad array of renewable energy technologies, including next-generation geothermal, bioenergy, hydropower, solar PV and wind.

Figure 8.6 ▷ Total final consumption by sector and fuel, and electricity generation by fuel in the United States in the CPS, 2015-2050



Oil demand in transport stays broadly flat, while natural gas demand rises in the power sector to 2035, and electricity use in buildings – including data centres – grows

Note: EJ = exajoule; TWh = terawatt-hour.

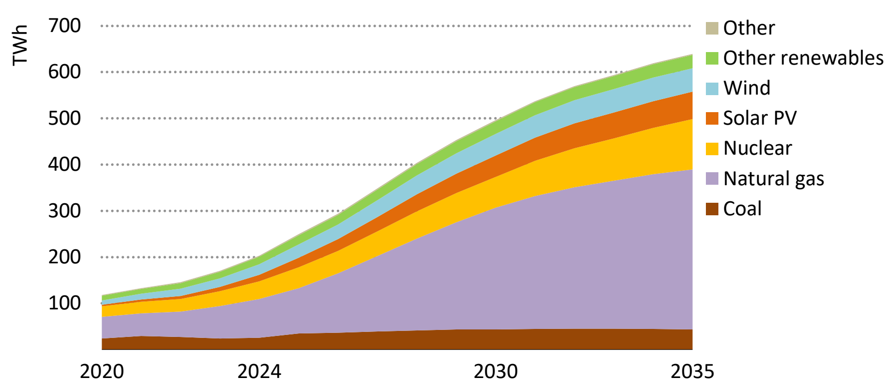
The long-term outlook is inevitably uncertain: it will alter as the policy framework evolves, and as energy stakeholders adapt to that evolution. In the Stated Policies Scenario (STEPS), the US trajectory reflects stronger influence from state-level actions that include, among other things, renewable portfolio standards in the power sector. In this scenario, total energy demand stays broadly stable through to 2035, with limited natural gas growth, a modest decline in oil and a significant reduction in coal use, a continued positive outlook for nuclear, and increasing adoption of renewables, driven in part by the assumed extension of state mandates in the STEPS.

Box 8.1 ▷ Update on electricity supply to power US data centres

The IEA published its first report on Energy and AI in April 2025 (IEA, 2025a). It includes detailed analysis of electricity demand for data centres and examines how electricity supply might meet that demand. Policy changes at the federal level since then have changed the outlook for the US electricity sector, and with it the outlook for electricity supply to power data centres. Taking this into account, we have updated our analysis to reflect the changed policy landscape, and in particular to take account of current plans to phase out tax credits for a number of renewable energy technologies, including solar PV and wind power. Yet, there are three key factors that remain largely unchanged: corporate renewable and other low-emissions energy and net zero emission targets, which many technology companies – including the big four – continue to pursue; state-level renewable portfolio standards; and bottlenecks in the gas turbine supply chain.

Natural gas was the biggest source for electricity to serve data centres in the United States in 2024, accounting for over 40% of supply. Renewables, predominantly solar PV and wind, contributed one-quarter of supply, while nuclear provided around 20% and coal close to 15%. Since nearly all data centres are connected to the grid, these shares essentially mirror the electricity mix of the states where the US data centres are concentrated.

Figure 8.7 ▷ Electricity generation for data centres in the United States in the CPS, 2020-2035



Recent policy changes mean that natural gas dominates the electricity supply for US data centres to 2030 and 2035; renewables and nuclear also contribute significantly

Note: TWh = terawatt-hour.

In the CPS, electricity generation to supply data centres more than triples from around 200 terawatt-hours (TWh) today to 640 TWh by 2035 (Figure 8.7). Natural gas-fired generation increases the most of any source to meet new data centre demand, rising 260 TWh to 2035, much of it before 2030. This increase reflects continued growth for natural gas and is largely achieved by operating existing, grid-connected gas-fired power plants more often. Some developers also plan to co-locate large-scale data centres with new, dedicated natural gas-fired power generators, although constraints in the gas turbine supply chain may delay some of these projects until after 2030.

The second-largest source of additional supply is from wind and solar PV that together increase by approximately 70 TWh by 2035. This is largely due to the growth of wind and solar capacity in states where data centres are located. To meet corporate clean energy targets, some data centre operators are also investing in renewables and signing power purchase agreements for hourly matched renewable electricity. The electricity supplied from other renewable energy sources that can provide baseload electricity also increases by around 13 TWh by 2035. Geothermal, backed by prominent hyper-scalers as a dispatchable source of low-emissions electricity, plays a bigger role, as does hydropower where the focus is on upgrading existing facilities.

Nuclear is the third-largest source of additional electricity supply, particularly after 2030, when several hyper-scalers are expected to commission small modular reactors to provide power direct to new data centres. As a result, nuclear generation for data centres rises by about 70 TWh by 2035. US technology companies already have plans to finance more than 25 gigawatts of small modular reactors, although most of this capacity is not expected to materialise until after 2035.

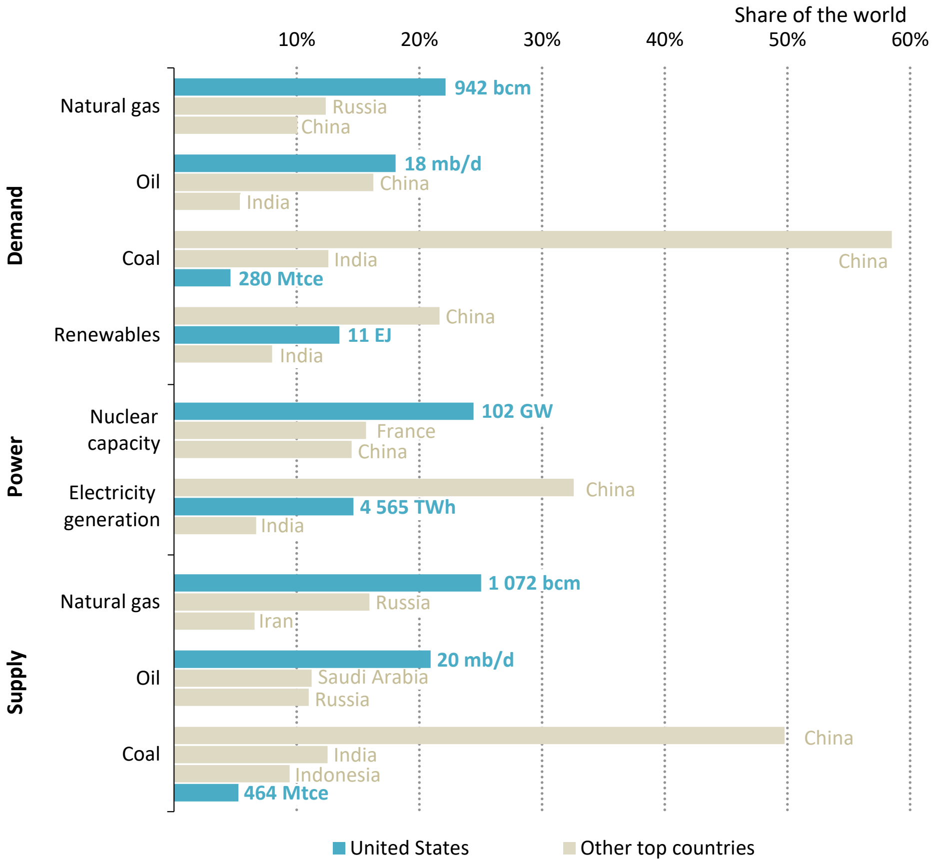
By 2035, natural gas is anticipated to provide over half of the electricity required by data centres in the United States, followed by renewables and nuclear, around 20% each, and coal at 7%.

These projections differ from those in the base case in the April 2025 Energy and AI report on the level of demand: they add nearly 70 TWh of additional annual electricity generation dedicated to data centres by 2035. They also differ on how demand will be met: the supply mix in our revised analysis shows a significant upward revision for natural gas and a downward revision for wind and solar PV, reflecting the changed policy environment with passage of the OBBBA.

8.2.2 What is next for the US energy powerhouse?

The scale of the US economy is reflected in its consumption of energy, with the country ranking first in global terms for both oil and natural gas demand. In 2024, US oil demand accounted for close to 20% of the global total, while natural gas consumption exceeded 940 billion cubic metres (bcm), about 80% more than any other country. The United States ranks third in coal demand. For renewables, the United States ranks second, with major contributions to supply from bioenergy, wind, solar, hydropower and geothermal. The United States is the second-largest generator of electricity in the world: it produces half as much as China but more than twice as much as India, which ranks third. The United States also operates the world's largest nuclear fleet, with over 100 gigawatts (GW) in operation today.

Figure 8.8 ▷ Top countries in fuel demand, power and supply, 2024



The United States leads the world in oil and natural gas production and in nuclear capacity; it is also a major consumer of a wide variety of types of energy

Note: bcm = billion cubic metres; mb/d = million barrels per day; Mtce = million tonnes of coal equivalent; EJ = exajoule; GW = gigawatt; TWh = terawatt-hour.

In recent years, the United States has become the leading producer of both oil and natural gas. Its oil production of 20 million barrels per day (mb/d) is nearly double that of the next largest producer, and its natural gas output accounts for one-quarter of the global total, 60%

higher than the second-ranked country (Figure 8.8). These levels of production have turned the United States into a net exporter of oil and gas, a huge turnaround from past trends, allowing the country to play an increasingly influential role in global energy markets and energy security.

Looking ahead, the United States is set to maintain its position as a global leader in oil and gas production, while expanding the use of other priority technologies such as nuclear. Against the background of the support for domestic oil and gas production provided by the OBBBA and other new federal policies, oil output rises by around 0.1 mb/d per year to 2035 in the CPS, outpacing domestic demand and increasing net exports by 0.5 mb/d. Natural gas production also expands steadily, exceeding demand growth, boosting net exports by over 130 bcm and cementing the position of the United States as the largest gas exporter globally. Coal production continues to decline from its 2022 peak, although enough is still produced to meet all domestic demand. The United States remains the largest global producer and consumer of oil and natural gas through to 2035 in both the CPS and the STEPS.

The OBBBA also spurs the expansion of a number of domestic energy technologies. Nuclear power is poised for renewed growth, supported by continued tax credits, increased financing and the removal or reduction of regulatory barriers. In the CPS, nuclear capacity remains stable to 2030 before increasing by one-third to 2040 and more than 80% by 2050. Despite this growth, China catches up the United States in nuclear capacity around 2030 and takes the lead through to 2050. Renewable energy capacity grows by two-thirds to 2035, with geothermal energy increasing by 75% in the CPS from a small base, supported by tax incentives and accelerated permitting, for its use in both electricity generation and direct heat applications. Biofuels remain part of the energy mix, with continued federal support focused on domestic resources, and more limited incentives for sustainable aviation fuel. The use of biofuels increases by 6% to 2035 in the CPS.

There is increasing recognition in the United States that resilient critical mineral supply chains are vital for energy technologies, industrial competitiveness and national security. The country is ramping up efforts to build diversified supply chains through public financing, industrial policy measures and strategic partnerships. The US Department of Energy and the Department of Defense have extended major financial support to domestic projects, including lithium and rare earth processing facilities, through the Defense Production Act and loan programmes. In early 2025, the US Export-Import Bank launched a new financing tool, the Supply Chain Resiliency Initiative, to provide targeted financing for critical mineral projects, and an Executive Order directed the Department of Defense and the US International Development Finance Corporation to establish a dedicated investment fund. Public-private partnerships are also scaling up, exemplified by a transformational deal between MP Materials, a leading rare earth producer in the United States, and the Department of Defense that involves large-scale financing support, long-term offtake and price floor commitments. These moves underscore the US ambition to play a leading role in shaping the future global critical minerals landscape.

8.3 Latin America and the Caribbean

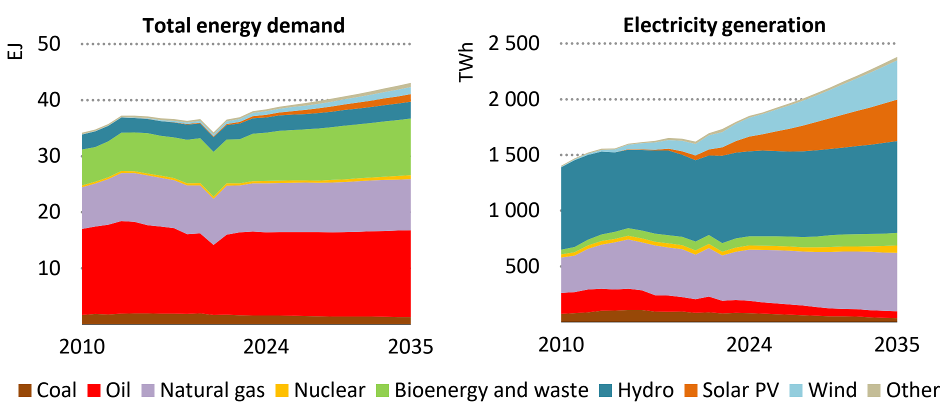
8.3.1 Key energy trends

The Latin America and the Caribbean (LAC) region has significant untapped energy resource potential ranging from solar and wind to oil, biofuels and critical minerals. Climate resilience is a pressing issue as the region faces ever more extreme weather events and the power outages and other disruptions that accompany them. In November 2025, Brazil hosts COP30 with the aim of accelerating efforts to implement climate pledges.

Around 65% of electricity in LAC is from renewables – more than in any other region – and the share of renewables in electricity generation is poised to expand further. In Brazil, the share has already reached nearly 90% thanks in large part to hydropower, while the proportion of electricity generated from wind and solar power in Chile and Uruguay is among the highest in the world. In 2010, around 40% of its capacity additions were renewables; in 2024 this share reached 90%, well above the global average of around 80%. The trend continues in the STEPS, with solar accounting for over 45% of new capacity from 2025 to 2035 (Figure 8.9). As a result, the share of renewables in power generation is around 70% by 2035, while the share of renewables in total energy supply rises from 30% to over 35%. Rapid growth in solar and wind is changing the power sector dynamics, with both Chile and Brazil having to curtail these sources at times in 2024 to balance the power grids. Further investment in high functioning grids is needed to support its evolving power mix.

8

Figure 8.9 ▷ Total energy demand and electricity generation in Latin America and the Caribbean in the STEPS, 2010-2035



Relatively high shares of renewables in power generation and bioenergy in industry and transport put the share of fossil fuels in the energy mix much lower than the global average

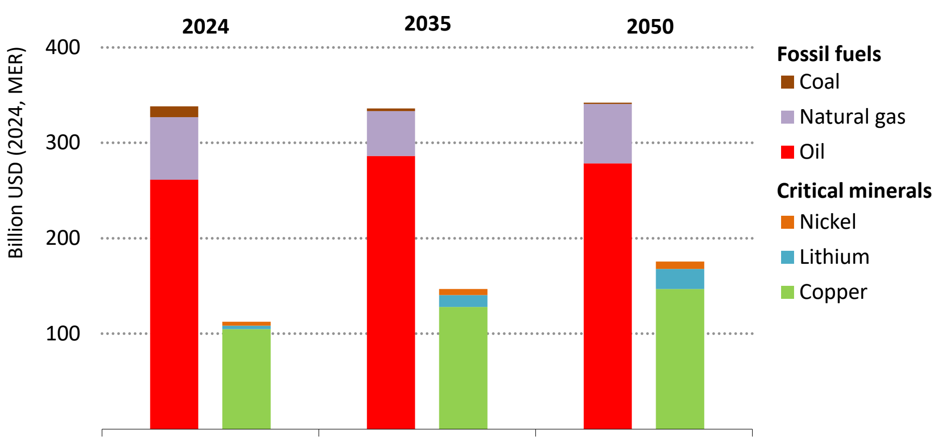
Notes: EJ = exajoule; TWh = terawatt-hour. Other includes geothermal and solar thermal.

Government incentives and competitively priced electric vehicles from China are boosting EV sales particularly in Brazil, Costa Rica, Uruguay and Colombia. Sales more than doubled in Brazil in 2024, with EVs from China accounting for 85% of the total. Chile and Colombia have some of the largest electric bus fleets globally, and close to 8% of buses sold in Mexico in 2024 were electric. In the STEPS, existing policies and industry projects mean that nearly 25% of vehicles sold in the region are electric by 2035. Despite this, oil remains the largest source of energy used in LAC in the STEPS, largely due to the transport sector.

The LAC region includes countries that are significant oil and gas exporters. The value of fossil fuel production remains broadly constant in the STEPS, with contrasting underlying trends. Oil production increases in Brazil, Guyana and Argentina, while it falls in Mexico, Venezuela and Ecuador. Argentina is the only country to see significant growth in natural gas production by 2035. Coal production decreases by around 65% by 2035, mostly due to lower output in Colombia.

The LAC region includes countries that are important producers and exporters of critical minerals, accounting for around one-third of the global market in 2024. Chile is the world's largest producer of copper and Peru is the third-largest. The region also includes the lithium triangle of Argentina, Bolivia and Chile. Argentina doubled its lithium production from 2022 to 2024. LAC is rich in other critical minerals too, including rare earths and nickel. Revenue from production of critical minerals rises in the STEPS (Figure 8.10). Expanding the capacity to process and refine extracted ores could boost local economies and help diversify global supply chains.

Figure 8.10 ▷ Production value of fossil fuels and critical minerals in LAC in the STEPS, 2024, 2035 and 2050



Critical minerals production is set to drive growth in the extractive industries

Note: MER = market exchange rate; LAC = Latin America and the Caribbean.

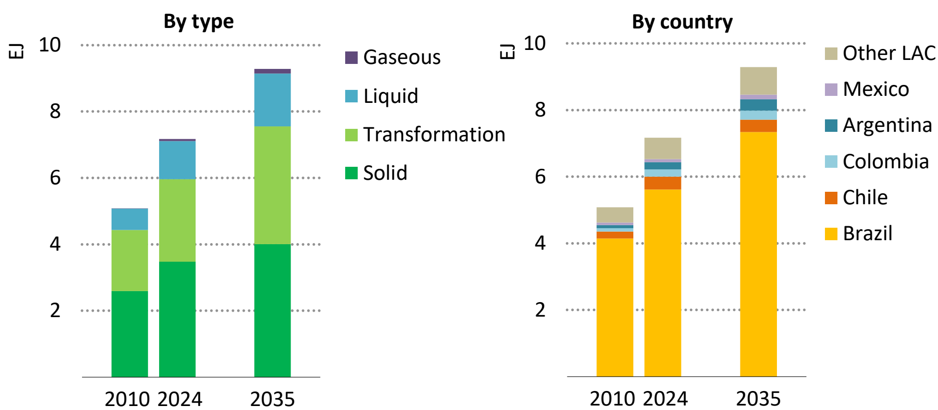
8.3.2 Prospects for bioenergy in Latin America and the Caribbean

The LAC region is a leader in bioenergy, which provided around one-fifth of its energy demand in 2024. Nearly 85% was from modern bioenergy. Solid modern bioenergy is its leading source of bioenergy, and is mostly used for light industry manufacturing activities such as food production. Robust bioenergy sustainability standards have an important part to play to limit the extent and impact of land-use change and to minimise methane emissions. Not all the bioenergy used in the region is modern. Despite progress in some countries, there are still nearly 70 million people in the region that rely on the traditional use of biomass for cooking and heating.

About one-quarter of global liquid biofuels were produced in the LAC in 2024. Biofuels account for over 10% of energy consumption in transport, compared to a global average below 5%. In response to the 1973 oil crisis, Brazil introduced the Pró-Álcool programme to produce bioethanol to reduce reliance on gasoline imports and bolster domestic supply security. Around 85% of the car fleet in Brazil today consists of flex fuel vehicles that can operate with high levels of ethanol blending: Brazil is the largest producer and consumer of biofuels in the region, and the second-largest producer of liquid biofuels worldwide. Argentina and Colombia are emerging as prominent suppliers.

In the STEPS, modern bioenergy use increases by around 30% by 2035, helping to meet a growing share of energy demand (Figure 8.11). Biofuel mandates in Argentina, Brazil and Colombia increase the share of modern bioenergy in their overall energy supply mixes: use of liquid biofuels ramps up significantly, and in relative terms, so does the use of biogases.

Figure 8.11 ▷ Modern bioenergy use by type and country in Latin America and the Caribbean in the STEPS, 2010-2035



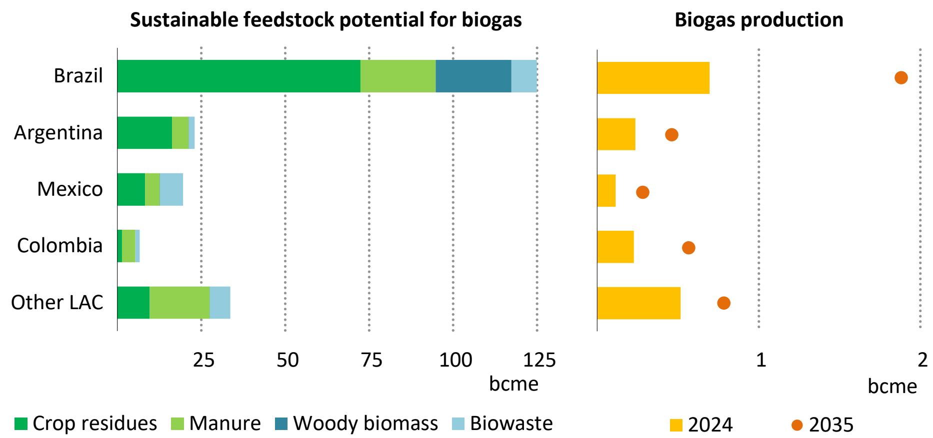
Brazil leads the expansion of modern bioenergy in the region and is among global leaders

Notes: EJ = exajoule. Transformation is energy loss from converting from primary solid bioenergy into usable final forms. Other LAC = Other countries in Latin America and the Caribbean.

There is also scope to ramp up biogas production. Brazil has the largest potential for biogas supply in the world, but its annual production remains relatively small, around 0.7 billion cubic metres of natural gas equivalent (bcme). Most of its biogas production is from landfill sites, but there is potential to make use of vinasse, which is a by-product from the ethanol industry, and to step up use of sustainable feedstocks such as crop residues and animal manure that remain largely untapped (Figure 8.12).The quota obligations in the new Fuel of the Future law in Brazil are likely to stimulate growth in biogas production.

In addition to its energy value, biogas production offers several co-benefits. Digestate, a nutrient-rich by-product of biogas production, can be used as a fertiliser, while upgrading biogas to biomethane produces a pure stream of biogenic carbon dioxide (CO_2) which can be captured and stored, or used in industry such as food and beverage production.

Figure 8.12 ▷ Sustainable feedstock potential and biogas production by source and country in LAC in the STEPS, 2024-2035



Biogas production is set to significantly increase, yet much feedstock potential remains untapped in 2035

Note: bcme = billion cubic metres of natural gas equivalent; LAC = Latin America and the Caribbean; Other LAC = Other countries in LAC.

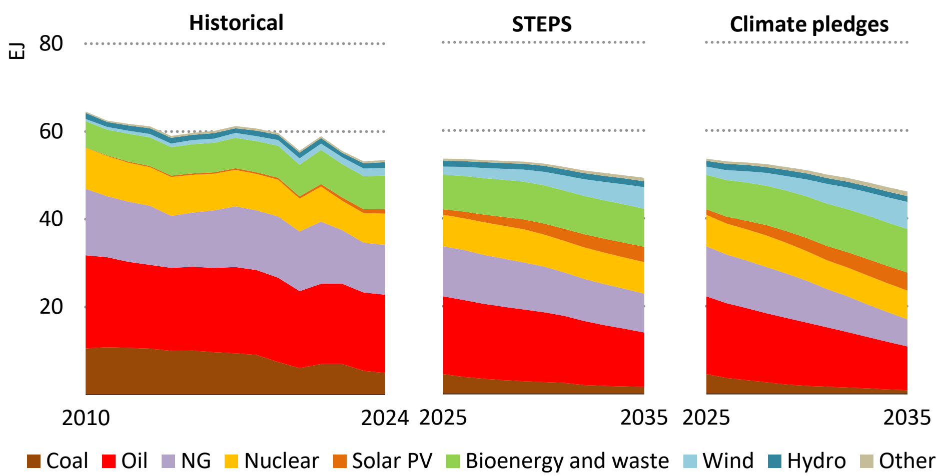
The average cost of producing biomethane in the region is around USD 23 per gigajoule (GJ), which is somewhat higher than end-user prices for natural gas in most LAC countries. Incentives for biomethane production could create new jobs, improve waste management and reduce the need to import natural gas. Improving access to infrastructure such as natural gas networks could help increase demand by broadening the potential market for biomethane. In Brazil, the Special Incentive Regime for Infrastructure Development already includes biomethane within the types of projects eligible for tax exemptions for materials and equipment.

8.4 European Union

8.4.1 Key energy trends

The European Union has ambitious energy and climate targets for 2030 which include a net reduction of 55% in GHG emissions, deployment of 600 GW of new solar PV, and a reduction in total final consumption of 11.7% compared with the levels in the European Commission EU Reference Scenario 2020. These targets aim to meet EU climate goals as well as to improve energy security and competitiveness by reducing dependence on expensive imported fossil fuels. The downside risks of such dependence were underscored in the aftermath of Russia's full-scale invasion of Ukraine when natural gas pipeline deliveries from Russia were cut, sparking an energy crisis. Despite government support for energy bills waning, average residential energy prices in the European Union have fallen slightly since the crisis, but they remain over 20% above their 2010-2019 average.

Figure 8.13 ▷ Energy demand by source in the STEPS and with climate pledges in the European Union, 2010-2035



Although fossil fuels decline in the STEPS, faster gains in efficiency and renewables deployment are needed to meet climate pledges

Notes: EJ = exajoule; NG = Natural gas. Other includes geothermal, marine and solar thermal. The climate pledges pathway outlines a trajectory towards the European Union achieving its long-term climate goals.

EU plans for a clean energy transition are predicated on developing cost-competitive sources of clean energy that reduce the share of fossil fuels in total final consumption. The power sector makes the biggest contribution to this goal as the share of renewables in the generation mix rises, with coal demand in 2035 falling to nearly one-ninth of today's level in the STEPS, and natural gas demand falling by over 40 bcm. Gas demand declines by 14% by 2035 in the buildings sector as more heat pumps are installed, and by 12% in the industry sector as efficiency improves. Oil demand declines as well, with the uptake of EVs cutting demand by close to 2 mbd/year in the STEPS by 2035. Meeting the EU long-term climate pledge to achieve carbon neutrality by 2050 requires a further 25% reduction in the use of fossil fuels from the level projected in the STEPS in 2035 (Figure 8.13).

The European Union decarbonisation trajectory relies heavily on its electricity system. Its system is interconnected and strong, but has faced some recent setbacks, including a blackout on the Iberian Peninsula (Box 8.2). The share of fossil fuels in generation dropped below 30% in 2024, below the combined share of solar PV and wind, and there has been a uptick in support for nuclear power in several EU member states: Belgium voted to keep its reactors online and to allow the construction of new ones; France plans to provide a loan to cover at least half of the construction costs for six nuclear reactors; and Italy announced plans to consider the reintroduction of nuclear power. In the STEPS, electricity generation increases by 40% and its share of final consumption by nine percentage points from the current level by 2035. Energy storage, market reform and grid expansion are needed to support the transition in the EU electricity sector. In the STEPS, grid investment almost doubles by 2035 compared to today. These investments have the potential to accelerate renewables integration and affordability for end-users, though consumers face very different electricity prices, depending on their country. For example, the average German household paid almost four-times higher electricity prices than the average Hungarian household in the second-half of 2024, driven by different market fundamentals, policies and subsidy levels.

The new EU NDC targets a cut of 66.25-72.5% in GHG emissions from 1990 levels by 2035, in line with the goal of a 90% reduction below 1990 levels by 2040, agreed by EU Environment Ministers in November 2025. In addition to measures to increase the electrification of end-uses, boost the share of low-emissions fuels in the power sector and improve efficiency, deep decarbonisation also requires making meaningful inroads into hard-to-abate sectors such as energy-intensive industry. Success will depend on the effectiveness of emerging strategies: for instance, in 2025 the European Union announced an intention to mobilise EUR 100 billion (USD 108 billion) to support industry decarbonisation as part of its Clean Industrial Deal. This funding can be used to support novel mechanisms, like the planned EUR 1 billion (USD 1.1 billion) EU-wide fixed premium auction related to decarbonising industrial process heat and is in addition to funding from individual member states, like the EUR 4 billion (USD 4.3 billion) allocated to carbon contracts for difference in Germany.

Box 8.2 ▹ Iberian blackout: lessons learned

On 28 April 2025, the Iberian Peninsula suffered a widespread blackout that interrupted electricity supply across Spain, Portugal and parts of southern France, affecting over 50 million people. According to the ENTSO-E factual report, the event was triggered by a rapid sequence of technical failures (ENTSO-E, 2025). In the minutes before the blackout, the electricity system became unstable, with unusual swings in voltage and power flows. This instability was followed by a sharp rise in voltage as generators that had been absorbing reactive power were erroneously shut down by protection systems, even though voltage levels had not yet exceeded thresholds defined by regulation. As more plants disconnected, the voltage rose further, leading to a cascade of additional shutdowns. Hundreds of megawatts (MW) of smaller, distributed sources switched off unexpectedly, making it even more difficult for system operators to respond. Ultimately, the Iberian system was disconnected from the rest of Europe, and automatic safety systems could not prevent a complete collapse. Following the outage, the Spanish and Portuguese system operators, working with neighbouring system operators, moved to restore supply using black-start hydropower, thermal plants and imports from France. By the early morning of 29 April, all transmission substations were energised, and nearly all demand was met.

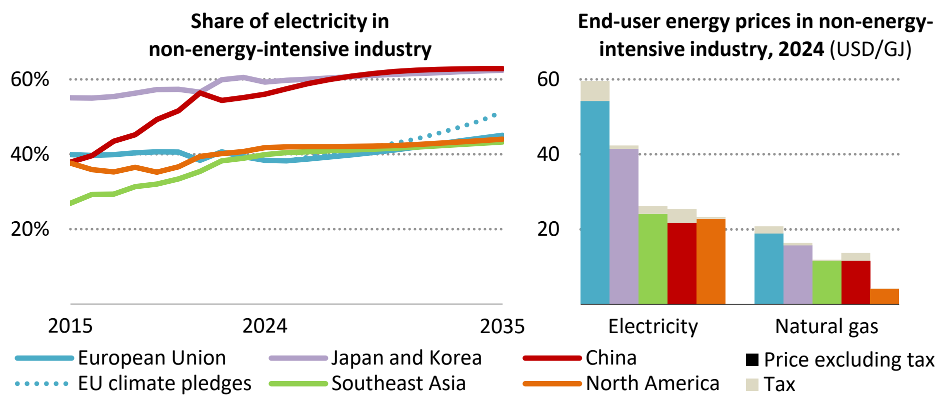
The incident demonstrates that electricity security in modern power systems depends not only on generation but also on the quality of grid operation and the behaviour of all connected assets. This highlights the need for enforceable rules that require all generators to support the system during emergencies and to disconnect only if clearly defined thresholds are breached. Preparedness remains essential. The rapid restoration of power in the Iberian Peninsula was made possible by strong interconnections with neighbouring countries, robust emergency protocols and available black-start capability. Maintaining and strengthening these capabilities is crucial.

The heightened international attention brought by the blackout provides an opportunity to revisit some common elements of electricity security and resilience as power systems evolve. While electricity systems and market structures differ from country to country, IEA analysis has identified four critical pillars that are necessary in every case (IEA, 2025b). First, robust grid infrastructure is vital, including strong networks and regional interconnections, as it provides the backbone for secure operations. Second, power system flexibility is essential to balance supply and demand, which includes demand-side response, storage and the maintenance of dispatchable generation, as well as measures to ensure that markets appropriately value these services. Third, technical solutions, such as synchronous condensers or batteries equipped with grid-forming inverters, are needed to support system stability as the generation mix evolves. Forth, it is crucial to adapt operational frameworks as power systems transform by updating grid codes, reserve requirements, balancing mechanisms and regulatory structures to keep pace with new challenges and technologies.

8.4.2 How can industrial heat pumps deliver competitiveness and decarbonisation?

Improving competitiveness is central to EU economic growth. Non-energy-intensive industries play an important role: while they consume 30% of energy in industry, they account for around 80% of the value it adds to the economy. Electrification in non-energy-intensive industries in the European Union has flatlined since 2015 at similar levels to the United States, and at much lower levels than major industrial hubs in Asia (Figure 8.14). Industrial heat pumps (IHPs) are a key technology for electrification of low and medium temperature processes: they use one-third to one-fifth of the energy of conventional boilers and do not rely directly on fossil fuels. Using IHPs for electrification is an effective way to decarbonise, improve competitiveness, and reduce import dependence (the region imports over 90% of its oil and almost 85% of its natural gas). The EU Industrial Clean Deal recognises the importance of electrification, aiming to raise the economy-wide electrification rate to 32% by 2030.

Figure 8.14 ▷ Electrification and end-user prices in non-energy-intensive industry in selected regions in the STEPS, 2015-2035



IEA. CC BY 4.0.

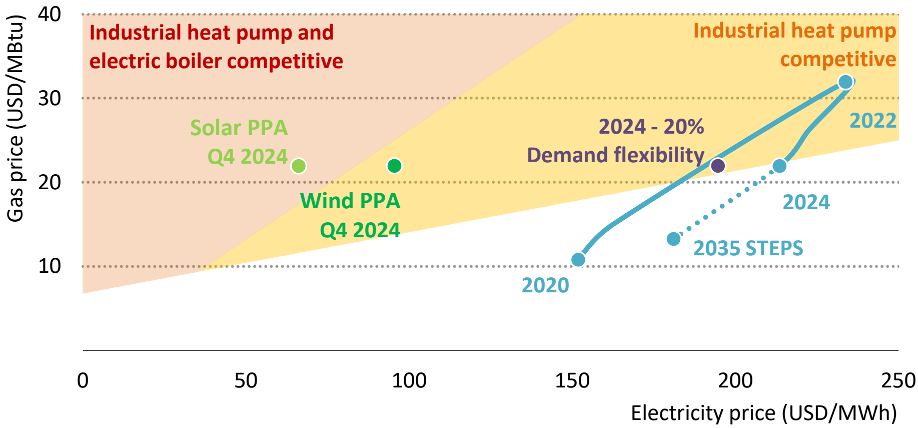
Despite importing most of its fossil fuels, the EU has seen the share of electrification in non-energy-intensive industries flatline; to meet climate pledges, this share needs to increase

Notes: USD/GJ = US dollar per gigajoule. The EU climate pledges pathway outlines a trajectory towards the European Union achieving its long-term climate goals.

Low electricity prices help drive electrification, but current prices are both volatile and high by historical standards. Natural gas set the day-ahead wholesale electricity price around 60% of the time, despite generating only 20% of electricity in 2022 (European Commission, 2024). Moreover, electricity taxes in most EU member states are high relative to gas and to other regions. Despite these hurdles, IHPs are competitive with gas based on current EU average industry end-use prices; regional price variation makes the advantage stronger in some member states than others (Figure 8.15). The superior efficiency of IHPs relative to gas boilers translates into lower operating costs which can mean lower lifetime costs, even though IHPs involve higher upfront capital expenditure. Industrial consumers with IHPs can reduce exposure to price volatility by using a power purchase agreement or reduce costs by curtailing heat production when prices are high, provided that suitable demand-side flexibility mechanisms are in place.

Electric boilers, which are less efficient than IHPs, could also be competitive if used flexibly because they require comparatively little upfront capital spending. Flexibility could be achieved through the use of thermal storage or by electrifying only part of a fleet of gas boilers, which could also reduce grid connection costs by lowering the required connection capacity. Using electricity flexibly opens new opportunities, including to accrue secondary revenue from ancillary services, and the chance to exploit negative wholesale prices, which are increasingly common in some EU markets: for example, they applied for almost 10% of the time in Finland in 2024.

Figure 8.15 ▷ Competitiveness of electrification routes compared to average end-user prices for industrial consumers in the Europe Union



Since 2022, electricity has been an economical source of heat for industry compared to gas, yet heat pump installation remains at a low level

Notes: MBtu = million British thermal unit; MWh = megawatt-hours; PPA = power purchase agreement; Q4 = fourth quarter. PPA price shown reflects the EU-wide average of deals, not including transmission or distribution charges. The coefficient of performance for the industrial heat pump is 3.5. Demand flexibility of 20% requires curtailing electric heating during the 20% of hours with the highest power price.

Despite their cost effectiveness in recent years, IHPs have made limited progress. High initial capital outlays which take a long time to recoup are a major barrier. IHP installation may also require facilities to reconfigure service utilities, further increasing cost and complexity. Policy can help ameliorate these challenges: the carbon contracts for difference auction by the German government in 2024 was mainly won by electrification projects, and industrial electricity prices may fall further there under a plan to subsidise electricity bills for industry. There are also examples from further afield that could serve as a blueprint for the European Union. In New Zealand, where policy has underpinned growth in IHPs, about one-quarter of the potential has been captured: assistance was provided to help with upfront costs, and a support programme addressed concerns about engineering expertise.

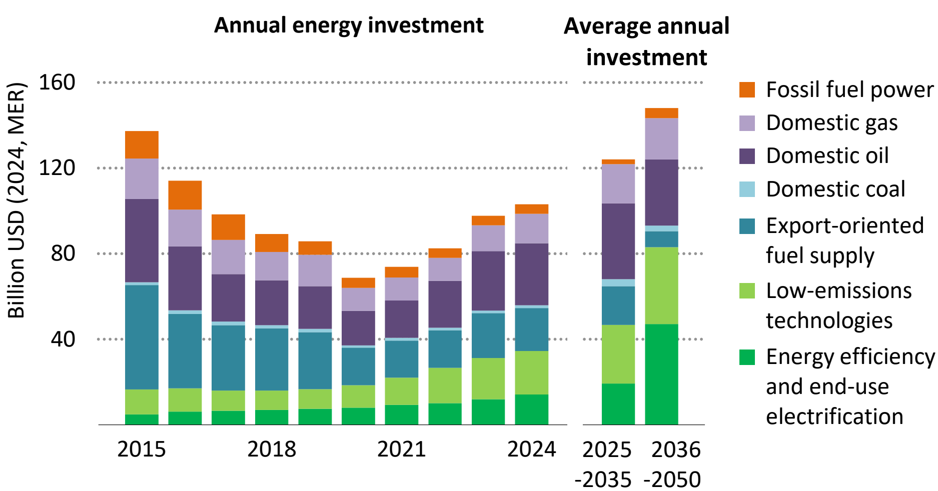
Spot prices for natural gas are not the only factor affecting electrification: energy security plays a key role. Motivated by energy security considerations as well climate goals, the European Union has a target for renewables to provide at least 42.5% of the energy mix by 2030, and in tandem its action plan for grids aims to add 64 GW of cross-border transmission between 2025 and 2030. These plans indicate a strong commitment to electricity security, and are likely to boost electrification, including the adoption of IHPs.

8.5 Africa

8.5.1 Key energy trends

Securing investment to expand domestic energy provision is a primary energy challenge in Africa. Over the last decade financing fell for export-oriented oil and gas projects, but investment rebounded since 2021, led by increases in spending on domestic energy infrastructure, especially in the power sector. This trend continues in the STEPS, with total energy investment by 2035 returning close to highs last seen in 2015 (Figure 8.16). However, investment levels in the STEPS still fall short of meeting basic energy needs. Chapter 6 explores what it would take to achieve universal access to modern energy in Africa by 2040, including the implications for investment.

Figure 8.16 ▷ Energy investment by target area in Africa, 2015-2024, and in the STEPS to 2050



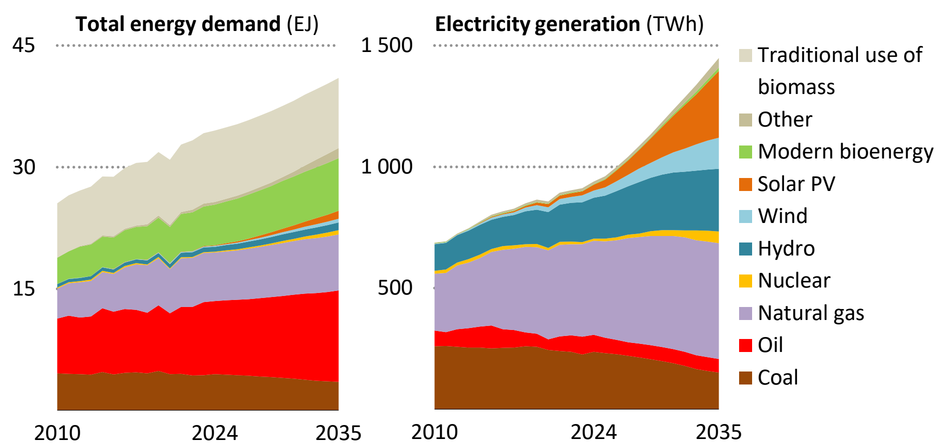
Energy investment fell after 2015 as oil and gas projects slowed, though it has rebound since 2021with domestic energy developments and new oil and gas projects

Note: MER = market exchange rate.

Efforts to progress modern energy access are gaining renewed momentum. The majority of Africans without access live in countries that have introduced new policies since 2024. Accordingly, the number of people gaining access to clean cooking by 2035 accelerates to 24 million per year in the STEPS, and begins to outpace population growth by 2030. Liquefied petroleum gas (LPG) plays the biggest role to extend access for cooking, with an increase in demand of 150 thousand barrels per day (kb/d) by 2035. Around 20 million people per year gain access to electricity to 2035 in the STEPS – a rate of progress 25% higher than in the 2010s.

Meeting rising electricity demand requires a major expansion of power systems in Africa. An average of 24 GW of new capacity is added each year to 2035 in the STEPS, which is double the rate seen over the past decade. More than 70% of these additions are renewables, with solar PV alone accounting for half. Solar PV is the cheapest new source of electricity in most African countries, and its expansion is further aided by a sharp increase in solar panel imports from China as excess PV panel manufacturers cultivate new markets. Solar PV overtakes hydropower as the second-largest electricity source by 2035 (Figure 8.17). Natural gas remains the largest source of electricity, helping to support grid reliability in sub-Saharan Africa. Coal continues to contribute to the generation mix, and nuclear power development gains momentum. In Egypt, the El Dabaa plant – North Africa's first nuclear power facility – is expected to reach full capacity by 2030. Many African countries have plans to diversify their generation mix, and these have been given added impetus by the recent crippling hydropower shortages. Grid networks expand in the STEPS, with an average of 190 000 kilometres (km) added each year to 2035, a 40% increase from the current level.

Figure 8.17 ▷ Total energy demand and electricity generation by source in Africa in the STEPS, 2010-2035



Energy demand rises and access to modern energy improves; electricity generation accelerates with recent positive trends in investment, with solar PV in the lead

Notes: EJ = exajoule; TWh = terawatt-hour. Other includes geothermal and solar thermal.

Africa sees an uptick in oil and gas investment activity in the STEPS. Incumbent oil producers such as Libya, Algeria and Nigeria see production remain broadly flat against a backdrop of higher OPEC+ production allowances; new exporters such as Uganda and Senegal are coming online; and Namibia begins adding barrels in the mid-2030s. The net result is that oil production in Africa remains broadly stable to 2035, accounting for 7-8% of the global total. Meanwhile natural gas production rises from 240 bcm in 2024 to around 260 bcm by 2035, when it accounts for over 5% of the global total. Production in Algeria and Egypt remains stable or slightly declines, but it almost doubles in Mozambique, rising to over 20 bcm: most of the increase comes from its offshore liquefied natural gas (LNG) projects.

8.5.2 Opportunities to step up the mineral supply chain in Africa

Africa holds 80% of global reserves of platinum-group metals and phosphate, over 55% of cobalt and chromium reserves, at least 25% of global reserves of manganese, bauxite and graphite, 20% of uranium and 10% of copper reserves. These minerals are critically important for a variety of energy technologies and for other industries. This geological wealth offers a path for African countries to move beyond their historical role as exporters of raw materials. Today, however, most of the mineral resources are exported directly as ore or in semi-processed forms to be refined overseas. For instance, the Democratic Republic of the Congo (DRC) accounted for two-thirds of global mined production of cobalt in 2024, but nearly all its output is exported with minimal processing: most of it goes to China, where it is refined into battery-grade material. This pattern is replicated across many other minerals, with few exceptions.

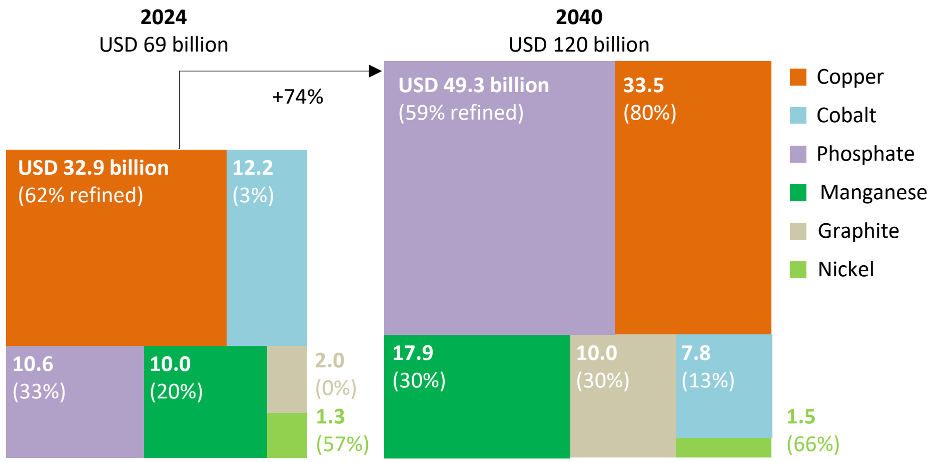
Some countries have decided to encourage domestic value added by following the example of Indonesia and prohibiting the export of unprocessed ores. For example, Zimbabwe introduced tighter controls on lithium extraction and exports in 2023, and in May 2025 Gabon announced its intention to ban the export of raw manganese ore from January 2029. Whatever the policy intention, the effectiveness of export bans is highly contingent on specific national and market conditions, and few countries have the market power to make this an effective strategy.

Moving successfully into downstream activities to increase the economic value of mineral resource endowments depends on the development of cost-effective local processing capabilities. Moving from raw ore to processed outputs captures a large part of the value added in the mineral supply chain, and stepping up the value chain in this way can be a catalyst for a virtuous cycle of industrialisation that results in higher value exports, additional skilled employment and lasting economic resilience. A domestic mineral processing industry can also stimulate investment in local energy infrastructure to meet the demand it creates.

If the enabling factors are favourable and policy and investment frameworks are in place, Africa could play a key role in the global supply of concentrates and refined minerals. To demonstrate this potential, we considered a representative portfolio of Africa's resource endowments: copper, cobalt, graphite, nickel, manganese and phosphate. The DRC and Zambia hold substantial copper and cobalt resources: refined copper is an essential component for many energy technologies and the broader economy, while battery-grade cobalt is used in the cathodes of nickel manganese cobalt (NMC) type lithium-ion batteries. NMC batteries also require refined manganese and nickel, and these metals are produced in South Africa, Gabon and Madagascar. Morocco could leverage its vast phosphate reserves to expand production of purified phosphoric acid, which is a key input for lithium-iron phosphate (LFP) batteries. Similarly, the graphite mined in Mozambique and Madagascar could be upgraded into spherical graphite, the processed anode material required for nearly all types of lithium-ion batteries.

We examined plausible pathways to increase domestic refining of the various minerals. Some 60% of its mined copper is already refined in Africa, which produced 9% of global refined copper output in 2024, and this could be increased to 80% by 2040 (Figure 8.18). Similarly, about 55% of its nickel production is refined in Africa today, though the overall volume remains small. This could rise to over 65% in 2040, boosting its market value by around 10% even as mine output remains stable. In the case of cobalt, refining in Africa could increase from 3% of mined output today to 13% in 2040, increasing refined output by 2.5-times to 16 thousand tonnes (kt). Battery-grade graphite production could rise from today's very low levels to reach 130 kt in 2040.

Figure 8.18 ⊳ Market value of selected minerals and share of minerals refined in Africa in 2024 and potential in 2040



If domestic refining is strategically scaled up, the combined market value of key minerals could increase by three-quarters between today and 2040 to reach USD 120 billion

Notes: Values in 2024 US dollars (USD). Percentage refined indicates volume share of mine output that is refined in Africa. Refined phosphate expressed in P_2O_5 content. Graphite refers to battery-grade spherical graphite.

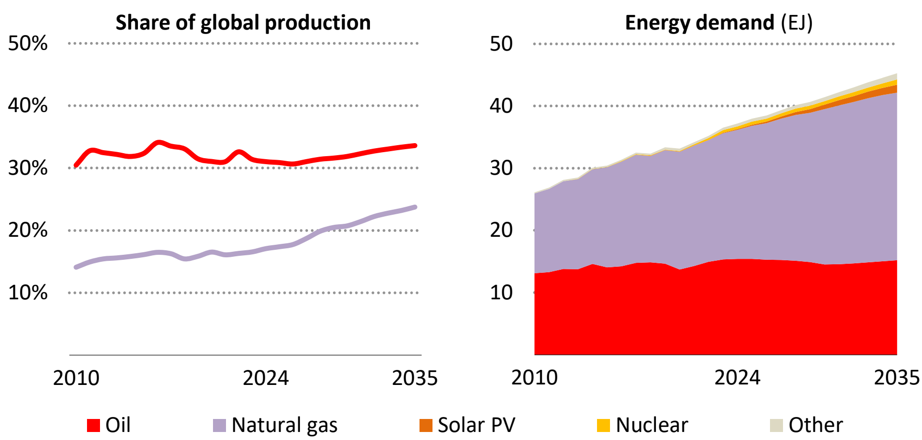
At current price levels, the result would be to increase the total market value of these minerals by nearly three-quarters from around USD 70 billion today to USD 120 billion in 2040. This takes account of projected changes in mined output, which declines in some cases, as well as the proportion of ore that is already refined in Africa. Refined phosphate could account for an additional USD 39 billion of value in 2040 compared to 2024. Refined cobalt could increase in value by more than USD 300 million, though this would not fully offset the decrease in mined production. (Further details can be found in the recently published report Stepping Up the Value Chain in Africa: Minerals, materials and manufacturing (IEA, 2025c) developed by the IEA as an input to G20 discussions in South Africa.)

8.6 Middle East

8.6.1 Key energy trends

The Middle East is a major producer and consumer of energy. It contains five of the world's top-ten oil producing countries, i.e. Saudi Arabia, Iran, Iraq, United Arab Emirates and Kuwait, and three of the top-ten natural gas producers, i.e. Iran, Qatar and Saudi Arabia (Figure 8.19). Oil production by OPEC+ countries, seven of which are in the Middle East, has increased since the start of 2025 as the bloc unwinds production cuts agreed in 2023. Those Middle East countries that are members of the Gulf Cooperation Council have high per capita energy consumption and income levels: they account for nearly 60% of the region's GDP in purchasing power parity (PPP) terms and over half of energy demand while making up just over a fifth of the regional population. Parts of the Middle East face geopolitical instability and conflict, and this inevitably affects their energy and economic outlook.

Figure 8.19 ▷ Oil and natural gas relative to global production and energy demand by source in the Middle East in the STEPS, 2010-2035

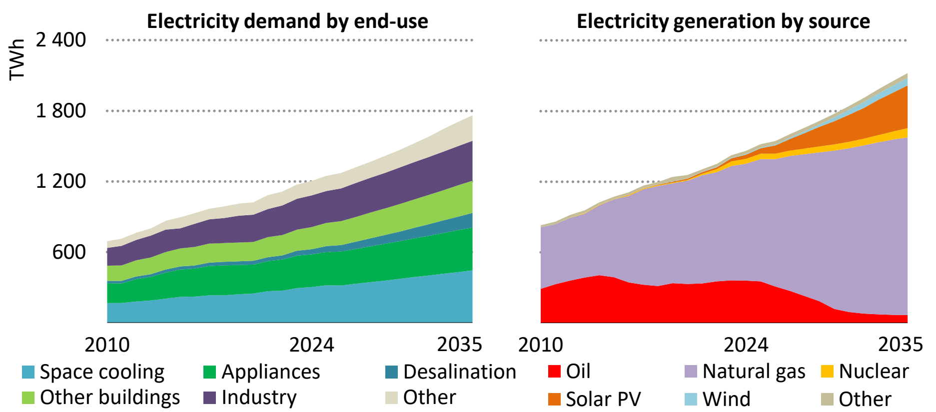


Oil and gas production in the Middle East account for a significant share of total global hydrocarbon output, and these sources also meet nearly all energy demand in the region

Notes: EJ = exajoule. Other energy demand includes bioenergy and waste, coal, solar thermal, hydro and wind.

Natural gas and oil meet 56% and 41% of the region's energy demand respectively, compared to global averages of 23% and 30%. The shares vary by country: for example, over 70% of energy demand in Iran is met by gas, and over 90% in Qatar, whereas over 80% of energy demand in both Yemen and Lebanon is met by oil. Per capita energy demand in the region varies widely among countries, but for the region as a whole it is more than twice the average of emerging market and developing economies. Several factors contribute to the high level of energy demand. Abundant energy resources combined with energy subsidies make oil and natural gas affordable and accessible in some Middle Eastern countries, while the presence of energy-intensive petrochemical industries, often integrated with refineries, drives energy consumption in industry. At 143 cars per 1 000 people, the ownership rate is about 45% higher than the average of emerging market and developing economies, reflecting relatively high average incomes in some countries. Space cooling needs are substantial because of the hot climate. In addition, most countries in the region face water stress or scarcity and turn to desalination where it is financially feasible.

Figure 8.20 ⊳ Electricity demand by end-use and generation by source in the Middle East in the STEPS, 2010-2035



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The electricity outlook shows a decline in the share of oil in generation and a rise in demand driven in large part by space cooling, appliances and desalination

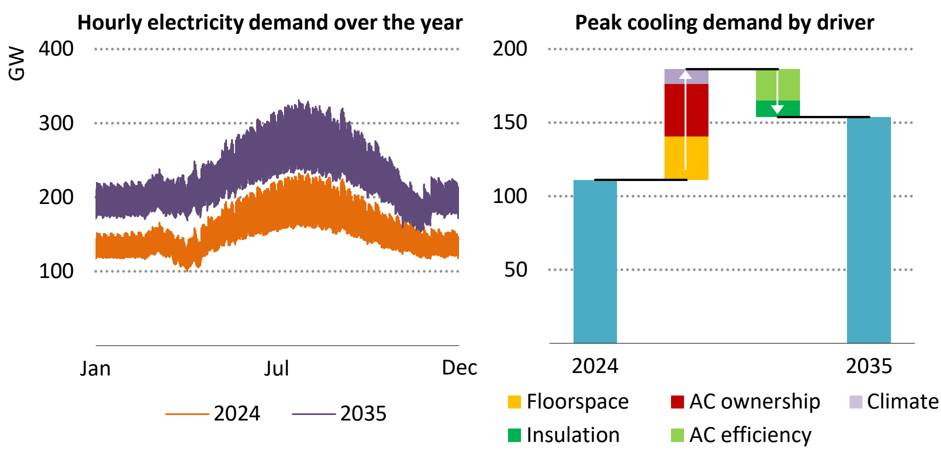
Notes: TWh = terawatt-hour. The difference between generation and demand reflects transmission and distribution losses, own use in the power sector and net imports. Other in demand includes transport and hydrogen production. Other in electricity generation includes bioenergy, coal and hydropower.

Energy demand in the Middle East increased at an annual rate of 2.6% between 2010 and 2024. This slows to an annual average of 1.8% to 2035 in the STEPS, and to 2.4% in the CPS. Natural gas demand rises 30% by 2035 in the STEPS, while oil demand declines marginally. Electricity consumption rises faster than overall energy demand in both scenarios (IEA, 2025d). Today, 64% of electricity used in the Middle East is consumed in commercial and residential buildings, and 4% in desalination. Around 80% of the world's thermal desalination plants, i.e. those using oil and gas, are in the Middle East, but there has been a shift in recent years towards more efficient electrified desalination technologies, notably reverse osmosis. Electricity demand for desalination increases by more than a factor of 2.5 in the STEPS by 2035. Despite this rapid increase in energy demand from desalination, space cooling is the largest end-use driver of electricity demand growth to 2035 (Figure 8.20). Although their share of the market is still very small, EVs are gaining ground in parts of the region. In Jordan, for example, EVs accounted for over 50% of new passenger car sales in 2024.

8.6.2 Synergies between increasing cooling demand and renewables uptake

The Middle East is among the hottest regions in the world, with temperatures regularly exceeding 40 degrees Celsius (°C) in the summer. As temperatures rise further, cooling degree days – a measure of cooling needs - are projected to increase by 10% by 2035. Electricity demand for space cooling nearly doubled between 2010 and 2024, from 166 TWh to over 300 TWh today: cooling now accounts for about a quarter of overall electricity demand in the region. Electricity consumption patterns are strongly influenced by the weather, especially in the summer season. When temperatures are at their highest, cooling can be responsible for nearly 50% of the peak electricity load.

Figure 8.21 ▷ Annual electricity load curve and peak cooling demand by driver in the Middle East in the STEPS, 2024-2035



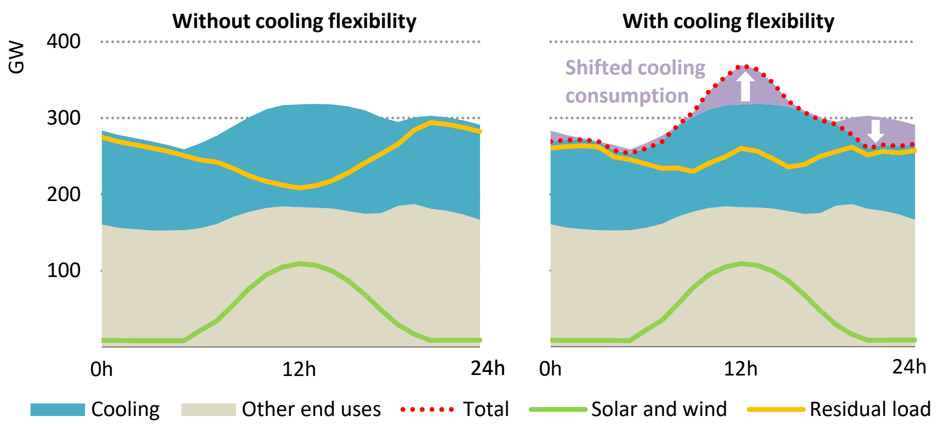
Space cooling drives variations in electricity demand over the year and accounts for a large share of peak demand

Notes: GW = gigawatt; AC = air conditioning. Insulation includes all measures to improve the energy performance of the building envelope. Hourly demand profiles reflect the reduction in demand during Ramadan, which was in March-April in 2024 and is scheduled for November in 2035.

Space cooling demand increases by a further 140 TWh by 2035 in the STEPS and by nearly 160 TWh in the CPS. This growth is driven by an increase in floorspace, rising air conditioner ownership and higher temperatures, and tempered by efficiency improvements in air conditioners and better insulation (Figure 8.21). Several countries in the Middle East have policies to moderate cooling demand: most countries in the region have minimum energy performance standards for air conditioners, and countries including Jordan and Lebanon are developing national cooling action plans. In the United Arab Emirates, regulations limit the minimum temperature setting for air conditioners to 20 °C.

Peak electricity demand in the Middle East rises by around 40% in the STEPS by 2035 compared to today, underscoring the importance of system adequacy for electricity security and the need for additional investment. Today, energy investment in the Middle East amounts to 6% of GDP, which is twice the global average. Around 78% of investment is expected to go to fossil fuels in 2025, compared to a global average of 35%. This share falls to 66% by 2035 in the STEPS as investment in grids, storage and low-emissions electricity increase.

Figure 8.22 ▷ Average summer daily electricity consumption with and without space cooling flexibility in the Middle East in the STEPS, 2035



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Cooling flexibility can be harnessed to align demand with renewables energy generation

Notes: GW = gigawatt; h = hours. Residual load is the difference between electricity demand and renewables generation.

Space cooling drives the peak electricity demand growth in the Middle East, yet it also presents an opportunity to support the integration of renewables power generation. The ability to shift cooling loads over time can be used to decrease the daily variation in residual load, defined as total electricity demand minus renewable generation. Reducing the magnitude of these variations is crucial to lower operational stress on dispatchable power sources required to balance the networks. Depending on the thermal inertia[1] of buildings, cooling demand loads can be shifted by a period of between a few dozen minutes to several hours, or even more in combination with thermal storage systems, such as water tanks. This can shift electricity consumption closer to midday, thereby enabling electricity systems to benefit from peak solar PV generation and avoid curtailment (Figure 8.22). By 2035, over 15% of electricity in the Middle East comes from solar PV in the STEPS, and 5% from other renewable sources including wind.

[1] How quickly a building heats up or cools down in response to outdoor temperature changes.

8.7 Eurasia

8.7.1 Key energy trends

Eurasia is both a major consumer and producer of fossil fuels. In 2024, fossil fuels met 90% of energy demand in the region, the second-highest regional average after the Middle East. Eurasia is also a large net exporter of fossil fuels, selling around 200 bcm of natural gas in 2024, along with 7 mb/d of oil and 130 million tonnes of coal equivalent (Mtce) of coal. Russia accounts for around 70% of its oil and gas exports, although these have been significantly affected by unilateral cuts to supply as well as sanctions imposed after its invasion of Ukraine: in 2024, Russian natural gas exports were 45% below their pre-war level of 250 bcm.

Several announcements were made by Caspian and Central Asian countries during the COP29 in Baku, including commitments to increase support for renewables and to improve infrastructure links. An example is the Trans-Caspian Green Energy Corridor that was the subject of a Strategic Partnership Agreement signed by Azerbaijan, Kazakhstan and Uzbekistan to integrate their power grids and export renewable energy. However, change in the energy sector has been slow in most cases. Ageing building stock and industrial facilities, undermaintained pipelines that transport fuel over large distances, and a cold climate mean that the regional energy intensity of GDP is 40% higher than the global average. This inefficiency translates into high energy costs, heavy environmental burdens and increased vulnerability to supply disruptions.

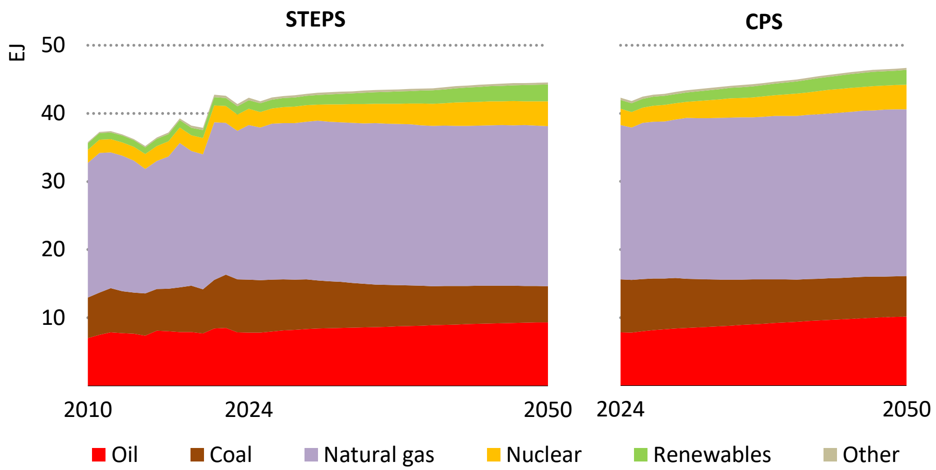
Ukraine – part of the Europe grouping in our modelling – has historically had strong ties with the Eurasian energy space. However, together with Moldova, it now has its sights set firmly on integration with the broader European energy system. Ukraine faces an especially daunting set of energy challenges, with Russia systematically targeting its energy assets during the war. Ukraine is now exploring a shift towards a more decentralised power system. This is being driven in the first instance by security considerations, but it could become the blueprint for a very different configuration of energy infrastructure in the longer term.

Natural gas is the largest contributor to the energy mix in the region and is emblematic of some of its dilemmas. Gas can be an enabler of change in many circumstances: it can, for example, replace fuels with higher emissions intensities and provide system flexibility that helps integrate new sources of low-emissions power. However, the gas sector in many parts of Eurasia is not playing this role: infrastructure is generally in poor condition, prices are often subsidised in ways that encourage wasteful consumption and undercut the competitiveness of alternatives, and high levels of methane leaks compromise the environmental case for gas use. Moreover, with few exceptions, gas resources in the region typically need long-distance pipelines to reach export markets, and this can put them at a disadvantage at a time when consumers appear to prefer the optionality and flexibility of LNG.

In the STEPS, total energy demand growth in Eurasia averages 0.2% per year through to 2050, among the lowest rate of growth in emerging market and developing countries. It is marginally higher in the CPS, but the overall amount of growth over the entire projection period, around 4 EJ, is still equivalent to just four years of average demand growth in Southeast Asia in the same scenario.

The energy mix is projected to remain static in both scenarios. Fossil fuels currently account for 90% of the energy mix in Eurasia and remains around that level in both scenarios by 2050 (Figure 8.23). Oil demand rises 0.5 mb/d by 2035 in the STEPS as a result of growth in the transport and industry sectors. Natural gas demand increases by 30 bcm over the same period: this mostly reflects increased demand in power and industry. More than half of the increase in electricity consumption in the STEPS to 2035 is met by natural gas. Renewables capacity nearly doubles between 2024 and 2050, which is the lowest regional rate of growth in the STEPS. Hydropower remains the dominant source of renewables electricity in 2050.

Figure 8.23 ▷ Energy demand by source and scenario in Eurasia, 2010-2050



Energy supply balance in Eurasia is similar in both scenarios, with natural gas dominating the energy mix

Note: EJ = exajoule.

Although the pace of change in Eurasia is slow, there are countries that have moved or are moving to diversify their energy and electricity mix. Tajikistan, Kyrgyzstan and Georgia are large and established producers of hydropower. Uzbekistan and Kazakhstan are expanding their use of renewables, with the focus mainly on solar PV but also wind. Following its hosting of the COP29, Azerbaijan is seeking to step up investment in low-emissions technologies, and it aims to increase the share of renewables in installed capacity to 30% by 2030.

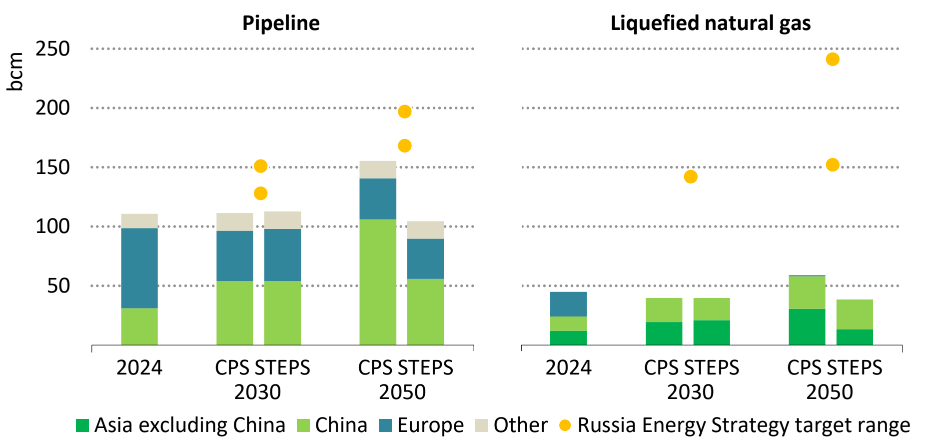
Nuclear energy also plays an important and growing role in many countries in Eurasia. Russia is a leading exporter of nuclear technology, and Rosatom is looking to expand co-operation in this area with countries in Central Asia. Kazakhstan is also the largest global producer of uranium, with a market share of around 40%.

8.7.2 Prospects for Russian natural gas exports

Russia's full-scale invasion of Ukraine threw its natural gas export strategy into disarray. Before the invasion, the official expectation was for steady growth in exports, with the established European market being supplemented over time by more diversified flows of LNG and pipeline gas, mainly to China and other destinations in Asia. Its previous Energy Strategy foresaw that Russia would be exporting more than 300 bcm of gas by 2024.

The actual figure for 2024 is estimated to be less than 160 bcm, and the push for new markets has become a strategic necessity for Russia in light of the huge drop in volumes sent to Europe. The new Russian Energy Strategy, adopted in 2025, is less ambitious than the previous one, but is nonetheless considerably more bullish than our projections. It foresees exports of between 320-375 bcm by the mid-2030s, compared to around 150 bcm in the STEPS (Figure 8.24).

Figure 8.24 ⊳ Natural gas pipeline and LNG exports from Russia by scenario relative to the 2025 Energy Strategy targets, 2024, 2030 and 2050



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Russia struggles to find export outlets for natural gas, with both pipeline and LNG trade through to 2050 well below government targets

Note: bcm = billion cubic metres.

There are four main avenues for Russian gas export: pipeline exports to Europe, China and Central Asia; and exports of LNG. Each of these faces market and political uncertainties.

Russian exports of gas to Europe consist mainly of deliveries to the European Union, Türkiye, Belarus, Moldova and the Balkan countries. In the STEPS, exports to Türkiye remain above 20 bcm, and volumes to other non-EU markets remain flat, but deliveries to the European Union fall to less than 10 bcm by 2030 as the Council adopted measures to phase out Russian LNG imports by 2027. Even in the event of a cessation of hostilities in Ukraine, we do not anticipate Russian gas returning to Europe at scale, especially given a relatively comfortable global supply balance in the second half of the 2020s. The loss of the European market has led Russia to look elsewhere for customers, including countries in Central Asia that already have pipeline connections. Exports to Kazakhstan and Uzbekistan have picked up, and a 15-year deal was recently concluded with the smaller Central Asian market of Kyrgyzstan. Consumption of Russian gas in Central Asia is not projected to exceed 10-20 bcm per year, but Central Asia could also act as a conduit for Russian exports to Iran and potentially also to China, although the volumes are not projected to be high.

Russian pipeline gas exports to China along the Power of Siberia-1 route reached their envisaged capacity of 38 bcm/year in 2025, and recent discussions have explored the possibility of increasing throughput capacity up to 44 bcm/year. A contract for an extra 10 bcm/year to bring gas from Sakhalin to Northeast China was signed in 2022, the so-called Far Eastern route, and there are prospects for a marginal increase in capacity on this line. Deliveries are scheduled from 2027, but they could slip by a few years.

A larger uncertainty relates to the negotiations on an additional large-scale pipeline, Power of Siberia-2, which would bring up to 50 bcm/year of gas from the main resource base in Western Siberia to China. This pipeline is assumed to go ahead in the CPS but not in the STEPS: the Chinese market already looks well supplied without it in this scenario. But this could change if the politics align, or if Russia is ready to cede ground in price negotiations. If it goes ahead in the STEPS and comes into operation in the early 2030s, it would prolong the period of well supplied global gas markets and undercut the commercial rationale for further expansion of LNG export projects, including those planned in Russia.

The new Russian Energy Strategy has LNG exports reaching 142 bcm by 2030, up by 100 bcm from today. Achieving this in practice will be extremely challenging; this target is considerably higher than the volumes reached in both the CPS and STEPS. Hurdles include the sanctions that limit access to western LNG technologies, finance and markets, and a shortage of LNG tankers that can operate in ice-bound Arctic waters. Russia is looking to relieve the latter constraint through domestically produced technologies and tankers, but these will take time to develop to the required performance standards. Even if these hurdles can be overcome, there are additional commercial obstacles in a fiercely competitive market, given that the second-half of this decade will see unprecedented growth in export capacity in other countries, led by the United States and Qatar.

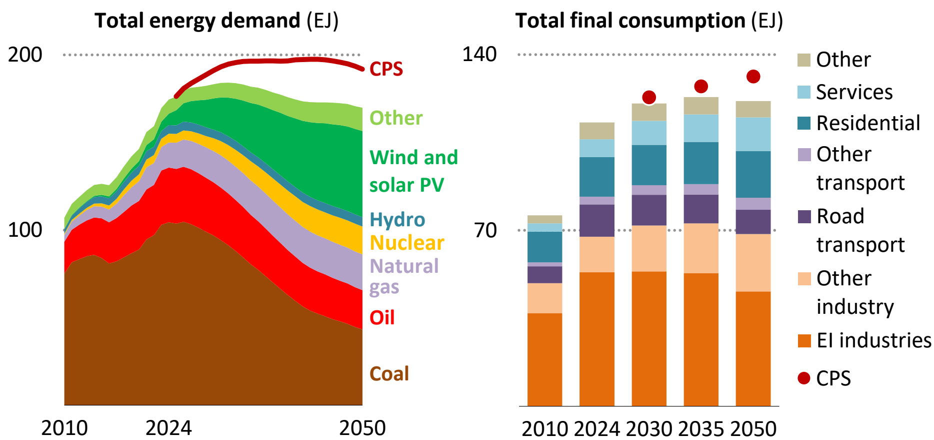
Overall, our analysis suggests that Russia faces an uphill struggle to re-establish its pre-eminence among global gas exporters, despite very competitive upstream costs. Russia's share of internationally traded gas, which stood at nearly 25% in 2021 before the invasion of Ukraine, never approaches these levels again in any scenario, and falls to 10 % by 2035 in the STEPS. This has implications for gas revenues, which decline from an average of USD 120 billion per year in the 2010s to USD 28 billion per year in the STEPS in the 2030s, and for Russia's influence as a global energy player. The downside risks for Russian gas outlook intensify in scenarios that see accelerated action to bring down emissions.

8.8 China

8.8.1 Key energy trends

In 2024, GDP per capita in China stood at USD 27 000 in purchasing power parity terms. China is set to graduate to high income status in 2025. Its economic growth thus far has been energy intensive: its GDP per capita is 10% above the world average, but its per capita energy consumption is 50% above. In this *Outlook*, GDP grows 3.5% per year to 2035. Output levels of established industries like steel and cement have peaked and continue to decline in our projections: other energy-intensive industry products such as chemicals, petrochemicals and non-ferrous metals rise, but GDP is increasingly driven by services and high value-added manufacturing. This structural trend, alongside continued efficiency and electrification, leads to a peak and plateau in energy consumption in China (Figure 8.25). This marks an important trend break after years of rapid growth.

Figure 8.25 ▷ Energy demand by source and final consumption by sector in China in the STEPS, 2010-2050



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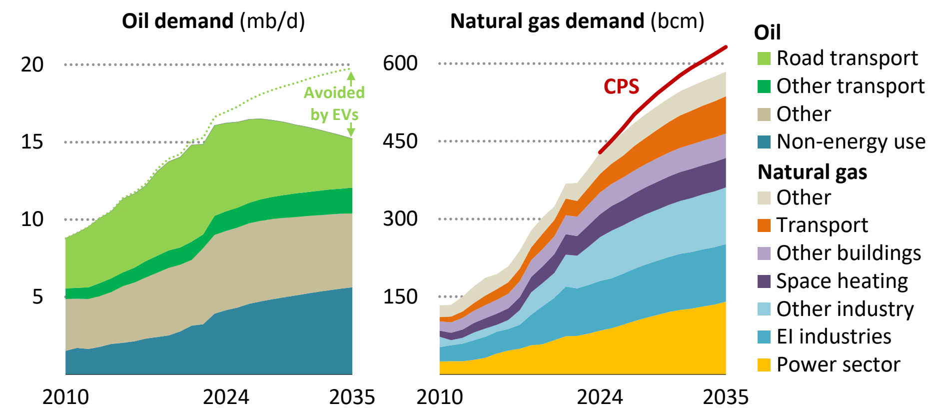
After years of rapid growth, energy consumption is set to peak and plateau in the next few years, driven by structural economic change, electrification and efficiency

Note: EJ = exajoule; CPS = Current Policies Scenario; EI industries = energy-intensive industries.

The structure of energy supply and consumption in China sees substantial shifts by 2035 in the STEPS. It already has one of the highest shares of electricity in final consumption in the world, and this rises from its current level of 27% to 35% by 2035. China adds on average 460 GW of wind and solar PV per year in the decade to 2035. When other renewables and nuclear are added in, low-emissions sources expand in total by around 600 TWh per year. By 2035, China generates over 10 000 TWh of low-emissions electricity, and its total energy supply from renewables and nuclear is 10% larger than supply from oil and natural gas combined.

In the decade to 2024, China was responsible for more than two-thirds of global demand growth for oil. Its demand for oil declines by 2035 in the STEPS and CPS, and EVs have much to do with this trend. In 2024, nearly half of car sales in China were electric, of which two-thirds were priced lower than their conventional equivalents. Their competitiveness sees electric cars rise to account for over 80% of sales by 2030 in the STEPS. The strong growth of high-speed rail also avoids oil demand (see Chapter 4, Box 4.1). As a result, oil demand for road transport in China starts to decline. By 2035, its total oil demand is around 15 mb/d or 5% below today's level (Figure 8.26). This is broadly in line with the projections of China's oil major, Sinopec (Sinopec EDRI, 2025). The CPS sees little additional upside for total oil demand in China by 2035, given the competitiveness of EVs and policy commitment to them.

Figure 8.26 ▷ Oil and natural gas demand by sector in China in the STEPS, 2010-2035



Oil demand peaks before 2030, curbed by EVs; gas demand rises, but electrification and energy efficiency limit the upside in key end-use sectors

Note: mb/d = million barrels per day; bcm = billion cubic metres; CPS = Current Policies Scenario; EI industries = energy-intensive industries.

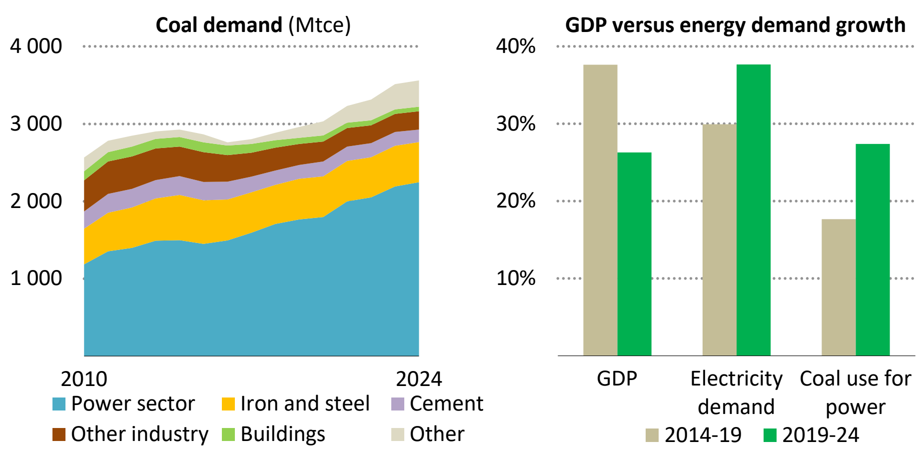
China was responsible for nearly one-third of the global increase in demand for natural gas over the past decade. Demand continues to grow in both the STEPS and CPS but is limited by the electrification of end-uses. Industrial production in China is already highly electrified, 27% of industry energy consumption versus nearly 10% for gas. Electricity continues to gain ground in industry in the future. The transport sector sees increasing natural gas demand for trucks, over 25% of heavy-freight truck sales were natural gas fuelled in 2024, but it still accounts for a relatively small share of total gas demand. In the power sector, natural gas demand increases, but its growth potential is limited by competition with coal, pumped hydro and batteries, which play critical roles in balancing rising shares of variable renewables. The CPS sees a slightly higher upside for gas, with demand reaching 630 bcm by 2035, an increase of 8% on the STEPS.

8.8.2 Future of coal in China: growth ahead or peak on the horizon?

The massive electricity sector in China accounts for two-thirds of its coal demand. Industry is responsible for most of the remainder, but its demand for coal is declining: coal consumption in the industry sector peaked in 2014 and has since declined by 25%. Given that most industrial coal use is to produce cement and steel in China, the saturation of its housing and infrastructure needs means that demand for coal in industry will continue to decline. By 2035, coal consumption in industry in China is a further 20% below the 2024 level in the STEPS.

Therefore, the electricity sector will determine the future of coal in China. In the last five years, China has added more renewables and nuclear generation capacity than the rest of the world combined, and solar PV and wind now account for 18% of generation. Despite this, coal demand for electricity rose by more than 25% from 2019 to 2024 (Figure 8.27). As a result, coal consumption in the electricity sector reached 2 250 Mtce in 2024 (65 EJ). This is more than the total energy demand from all sources combined – coal, gas, nuclear, oil and renewables – of any other country in the world, except the United States.

Figure 8.27 ⊳ Coal demand by sector in China, 2010-2024, and GDP growth versus energy demand, 2014-2024



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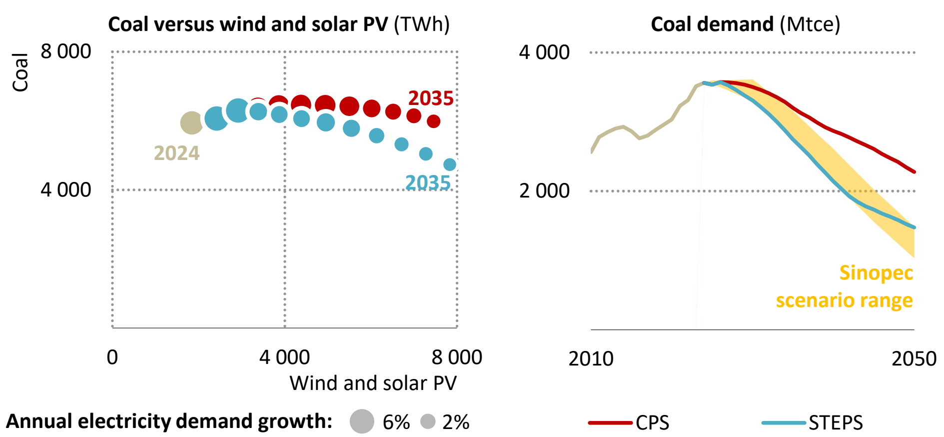
From 2010 to 2024, the share of electricity generation in China's coal demand increased from 45 to 65%, driven by strong electricity demand growth

Note: Mtce = million tonnes of coal equivalent; GDP = gross domestic product.

Economic growth in China has been very electricity-intensive in the post Covid pandemic period. Electricity consumption in the residential, industry and services sectors rose faster than economic activity in the 2019 to 2024 period.

To integrate expanding shares of variable resources, China is investing in grids and dispatchable capacity, including batteries, pumped hydro and nuclear, as well as undertaking reforms to incentivise flexibility, and a more grid-friendly deployment of renewables. However, it also has over 200 GW of coal generation capacity under construction. The low capital costs of coal plants in China means that operating them flexibly to support renewables has much lower opportunity costs than in other markets. Even at a 30% capacity factor, its average levelised cost of coal generation at USD 80 per megawatt-hour (MWh) is lower than the levelised cost of gas at USD 110/MWh.

Figure 8.28 ▷ Electricity generation from coal and renewables to 2035 by scenario and coal demand by scenario in China to 2050



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Coal demand peaks and declines by 20% in the STEPS, led by declines in coal-fired power generation; in the CPS, higher demand and lower renewables keep coal higher for longer

Notes: TWh = terawatt-hour; Mtce = million tonnes of coal equivalent. Sinopec scenario results are from China Energy Outlook 2060 (Sinopec EDRI, 2025).

Therefore, the outlook for coal in China is shaped by a three-way race between booming renewables growth, rising electricity demand, and efforts to make the grid more modern and flexible. How this race plays out differs in the STEPS and CPS, but the long-term trends point to a peak and decline (Figure 8.28). In the CPS, electricity demand is higher than in the STEPS by 2035: the CPS sees a lower level of electrification, but it also sees fewer of the efficiency gains that dampen demand growth in the STEPS. Capacity additions of renewables average around 480 GW per year in the STEPS, compared to around 450 GW per year in the CPS. Curtailment rises in the STEPS, but efforts to add more flexibility through battery storage, pumped hydro and grid capacity keep the curtailment rate far lower than in the CPS. Even with the higher levels of electricity demand seen in the CPS, China's huge renewables manufacturing capacity and the economic competitiveness of renewables lead to sufficient growth in renewables capacity to put coal into decline. As a result, total coal demand falls by around 20% to 2035 in the STEPS and by around 10% in the CPS.

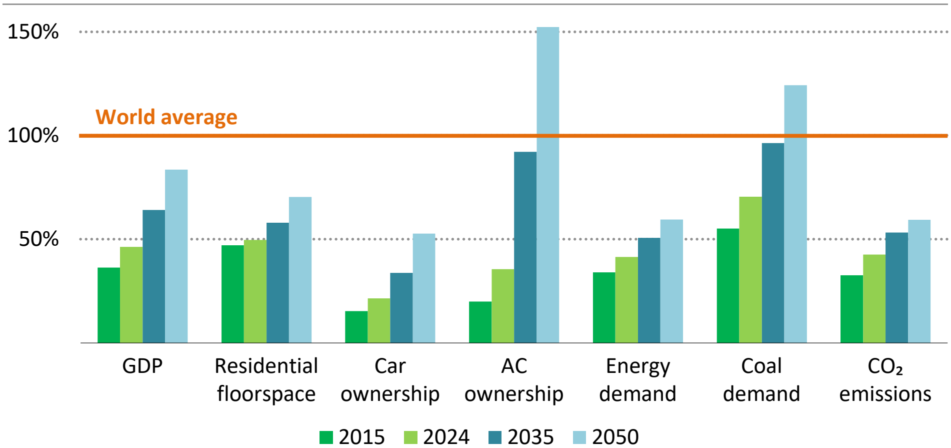
8.9 India

8.9.1 Key energy trends

India is the largest source of energy demand growth in the world in our *Outlook*. Energy demand increases by over 15 EJ by 2035 in the STEPS, which is nearly as much as the demand growth in China and all Southeast Asian countries combined. India is the largest contributor to growth in oil demand in this period, the second-largest for electricity generation and coal demand growth, and third-largest natural gas demand growth.

Energy demand in India is being propelled by increasing economic activity. Between 2010 and 2024, its GDP growth rate was second only to that of China among major countries and regions. In the period to 2035, GDP grows on average by 6.1% each year in India, which is more than any other major country or region, and its GDP per capita is 75% higher in 2035 than today (see Chapter 2, Table 2.1). India is currently well below the global average on a range of key energy and economy-wide indictors, but it has been moving towards them, and it continues to do so over the next decade (Figure 8.29). India adds the equivalent of one Bangalore every year to its urban population to 2035, and its built floor space expands by 40%. It also adds nearly 12 000 cars to its roads every day, and well over 250 million air conditioners to its homes over the next decade.

Figure 8.29 ▷ Per capita energy and economy indicators in India relative to the world average in the STEPS, 2015-2050



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India has been steadily catching up with world averages on key energy and economic indicators, although many remain below the global average to 2050

Note: AC = air conditioner; CO_2 = carbon dioxide.

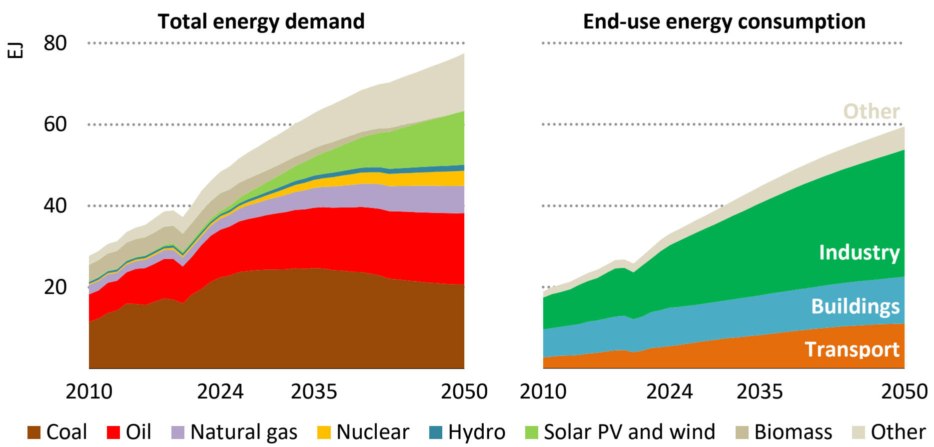
In addition to boosting energy supply to meet fast-growing demand, India is tackling a variety of other energy-related challenges. These include: ensuring universal access to modern energy; reducing fossil fuel import dependence; improving the reliability of electricity supplies; reducing air pollution; and cutting GHG emissions. To meet its myriad energy sector challenges and ambitions, India has instituted a wide range of policies and programmes.

A key challenge is to provide universal access to modern energy. India has made remarkable progress in improving energy access in recent decades, but nearly 20% of its population continues to rely in whole or in part on traditional biomass for cooking. The Pradhan Mantri Ujjwala Yojana policy seeks to address this by providing subsidies for LPG use for poor households.

India has pledged to achieve net zero emissions by 2070, and has adopted several short-term targets, one of which aims to increase non-fossil power generation capacity (section 8.9.2). Its long-term targets are supported by a goal to scale up nuclear power capacity to 100 GW by 2047 from 8 GW today, its plan to implement a carbon market for select industries in 2026, and a biofuels mandate that has achieved an ethanol blending rate of 20% in gasoline in 2025 with a view to also displace oil imports.

With policy support, solar PV and wind are the fastest growing sources of energy to 2050 in the STEPS, and reach nearly 20% of the energy mix, although coal and oil remain mainstays (Figure 8.30). Energy demand grows fastest in the industry and transport sectors, with industry alone accounting for over half of the demand increase by 2050. CO_2 emissions in India peak around 2040 in the STEPS, and by 2050 they stand at around 3.4 gigatonnes (Gt) per year.

Figure 8.30 ▷ Total energy demand by source and total final consumption by sector in India in the STEPS, 2010-2050



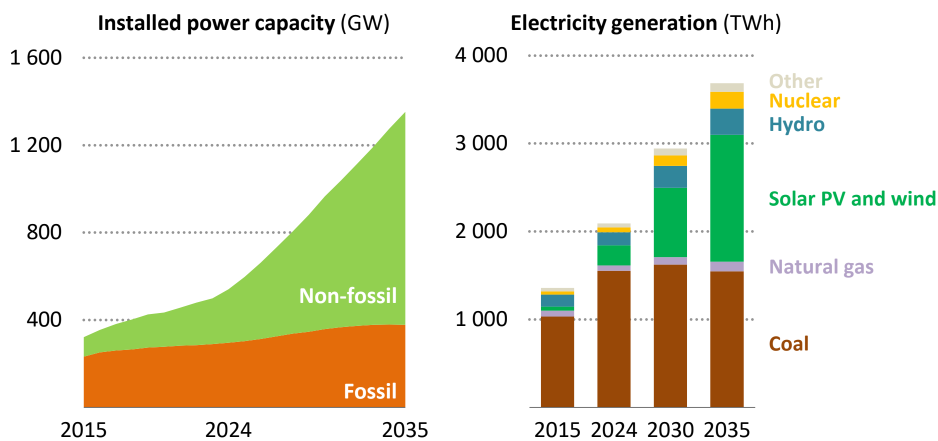
Solar PV and wind contribution to energy demand increases from 2% today to nearly 20% by 2050, a period in which consumption nearly doubles

Note: EJ = exajoule; Biomass = Traditional use of biomass.

8.9.2 India hits 50% non-fossil power capacity target early: what is next?

In support of its long-term objective of net zero emissions by 2070, in 2022 India announced an objective to increase the share of non-fossil sources in the power generation mix to 50% by 2030. India met this target for grid-connected capacity in 2025, five years ahead of schedule. In the STEPS, it meets it in 2026 even when auto-producers, which is production of electricity by a facility primarily for its own use, is included (Figure 8.31). This success was underpinned by surging investment in renewables. In 2015, every dollar invested in fossil power generation sources in India was broadly matched by a dollar invested in non-fossil sources, a 1:1 ratio. By 2025, this ratio had increased to 1:4 in favour of non-fossil sources. Solar PV alone has attracted USD 113 billion in cumulative investment in the past decade, compared with USD 112 billion for all fossil fuel power generation sources combined.

Figure 8.31 ▷ Installed power capacity and electricity generation by source in India in the STEPS, 2015-2035



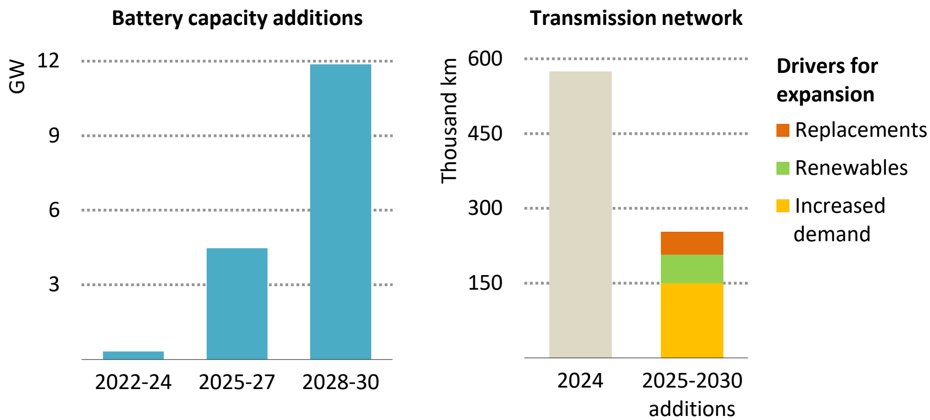
India has achieved its target of 50% non-fossil power generation capacity ahead of its target year of 2030 by 2035, non-fossil sources contribute to over half of generation

Notes: GW = gigawatt; TWh = terawatt-hour. Excludes battery storage and includes auto-producers.

The share of non-fossil sources in installed generation capacity rises to 60% in 2030 and 70% in 2035 in the STEPS, and accounts for over 95% of capacity increases to 2035. This is a striking contrast to the 2015-2024 period, when coal and natural gas accounted for over 70% of increased generation. Nevertheless, led by industry, demand for coal rises moderately to 2035, and coal continues to be a mainstay in the electricity generation mix, providing valuable dispatchable generation and flexibility. Solar PV and wind power see their share of generation rise from 11% today to over 25% by 2030 and to nearly 40% by 2035. Generation from nuclear triples by 2035. As a result, non-fossil sources are responsible for over half of electricity generation in India by 2035 in the STEPS. This reduces the carbon intensity of electricity generation by nearly 45% to around 400 grammes of carbon dioxide per kilowatt-hour, which narrows India's gap with the global average level of carbon intensity of electricity generation. Other benefits include significant declines in emissions of key air pollutants such as fine particulates and sulphur dioxide.

The rising share of variable renewables in power generation brings with it both challenges and opportunities. One challenge is the need for investment in storage and transmission to facilitate the deployment of renewables. In the STEPS, over 230 gigawatt-hours (GWh) of battery storage are added to the system by 2030 (Figure 8.32). The government is in the process of putting out tenders for new storage capacity. By 2030 in the STEPS, the transmission network expands by 35% with over 200 000 km of new transmission lines, including nearly 60 000 km of lines to facilitate the integration of renewables. India's Green Energy Corridor project seeks to address some of this gap by facilitating the construction of transmission lines to support generation from renewable sources.

Figure 8.32 ▷ Battery capacity additions, 2022-2030, and transmission network expansion in India in the STEPS to 2030



Rising power generation from variable renewables is complemented by accelerating battery capacity additions and grid expansion

Note: GW = gigawatt; km = kilometres.

India faces challenges arising from the financial weakness of distribution companies, exemplified by delayed payments to generation companies totalling USD 7 billion in October 2025. A range of reforms have been instituted including: establishment of a payment security mechanism; a payment security fund; and state government guarantees to increase investor confidence in renewable energy projects. These reforms along with other risk mitigation measures have helped double the share of foreign direct investment in total power sector investment to nearly 10% over its average between 2015 and 2020 (IEA, 2025e).

8.10 Japan and Korea

8.10.1 Key energy trends

GDP in Japan and Korea is set to grow by 0.8% per year to 2050 while the population in the region continues to contract by 0.6% per year over the period. Digitalisation, automation and high value-added sectors, e.g. AI, robotics and semiconductors, underpin the economic outlook as governments double down on innovation, productivity gains, and industry transformation to offset labour shortages and sustain economic growth.

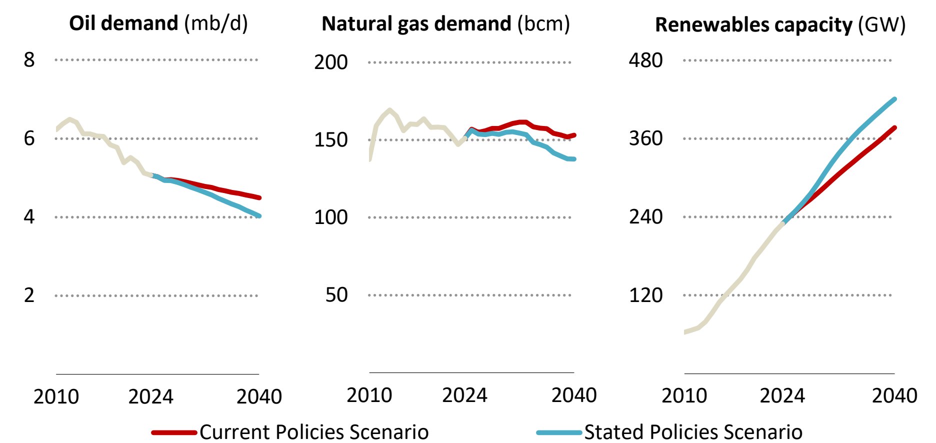
Japan's energy strategy, guided by the 7th Strategic Energy Plan, adopted in February 2025, outlines multiple pathways to achieve decarbonisation and energy security. A key shift is the explicit elevation of renewables to a mainstream power source to provide 40-50% of power generation by 2040, up from 24% in 2024. The Energy Plan also marks a turning point in nuclear policy: it positions nuclear power – alongside renewables – as indispensable for both energy security and effective decarbonisation. It envisages to increase in the share of nuclear power from 9% in 2024 to approximately 20% by 2040. However, uncertainties remain around reactor restarts, including that the timing of restarts will depend on safety reviews and facility upgrades, and public understanding. Delays could force reliance on alternative sources, complicating the decarbonisation and energy security path.

Korea's 11th Basic Plan for Power Supply and Demand, 2024-2038, seeks to balance rising demand with commitments to decarbonise while taking account of energy security considerations. The share of nuclear in power generation is set to expand from around 30% to 35% by 2038 as new reactors and small modular reactors are brought into service. The share of renewables in generation is expected to increase, and the shares of coal and LNG to decrease. By 2038, over 70% of generation is expected to come from low-emissions sources including nuclear, renewables and hydrogen/ammonia, with the twin aims of enhancing energy security and moving toward carbon neutrality. Uncertainties remain, but Korea is likely to maintain support for existing nuclear plant life extensions and small modular reactor development, though the pace of large new nuclear projects may slow. Its overall focus may increasingly shift toward renewables and next-generation technologies.

Reflecting these strategies and policies, electricity demand in the region increases to about 1 660 TWh in the STEPS and to just over 1 670 TWh in the CPS by 2040 from around 1 460 TWh in 2024. In the STEPS, the transport sector is responsible for over 35% of electricity demand growth. In the CPS, demand growth is led by the buildings sector, which accounts for almost 50% of the total. One cause of demand growth in both scenarios is a rapid increase in electricity demand to serve data centres. Their electricity demand in Japan and Korea today is a little over 20 TWh and is supported by just over 5 GW of installed capacity. In the near term, electricity demand for data centres is projected to nearly double in both scenarios, contributing to about 20% of growth in electricity demand between 2024 and 2030.

With policy support in both countries for low-emissions fuels and enhanced energy security, fossil fuel demand decreases between 2024 and 2040 at an annual average rate of 1.5% in the CPS and over 2% in the STEPS (Figure 8.33). Regional energy-related CO_2 emissions have been decreasing since 2014 with minor fluctuations along the way, and this trend continues in both scenarios. In 2040, energy-related CO_2 emissions in the region are over 30% lower than today in the CPS, and 40% lower in the STEPS.

Figure 8.33 ▷ Oil and natural gas demand and renewables capacity by scenario in Japan and Korea, 2010-2040



Stable transitions reflect continued progress toward cleaner energy systems while maintaining reliable supply amid electricity demand growth

Note: mb/d = million barrels per day; bcm = billion cubic metres; GW = gigawatts.

Natural gas plays an important role in both scenarios as a dispatchable energy source, but both see a gradual reduction in its use after 2030. Renewables capacity increases less rapidly in the CPS than in the STEPS, which means that demand for gas stays higher. Natural gas demand currently stands at around 150 bcm. In the CPS, this is projected to increase until the early 2030s before returning to around today's level in 2040. In the STEPS, natural gas demand declines by 10% by 2040 from the current level.

Both countries attach significant importance to boosting renewables as they seek to make progress towards the goal of achieving net zero emissions. Renewables capacity increases in both scenarios, though at different rates. In the CPS, it is projected to increase by about 1.5 times by 2040; in the STEPS, it almost doubles to 420 GW thanks to additional policy support and more rapid technology development.

8.10.2 Energy security in a shifting geopolitical landscape

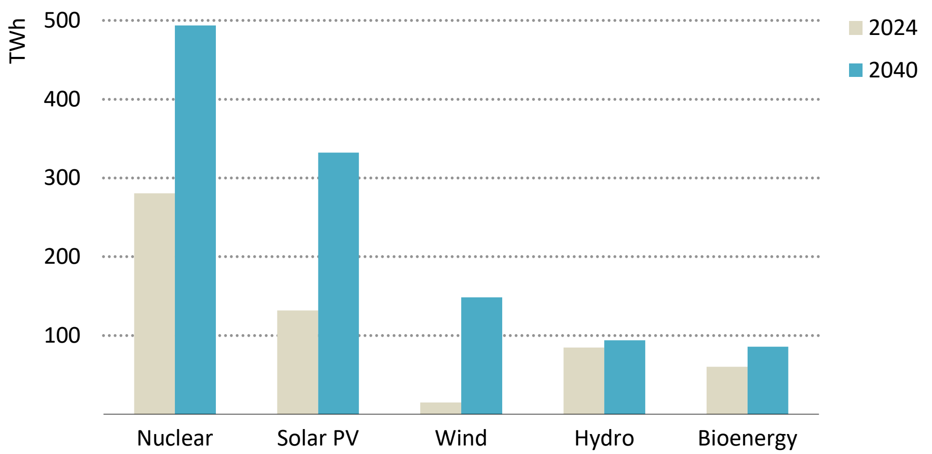
Fossil fuels accounted for 80% of total energy demand in Japan and Korea in 2024, almost all of which was imported. These fossil fuel imports travel through critical chokepoints: approximately 70% of crude oil imports through the Strait of Hormuz; 85% through the Strait of Malacca; and over 70% of LNG imports through the South China Sea. Price levels for spot LNG have been very volatile in recent years, reaching an average of USD 34 per million British thermal units (MBtu) and peaking at USD 85/MBtu in 2022 as prices rose for a prolonged period during the energy crisis experienced that year. In 2024 the price fell to an average of USD 12/MBtu, but the geopolitically driven price swings in 2022 prompted Japan and Korea to boost investment in regional energy sources, expand strategic reserves, and seek to build diversified supply chains through new policies and corporate commitments (Table 8.2). In parallel, both governments introduced emergency fiscal measures to cushion short-term price shocks; Japan has spent over JPY 10 trillion (USD 67 billion considering the 2024 annual average exchange rate) since 2022 on subsidies for gasoline, electricity and gas consumption.

Table 8.2 ▷ Key areas of co-operation to enhance energy security in the Asia Pacific region by Japan and Korea

Area	Example
Regional partnerships	• Asia Zero Emission Community (AZEC) (Japan). • ASEAN-ROK Strategic Partnership, Minerals Security Partnership (Korea).
Regional (near-shore) **energy supply diversification**	• Investment in various LNG and gas upstream ventures including foreign direct investment in the Asia Pacific region since 2022: SK Innovation, JAPEX in Indonesia; Mitsui in Viet Nam; Mitsubishi in Malaysia; SK E&S, JERA and JOGMEC in Australia; JERA in United States; Mitsubishi in Canada.
Self/regional sufficiency in renewable energy	• Ministry of Economy, Trade and Industry and Siemens Partnership to build wind supply chains in Japan, various projects in ASEAN under the AZEC. • Korean battery-cell manufacturing (LG/HYUNDAI) in Indonesia supports regional EV/renewables.
Critical minerals diversification	• Approved battery minerals and uranium projects under the Economic Security Promotion Act, including nickel mining project in Australia (Japan). • Reintroduced the investment tax credit system for overseas resource development and established the Supply Chain Stabilisation Fund (Korea).

Japan and Korea have been pursuing various measures to boost investor confidence in stable, low-emissions technologies to support decarbonisation, energy security and affordability. Nuclear power is one such technology. It is being promoted by the two countries as a dispatchable, low-carbon source which complements variable renewables and can help achieve decarbonisation goals, enhance energy self-sufficiency and reduce fossil fuel import bills. Today, nuclear generates 280 TWh of electricity in the region, which is close to the combined generation of other major low-emissions sources including solar PV, hydro, bioenergy and wind (Figure 8.34). In both scenarios, nuclear remains the largest source of low-emissions electricity in the region, reaching almost 500 TWh in 2040. In Japan, the priority now is to restart existing reactors to increase the share of generation in addition to announcing plans to build new reactors. In Korea, the priority is to move ahead with two new reactors (Saeul 3 and 4) under construction. If nuclear power development is delayed and generation remains at current levels, more than 180 GW of additional solar PV capacity or almost 40 bcm of extra gas will be required in the region in 2040 to fill the gap.

Figure 8.34 ▷ Low-emissions electricity generation by source in Japan and Korea in the STEPS, 2024 and 2040



Nuclear energy plays a central role to decarbonise the power sector, accounting for about 40% of low-emissions electricity in 2040

Note: TWh = terawatt-hour.

Circumstances in the two countries differ, but public leadership is essential in both to establish predictable licensing processes for the development of nuclear power, implement institutional reforms that improve profitability, and create financial instruments such as loan guarantees, green bonds or dedicated investment funds to mobilise private capital. At the same time, investing in workforce development and diversifying supply chains will strengthen resilience and competitiveness. Korea has a key strength in this area, supported by robust domestic and international nuclear projects. Equally important is a clear pathway for the safe and final disposal of nuclear waste, which is critical for both public trust and long-term sustainability. In Japan, the legal process for selecting a site has been progressing steadily. By providing transparent roadmaps and addressing public concerns, policy makers can help to ensure nuclear energy remains a pillar of a low-emissions future.

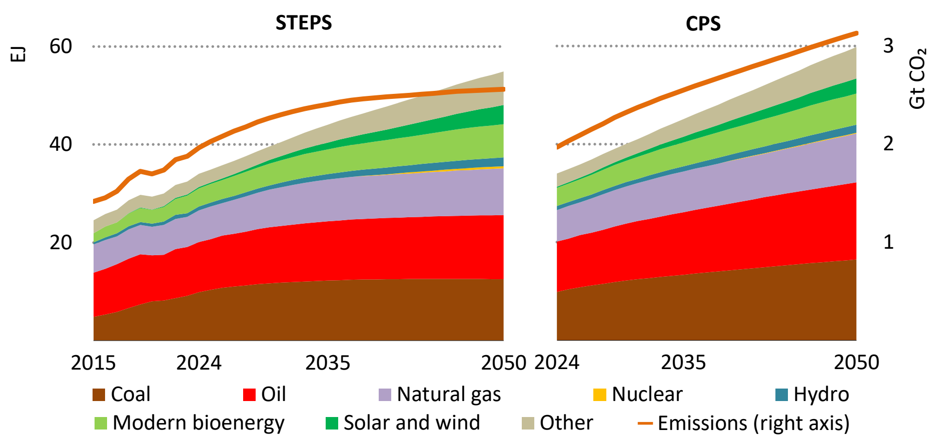
Electricity grids are another essential investment in energy security. It has been difficult for some system operators in Japan to advance transmission projects under the national Master Plan of Nationwide Power Transmission, including the largest project that costs JPY 3 trillion (USD 20 billion), but these are essential for secure operation of the power sector.

8.11 Southeast Asia

8.11.1 Key energy trends

Southeast Asia is one of the world's fastest growing regions. Its GDP increased by nearly 5% year-on-year in 2024 and is expected to continue to increase by 4% per year on average through to 2035, boosted by its position as a global manufacturing hub. Total energy demand in Southeast Asia has increased by 40% since 2015 as its economy expanded. Some 97% of households now have access to electricity, and the region is on track to achieve full access by 2030. The surge in energy demand resulted in a doubling of coal consumption since 2015, mostly for power, while demand for oil and natural gas rose by more than 10%. Modern bioenergy has emerged as an important fuel, with its consumption doubling since 2015, second only to coal in terms of absolute growth since 2015.

Figure 8.35 ▷ Energy demand by source and total energy-related CO_2 emissions by scenario in Southeast Asia, 2015-2050



Building on a 40% increase since 2015, total energy demand rises another third by 2035 in the STEPS; coal demand grows the most in absolute terms

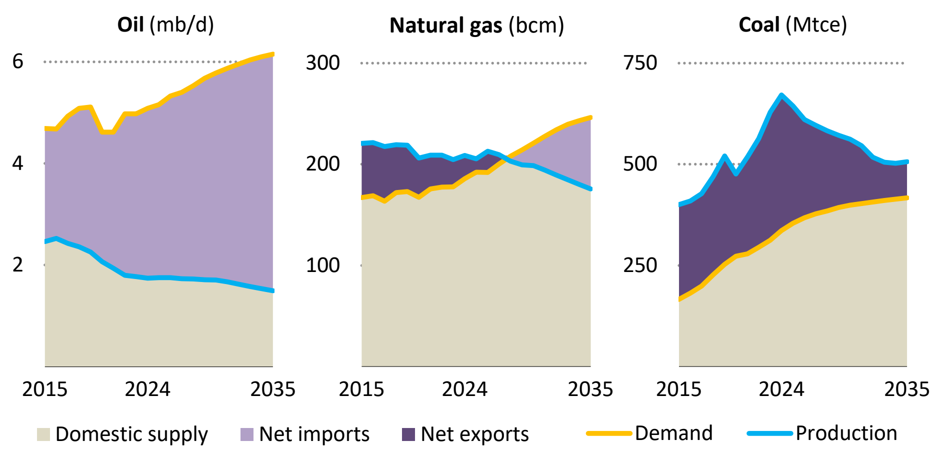
Note: EJ = exajoule; Gt CO_2 = gigatonnes of carbon dioxide.

In the STEPS, energy demand continues to rise rapidly, by nearly a third by 2035 (Figure 8.35). Coal sees the largest absolute increase, followed by natural gas and oil. Bioenergy demand slows, while solar PV and wind power meet an increasing share of demand. In the CPS, energy demand rises faster: coal and natural gas consumption increases by roughly a third to 2035, and oil and bioenergy consumption by about a quarter. Integration challenges associated with a less flexible generation mix and more constrained grids mean that solar PV and wind expand nearly 20% more slowly in the CPS than in the STEPS.

Eight Southeast Asian countries have targets to reach net zero emissions by years in the 2050-2065 range. In the STEPS, regional CO_2 emissions rise from 2 Gt today to 2.4 Gt by 2035. They start to plateau by the late 2040s, but fossil fuel consumption continues to increase by about 0.5% per year, and annual emissions reach 2.5 Gt by 2050. In the CPS, emissions rise to over 3 Gt by mid-century.

Falling oil production and rising demand in the transport sector lead to net oil imports increasing in Southeast Asia from 3.3 mb/d in 2024 to 4.7 mb/d by 2035 in the STEPS and 4.8 mb/d in the CPS. A combination of declining natural gas production and increasing demand shifts the region from a net exporter to a net importer of gas before the end of this decade. Demand for imported gas is met primarily through an increase in LNG imports by countries such as Singapore, Thailand, Philippines and Viet Nam, where the gas is mostly used to meet growing demand in the power and industry sectors. Net imports reach almost 70 bcm in the STEPS by 2035 but are roughly 20% lower in the CPS, reflecting slightly weaker demand and higher domestic production.

Figure 8.36 ▷ Fossil fuel production, demand and trade balance in Southeast Asia in the STEPS, 2015-2035



IEA. CC BY 4.0.

Southeast Asia is set to become a net importer of natural gas over the course of the next decade, while oil import dependency continues to increase

Note: mb/d = million barrels per day; bcm = billion cubic metres; Mtce = million tonnes of coal equivalent.

Coal production in Southeast Asia surged from 400 Mtce to 670 Mtce between 2015 and 2024 as a result of rising consumption in the power sector and robust demand for exports, notably from China and India. The next decade, however, is set to mark a turnaround: in the STEPS, a slowdown in the rate of growth of domestic coal consumption and falling exports of Indonesian coal to China lead to a sustained decline in regional coal production to around

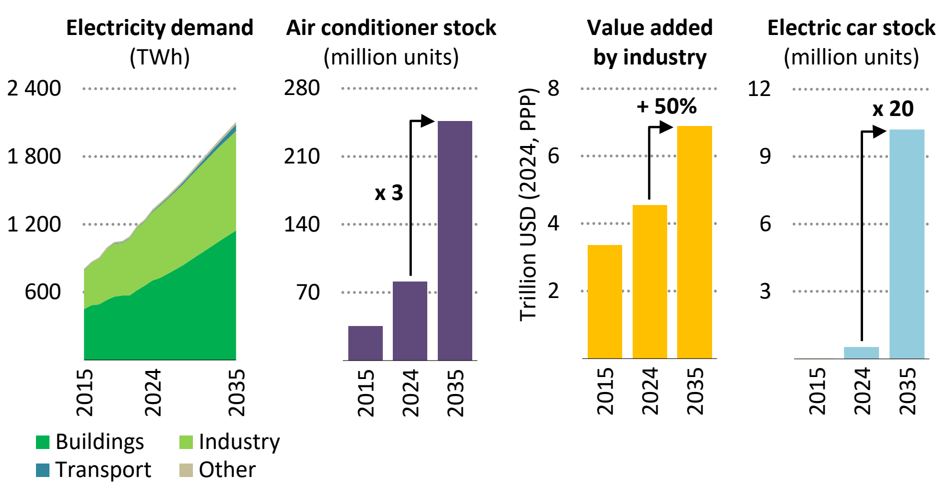
500 Mtce in 2035 (Figure 8.36). In the CPS, higher demand means that coal production declines more slowly than in the STEPS.

8.11.2 Unpacking the fast growth of electricity demand and supply

Southeast Asia recorded the second-fastest rate of electricity demand growth in 2024 among major regions and countries: only in China did it increase more rapidly. Demand was up by 7% year-on-year, rising to 1 300 TWh, with Indonesia seeing the fastest rate of growth at over 9%. The rate of growth in 2024 was in line with the trend in recent years. Since 2015, the electricity demand in Southeast Asia has increased by 65%, with non-energy-intensive industries accounting for over 40% of it, supported by electrification of their processes. Today, its industrial electrification rate is comparable to that of the European Union.

Southeast Asia remains one of the world's fastest growing regions for industrial production to 2035. In the STEPS, electricity demand rises by around 4% a year to reach 2 100 TWh by 2035 (Figure 8.37). Efficiency gains moderate demand growth, which would otherwise rise to about 6% per year. Non-energy-intensive industries account for more than 25% of the electricity demand growth to 2035. Annual demand from data centres increases from just over 10 TWh today to 25 TWh by 2030. Much of the data centre demand is concentrated in Singapore and the Johor province of Malaysia.

Figure 8.37 ▷ Electricity demand by sector and drivers of growth in Southeast Asia in the STEPS, 2015-2035



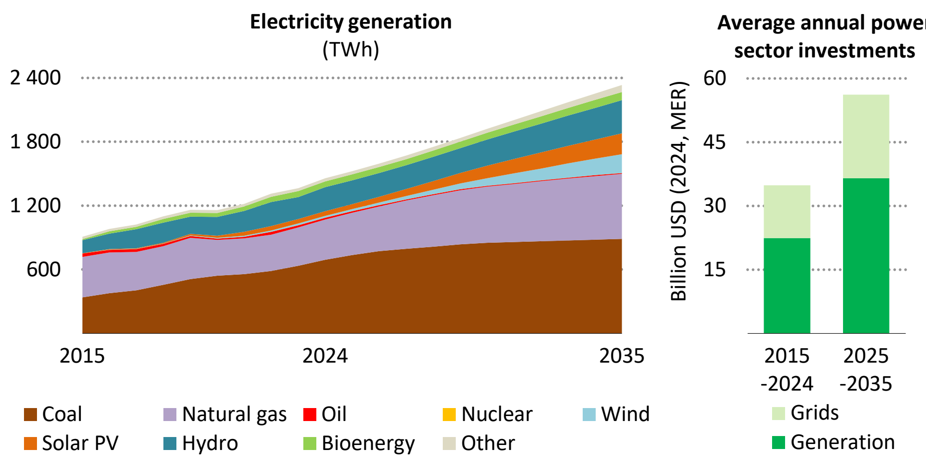
IEA. CC BY 4.0.

Rapid electricity demand growth since 2015 continues to increase to 2035, driven by rising cooling demand and non-energy-intensive industries output

Note: TWh = terawatt-hour; USD = United States dollar; PPP = purchasing power parity.

Space cooling accounts for about a quarter of the electricity demand increase to 2035. Today, despite having among the highest cooling needs in the world, fewer than 30% of households in Southeast Asia have air conditioning. By 2035, the ownership ratio more than doubles in the STEPS to about the levels seen in advanced economies today. Over 30% of new cars sold by 2035 are electric in the STEPS, and around 15% in the CPS, up from around 10% today. The impact on overall electricity demand growth is small, but EVs displace around 0.5 mb/d of oil use in the STEPS by 2035, making oil demand 6% lower than it would be otherwise.

Figure 8.38 ▷ Electricity generation by source and average annual power sector investment in Southeast Asia in the STEPS, 2015-2035



Natural gas, coal, wind and solar PV supply most of the additional power needed by 2035 in the STEPS and power sector investment increases significantly

Notes: TWh = terawatt-hour; MER = market exchange rate. Other includes marine, concentrating solar power, waste-to-energy and other sources.

Coal has met most of the increase in electricity demand over the past two decades in Southeast Asia. Demand for coal continues to rise in the STEPS, but it is supplanted by natural gas as the largest source of additional electricity. Meanwhile additions of wind and solar PV capacity accelerate, supported by policy initiatives and declining costs, and combined they account for 35% of the additional electricity generated in 2035 in the STEPS. Towards 2035, battery storage plays an increasingly important role to help integrate the rising share of variable renewables into the power grids, together with grid modernisation, demand response and measures to increase the flexibility of the conventional power plant fleet. Nuclear enters the supply mix after 2035, with both Indonesia and Viet Nam seeking to commission their first reactors by the middle of the next decade. Coal-fired electricity generation increases more strongly in the CPS, driven by slower uptake of wind and solar PV.

Meeting the projected growth in electricity demand and ensuring security of supply will require scaling up investment in generation, domestic networks and interconnections. In the STEPS, total power sector investment increases 80% to USD 60 billion in 2035 (Figure 8.38). Various sources of finance will be required to support the region's energy and sustainability objectives, including a role for transition finance (Box 8.3). However, regulatory barriers, policy instability, high interest rates and a lack of public financial commitments remain barriers for the mobilisation of the necessary capital in the Southeast Asian emerging economies.

Box 8.3 ▹ Role of transition finance in Southeast Asia and the world

Actions by the most emissions-intensive sectors, companies and countries are crucial to placing the world on a sustainable path, and efforts within the Southeast Asian region hold a position of particular importance. While there is strong attention on supporting green investment in the region, and such support will need to remain a priority going forward, such investment alone cannot deliver all the change needed to cut emissions, especially in areas where clean technologies are not yet commercially available or cost competitive. Transition finance can help emissions-intensive countries, companies, and sectors shift over time towards sustainable practices, aligned with long-term climate and development goals.

At present, transition finance flows in Southeast Asia and elsewhere remain modest. But scenarios consistent with national or global emissions reduction targets suggest that USD 400-500 billion per year in transition finance could be mobilised over the next decade. This totals to USD 4-5 trillion in this period, with more than half directed to emerging market and developing economies. This is comparable in scale to the current global green bond market. Uptake has been slowed thus far by challenges associated with defining transition finance, but with credible government and corporate strategies, transition finance can help unlock investment for projects that fall outside the green finance label but are nonetheless essential for sustainable transitions (IEA, 2025f).

Guidance on applying transition finance in Southeast Asia was prepared in the framework of the ASEAN Capital Markets Forum, a group of capital market regulators (ACMF, 2024). Recognising that not every company in the region is able to commit to a 1.5 °C target, the framework introduced a tiered approach to enable companies to be categorised as aligned and aligning to 1.5 °C, aligned and aligning to well below 2 °C, or those that are 'progressing', referring to companies that have not yet committed to these targets, but are taking steps to align in the near future. The guidance provides entities with a framework to evaluate and demonstrate a credible transition in the region and to facilitate access to financing. It also recognises the need for flexibility to accommodate the region's small and medium-size enterprises that may otherwise lack the capacity and expertise to participate in the market for transition finance.

ANNEXES

Box A.1 ▻ *World Energy Outlook* links

WEO homepage

WEO-2025 information **iea.li/WEO2025**

WEO-2025 datasets

Data in Annex A is available to download for free in electronic format at:
iea.li/weo-data

An extended dataset, including the data behind figures, tables and the *WEO-2025* slide deck is available to purchase at:
iea.li/weo-extended-data

Modelling

Documentation and methodology / Investment costs
iea.li/model

Recent analysis

The Future of Geothermal Energy

The Path to a New Era for Nuclear Energy

Energy and AI

Global Methane Tracker 2025

Global EV Outlook 2025

Global Critical Minerals Outlook 2025

World Energy Investment 2025

Outlook for Biogas and Biomethane

Universal Access to Clean Cooking in Africa

The Implications of Oil and Gas Field Decline Rates

The Future of Electricity in the Middle East and North Africa

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

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 total final 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) Current Policies Scenario (CPS) [Tables A.1a. to A.5a]; (b) Stated Policies Scenario (STEPS) [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 CPS and the STEPS 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.23: Electricity demand and electricity generation by total and by source (renewables, solar photovoltaics [PV], wind, nuclear, natural gas, coal) in terawatt-hours (TWh).
- Tables A.24 – A.27: Total final consumption and consumption by sector (industry, transport and buildings) in exajoules (EJ).
- Tables A.28 – A.29: Hydrogen demand (PJ) and the low-emissions hydrogen balance in million tonnes of hydrogen equivalent (Mt H_2 equivalent).
- Tables A.30 – A.32: Total carbon dioxide (CO_2) emissions, electricity and heat sectors CO_2 emissions, final consumption in million tonnes of CO_2 emissions (Mt CO_2).

Tables A.6 to A.32 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.

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. Use of fossil fuels in facilities without CCUS is classified as "unabated".

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 2023, 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 2024 estimates for energy production and demand in this annex. Estimates for the year 2024 are based on the IEA *Global Energy Review 2025* 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 2025 data, based on the IEA *World Energy Investment 2025* report. Historical data for gross power generation capacity (Table A.3) are drawn from the Power Plant Units database and the World Electric Power Plants 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 both published by Global Energy Monitor.

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

[1] The quarterly published S&P World Electric Power Plants database has been discontinued with March 2023 the last edition. This product has been largely subsumed into the online 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, historical capacity differences may be observed and in particular for fossil-fuelled power plant compared to the *WEO-2023* and earlier editions.

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, hydrogen based fuels 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.

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. include 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 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. For tables A.30 and A.32 the total CO_2 emissions for world include international aviation and shipping 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 truck 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 metre; Mt = million tonnes; pkm = passenger-kilometres; PPP = purchasing power parity; tkm = tonne-kilometre.

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 hydrogen balance table A.29 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

[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.

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

				Current Policies (EJ)			Shares (%)			CAAGR (%) 2024 to:	
	2010	**2023**	**2024**	**2035**	**2040**	**2050**	**2024**	**2035**	**2050**	**2035**	**2050**
Total energy supply	**536**	**641**	**654**	**744**	**777**	**838**	**100**	**100**	**100**	**1.2**	**1.0**
Renewables	43	78	83	142	169	217	13	19	26	5.1	3.8
Solar	1	8	9	35	47	66	1	5	8	13	7.8
Wind	1	8	9	23	28	35	1	3	4	8.7	5.4
Hydro	12	15	16	18	20	23	2	2	3	1.3	1.3
Modern solid bioenergy	23	35	37	47	51	59	6	6	7	2.3	1.8
Modern liquid bioenergy	2	5	5	7	8	11	1	1	1	3.2	3.2
Modern gaseous bioenergy	1	2	2	3	4	6	0	0	1	5.3	5.3
Traditional use of biomass	21	19	19	17	16	14	3	2	2	-1.0	-1.0
Nuclear	30	30	31	42	49	57	5	6	7	2.9	2.4
Natural gas	115	144	148	175	182	194	23	24	23	1.6	1.1
Unabated	109	136	139	164	170	182	21	22	22	1.5	1.0
With CCUS	0	1	1	2	2	2	0	0	0	9.9	4.8
Oil	174	192	193	201	204	215	30	27	26	0.4	0.4
Non-energy use	26	31	32	41	43	47	5	5	6	2.2	1.5
Coal	153	176	178	165	155	138	27	22	17	-0.7	-1.0
Unabated	151	173	175	160	150	134	27	22	16	-0.8	-1.0
With CCUS	-	0	0	0	0	0	0	0	0	25	13
Electricity and heat sectors	**200**	**257**	**265**	**321**	**343**	**378**	**100**	**100**	**100**	**1.8**	**1.4**
Renewables	20	44	48	97	119	156	18	30	41	6.7	4.7
Solar PV	0	6	7	33	43	61	3	10	16	14	8.4
Wind	1	8	9	23	28	35	3	7	9	8.7	5.4
Hydro	12	15	16	18	20	23	6	6	6	1.3	1.3
Bioenergy	4	10	10	15	16	19	4	5	5	3.4	2.5
Hydrogen	-	-	-	0	0	0	-	0	0	n.a.	n.a.
Ammonia	-	-	-	0	0	0	-	0	0	n.a.	n.a.
Nuclear	30	30	31	42	49	57	12	13	15	2.9	2.4
Unabated natural gas	47	58	60	69	71	76	23	22	20	1.4	1.0
Natural gas with CCUS	-	-	-	0	0	0	-	0	0	n.a.	n.a.
Oil	11	9	8	4	3	2	3	1	0	-7.1	-5.6
Unabated coal	91	115	117	108	100	85	44	34	22	-0.8	-1.2
Coal with CCUS	-	0	0	0	0	0	0	0	0	33	17
Other energy sector	**50**	**67**	**69**	**77**	**80**	**91**	**100**	**100**	**100**	**1.0**	**1.0**
Biofuels conversion losses	-	6	7	9	10	13	100	100	100	2.6	2.6
Low-emissions hydrogen (offsite)											
Production inputs	-	0	0	2	3	5	100	100	100	n.a.	n.a.
Production outputs	-	0	0	1	2	4	100	100	100	52	25
For hydrogen-based fuels	-	-	0	0	1	2	9	46	60	76	34

Table A.2a: World total final consumption

				Current Policies (EJ)			Shares (%)			CAAGR (%) 2024 to:	
	2010	2023	2024	2035	2040	2050	2024	2035	2050	2035	2050
Total final consumption	**378**	**444**	**453**	**523**	**549**	**599**	**100**	**100**	**100**	**1.3**	**1.1**
Electricity	64	91	95	131	145	172	21	25	29	2.9	2.3
Liquid fuels	154	178	180	195	200	216	40	37	36	0.7	0.7
Biofuels	2	5	5	7	8	11	1	1	2	3.2	3.2
Ammonia	-	-	-	0	0	0	-	0	0	n.a.	n.a.
Synthetic oil	-	-	-	0	0	1	-	0	0	n.a.	n.a.
Oil	152	173	175	187	192	204	39	36	34	0.7	0.6
Gaseous fuels	57	71	73	89	94	102	16	17	17	1.8	1.3
Biomethane	0	0	0	1	1	3	0	0	1	9.1	8.8
Hydrogen	-	0	0	0	0	1	0	0	0	31	18
Synthetic methane	-	-	-	-	-	-	-	-	-	n.a.	n.a.
Natural gas	57	70	72	87	91	97	16	17	16	1.7	1.1
Solid fuels	90	87	87	87	87	87	19	17	14	0.0	-0.0
Solid bioenergy	33	35	35	36	37	38	8	7	6	0.3	0.3
Coal	56	51	51	50	50	48	11	10	8	-0.2	-0.2
Heat	12	16	16	19	19	19	4	4	3	1.3	0.6
Industry	**142**	**170**	**174**	**205**	**214**	**229**	**100**	**100**	**100**	**1.5**	**1.1**
Electricity	27	39	40	50	52	57	23	24	25	1.9	1.3
Liquid fuels	29	33	34	42	45	49	19	21	21	2.0	1.4
Oil	29	33	34	42	45	48	19	21	21	2.0	1.4
Gaseous fuels	24	32	33	41	44	49	19	20	22	2.1	1.6
Biomethane	0	0	0	0	1	1	0	0	1	9.8	9.4
Hydrogen	-	-	0	0	0	0	0	0	0	13	5.5
Unabated natural gas	21	28	29	36	39	43	17	18	19	2.0	1.5
Natural gas with CCUS	0	0	0	0	0	0	0	0	0	8.5	3.5
Solid fuels	57	58	58	62	63	64	33	30	28	0.5	0.4
Modern solid bioenergy	8	11	11	14	15	17	7	7	7	1.9	1.6
Unabated coal	48	44	44	44	44	43	25	21	19	0.1	-0.0
Coal with CCUS	-	0	0	0	0	0	0	0	0	3.5	0.9
Heat	5	9	9	10	10	10	5	5	4	1.2	0.6
Chemicals	37	50	52	64	67	72	30	31	31	1.9	1.3
Iron and steel	31	37	36	37	38	39	21	18	17	0.3	0.3
Cement	10	12	11	12	12	12	7	6	5	0.2	0.1
Aluminium	5	7	7	8	8	9	4	4	4	1.0	0.8

Table A.2a: World total final consumption (continued)

				Current Policies (EJ)			Shares (%)			CAGR (%) 2024 to:	
	2010	2023	2024	2035	2040	2050	2024	2035	2050	2035	2050
Transport	**102**	**123**	**125**	**140**	**147**	**163**	**100**	**100**	**100**	**1.1**	**1.0**
Electricity	1	2	2	7	9	12	2	5	8	12	7.3
Liquid fuels	97	116	117	124	127	139	94	88	85	0.5	0.7
Biofuels	2	5	5	7	8	11	4	5	7	3.2	3.2
Oil	95	111	112	117	118	127	90	83	78	0.4	0.5
Gaseous fuels	4	5	5	9	10	12	4	7	7	4.9	3.1
Biomethane	0	0	0	0	0	1	0	0	1	8.7	9.3
Hydrogen	-	0	0	0	0	1	0	0	1	30	18
Natural gas	4	5	5	9	10	10	4	6	6	4.6	2.4
Road	76	93	93	101	105	115	75	72	70	0.7	0.8
Passenger cars	39	48	48	48	49	54	39	35	33	0.0	0.5
Heavy-duty trucks	23	29	29	36	38	43	24	25	26	1.7	1.4
Aviation	11	13	14	19	21	25	11	14	15	2.8	2.2
Shipping	10	11	11	14	15	17	9	10	11	1.9	1.6
Buildings	**112**	**124**	**127**	**146**	**154**	**171**	**100**	**100**	**100**	**1.3**	**1.2**
Electricity	35	47	49	69	77	95	38	47	56	3.2	2.6
Liquid fuels	13	13	13	11	10	9	10	7	5	-1.6	-1.1
Biofuels	-	-	-	0	0	0	-	0	0	n.a.	n.a.
Oil	13	13	13	11	10	9	10	7	5	-1.6	-1.1
Gaseous fuels	27	29	30	32	33	34	23	22	20	0.8	0.6
Biomethane	0	0	0	0	0	1	0	0	0	8.6	7.6
Hydrogen	-	-	-	0	0	0	-	0	0	n.a.	n.a.
Natural gas	26	29	29	32	32	33	23	22	19	0.7	0.5
Solid fuels	31	27	26	23	22	20	21	16	12	-1.3	-1.0
Modern solid bioenergy	4	4	4	5	5	5	3	3	3	1.2	1.0
Traditional use of biomass	21	19	19	17	16	14	15	12	8	-1.0	-1.0
Coal	6	3	3	1	1	0	3	1	0	-8.5	-7.2
Heat	6	7	8	9	9	9	6	6	5	1.4	0.5
Residential	78	85	86	95	99	109	68	65	64	0.8	0.9
Services	34	39	40	51	55	62	32	35	36	2.2	1.7

Table A.3a: World electricity sector

				Current Policies (TWh)			Shares (%)			CAAGR (%) 2024 to:	
	2010	2023	2024	2035	2040	2050	2024	2035	2050	2035	2050
Total generation	**21 519**	**29 975**	**31 229**	**45 109**	**50 488**	**59 426**	**100**	**100**	**100**	**3.4**	**2.5**
Renewables	4 207	9 011	9 935	21 940	27 040	35 441	32	49	60	7.5	5.0
Solar PV	32	1 605	2 073	9 068	12 033	17 015	7	20	29	14	8.4
Wind	342	2 333	2 533	6 327	7 806	9 855	8	14	17	8.7	5.4
Hydro	3 453	4 249	4 448	5 132	5 502	6 287	14	11	11	1.3	1.3
Bioenergy	310	709	760	1 140	1 269	1 550	2	3	3	3.8	2.8
of which BECCS	-	-	-	4	4	4	-	0	0	n.a.	n.a.
CSP	2	16	20	60	117	234	0	0	0	11	10
Geothermal	68	98	100	199	276	418	0	0	1	6.4	5.6
Marine	1	1	1	14	36	82	0	0	0	28	19
Nuclear	2 756	2 740	2 835	3 856	4 445	5 192	9	9	9	2.8	2.4
Hydrogen and ammonia	-	-	-	54	77	87	-	0	0	n.a.	n.a.
Fossil fuels with CCUS	-	1	1	16	37	44	0	0	0	31	17
Coal with CCUS	-	1	1	14	27	33	0	0	0	29	15
Natural gas with CCUS	-	-	-	2	10	10	-	0	0	n.a.	n.a.
Unabated fossil fuels	14 468	18 099	18 338	19 150	18 803	18 572	59	42	31	0.4	0.0
Coal	8 680	10 686	10 797	10 308	9 619	8 462	35	23	14	-0.4	-0.9
Natural gas	4 819	6 630	6 785	8 517	8 921	9 951	22	19	17	2.1	1.5
Oil	968	783	757	325	263	160	2	1	0	-7.4	-5.8

				Current Policies (GW)			Shares (%)			CAAGR (%) 2024 to:	
	2010	2023	2024	2035	2040	2050	2024	2035	2050	2035	2050
Total capacity	**5 254**	**9 441**	**10 249**	**20 045**	**23 691**	**28 941**	**100**	**100**	**100**	**6.3**	**4.1**
Renewables	1 332	4 249	4 935	12 652	15 665	20 023	48	63	69	8.9	5.5
Solar PV	40	1 625	2 164	8 067	10 415	13 804	21	40	48	13	7.4
Wind	181	1 016	1 131	2 552	2 995	3 561	11	13	12	7.7	4.5
Hydro	1 026	1 410	1 437	1 730	1 891	2 174	14	9	8	1.7	1.6
Bioenergy	73	175	181	247	274	327	2	1	1	2.9	2.3
of which BECCS	-	-	-	1	1	1	-	0	0	n.a.	n.a.
CSP	1	7	8	20	34	65	0	0	0	9.2	8.6
Geothermal	10	15	15	30	41	60	0	0	0	6.2	5.3
Marine	0	1	1	6	15	32	0	0	0	25	17
Nuclear	401	415	420	563	638	728	4	3	3	2.7	2.1
Hydrogen and ammonia	-	-	-	16	25	28	-	0	0	n.a.	n.a.
Fossil fuels with CCUS	-	0	0	4	10	12	0	0	0	40	20
Coal with CCUS	-	0	0	4	8	10	0	0	0	38	19
Natural gas with CCUS	-	-	-	1	3	3	-	0	0	n.a.	n.a.
Unabated fossil fuels	3 509	4 669	4 708	5 383	5 409	5 380	46	27	19	1.2	0.5
Coal	1 615	2 240	2 259	2 550	2 451	2 115	22	13	7	1.1	-0.3
Natural gas	1 467	2 024	2 049	2 555	2 720	3 110	20	13	11	2.0	1.6
Oil	426	406	401	279	238	154	4	1	1	-3.2	-3.6
Battery storage	1	89	166	1 414	1 934	2 760	2	7	10	21	11

Table A.4a: World CO_2 emissions

				Current Policies (Mt CO_2)			CAAGR (%) 2024 to:	
	2010	2023	2024	2035	2040	2050	2035	2050
Total CO_2*	**32 854**	**37 820**	**38 153**	**38 503**	**38 126**	**37 779**	**0.1**	**-0.0**
Combustion activities (+)	**30 619**	**34 871**	**35 233**	**35 442**	**34 987**	**34 573**	**0.1**	**-0.1**
Coal	13 806	15 575	15 730	14 662	13 842	12 303	-0.6	-0.9
Oil	10 548	11 403	11 451	11 380	11 411	11 870	-0.1	0.1
Natural gas	6 077	7 608	7 768	9 152	9 498	10 167	1.5	1.0
Bioenergy and waste	187	286	284	248	236	233	-1.2	-0.8
Other removals (-)**	**-**	**1**	**1**	**3**	**3**	**8**	**10**	**8.6**
Biofuels production	-	1	1	2	2	7	7.7	8.3
Direct air capture	-	0	0	1	1	1	44	17
Electricity and heat sectors	**12 525**	**15 311**	**15 588**	**14 794**	**14 035**	**12 809**	**-0.5**	**-0.8**
Coal	8 958	11 254	11 458	10 511	9 704	8 264	-0.8	-1.2
Oil	828	653	637	286	233	144	-7.0	-5.5
Natural gas	2 625	3 256	3 345	3 880	3 991	4 291	1.4	1.0
Bioenergy and waste	115	148	148	117	107	110	-2.1	-1.1
Other energy sector**	**1 441**	**1 627**	**1 631**	**1 707**	**1 714**	**1 741**	**0.4**	**0.3**
Final consumption**	**18 630**	**20 609**	**20 657**	**21 776**	**22 149**	**22 991**	**0.5**	**0.4**
Coal	4 646	4 218	4 171	4 057	4 047	3 952	-0.3	-0.2
Oil	9 086	10 144	10 223	10 539	10 640	11 218	0.3	0.4
Natural gas	2 867	3 543	3 604	4 345	4 555	4 858	1.7	1.2
Bioenergy and waste	72	136	136	131	129	124	-0.3	-0.4
Industry**	8 249	9 074	9 057	9 866	10 141	10 390	0.8	0.5
Chemicals**	1 163	1 362	1 394	1 631	1 693	1 725	1.4	0.8
Iron and steel**	2 120	2 761	2 750	2 796	2 837	2 866	0.2	0.2
Cement**	1 980	2 409	2 324	2 411	2 451	2 433	0.3	0.2
Aluminium**	176	241	251	280	290	313	1.0	0.9
Transport	7 022	8 278	8 358	8 856	9 017	9 626	0.5	0.5
Road	5 219	6 219	6 232	6 313	6 328	6 688	0.1	0.3
Passenger cars	2 634	3 193	3 208	3 006	2 967	3 119	-0.6	-0.1
Heavy-duty trucks	1 586	1 956	1 968	2 218	2 290	2 478	1.1	0.9
Aviation	758	957	1 018	1 325	1 449	1 641	2.4	1.9
Shipping	798	825	847	976	1 000	1 060	1.3	0.9
Buildings	2 917	2 812	2 802	2 605	2 541	2 524	-0.7	-0.4
Residential	1 960	1 921	1 911	1 767	1 731	1 726	-0.7	-0.4
Services	957	891	891	838	810	797	-0.6	-0.4
Total CO_2 removals**	**-**	**1**	**1**	**5**	**5**	**10**	**17**	**9.5**
Total CO_2 captured**	**16**	**44**	**43**	**151**	**201**	**271**	**12**	**7.3**

*Includes industrial process and flaring emissions.
**Includes industrial process emissions.

Table A.5a: World economic and activity indicators

	2010	2023	2024	Current Policies 2035	2040	2050	CAAGR (%) 2024 to: 2035	2050
Indicators								
Population (million)	6 967	8 022	8 091	8 805	9 093	9 572	0.8	0.6
GDP (USD 2024 billion, PPP)	127 344	190 196	196 346	270 572	307 510	384 635	3.0	2.6
GDP per capita (USD 2024, PPP)	18 277	23 710	24 267	30 729	33 819	40 183	2.2	2.0
TES/GDP (GJ per USD 1 000, PPP)	4.2	3.4	3.3	2.8	2.5	2.2	-1.7	-1.6
TFC/GDP (GJ per USD 1 000, PPP)	2.8	2.2	2.2	1.9	1.7	1.5	-1.5	-1.4
CO_2 intensity of electricity generation (g CO_2 per kWh)	529	457	446	291	246	192	-3.8	-3.2
Industrial production (Mt)								
Primary chemicals	508	732	754	951	1 009	1 081	2.1	1.4
Steel	1 435	1 903	1 883	2 090	2 205	2 407	1.0	0.9
Cement	3 280	4 110	3 950	4 200	4 314	4 364	0.6	0.4
Aluminium	60	108	113	137	147	169	1.8	1.6
Transport								
Passenger cars (billion pkm)	16 342	25 096	25 835	34 223	38 708	46 344	2.6	2.3
Heavy-duty trucks (billion tkm)	25 614	34 657	35 104	46 923	52 391	62 458	2.7	2.2
Aviation (billion pkm)	5 157	8 408	9 323	13 894	15 788	19 440	3.7	2.9
Shipping (billion tkm)	80 106	115 314	121 712	144 701	156 402	184 138	1.6	1.6
Buildings								
Households (million)	1 836	2 256	2 284	2 595	2 728	2 967	1.2	1.0
Residential floor area (million m^2)	161 023	207 792	211 202	251 379	269 221	301 970	1.6	1.4
Services floor area (million m^2)	41 067	60 433	61 779	77 407	83 458	93 357	2.1	1.6

Table A.1b: World energy supply

	2010	2023	2024	Stated Policies (EJ) 2035	2040	2050	Shares (%) 2024	2035	2050	CAAGR (%) 2024 to: 2035	2050
Total energy supply	**536**	**641**	**654**	**708**	**717**	**747**	**100**	**100**	**100**	**0.7**	**0.5**
Renewables	43	78	83	149	179	233	13	21	31	5.5	4.1
Solar	1	8	9	40	54	79	1	6	11	14	8.5
Wind	1	8	9	25	31	40	1	4	5	9.6	5.8
Hydro	12	15	16	19	20	23	2	3	3	1.3	1.4
Modern solid bioenergy	23	35	37	47	49	56	6	7	7	2.2	1.7
Modern liquid bioenergy	2	5	5	7	8	9	1	1	1	3.1	2.4
Modern gaseous bioenergy	1	2	2	3	5	9	0	0	1	6.7	6.4
Traditional use of biomass	21	19	19	14	13	10	3	2	1	-2.7	-2.3
Nuclear	30	30	31	43	50	61	5	6	8	3.0	2.6
Natural gas	115	144	148	165	165	161	23	23	22	1.0	0.3
Unabated	109	136	139	155	153	149	21	22	20	0.9	0.3
With CCUS	0	1	1	1	2	2	0	0	0	9.5	5.1
Oil	174	192	193	192	187	184	30	27	25	-0.1	-0.2
Non-energy use	26	31	32	39	41	44	5	6	6	1.8	1.2
Coal	153	176	178	143	121	95	27	20	13	-2.0	-2.4
Unabated	151	173	175	139	116	91	27	20	12	-2.1	-2.5
With CCUS	-	0	0	0	0	1	0	0	0	26	14
Electricity and heat sectors	**200**	**257**	**265**	**306**	**318**	**348**	**100**	**100**	**100**	**1.3**	**1.1**
Renewables	20	44	48	103	130	174	18	34	50	7.3	5.1
Solar PV	0	6	7	36	50	73	3	12	21	15	9.2
Wind	1	8	9	25	31	40	3	8	11	9.6	5.8
Hydro	12	15	16	19	20	23	6	6	7	1.3	1.4
Bioenergy	4	10	10	15	16	20	4	5	6	3.5	2.5
Hydrogen	-	-	-	0	0	0	-	0	0	n.a.	n.a.
Ammonia	-	-	-	0	0	0	-	0	0	n.a.	n.a.
Nuclear	30	30	31	43	50	61	12	14	18	3.0	2.6
Unabated natural gas	47	58	60	65	63	60	23	21	17	0.8	-0.0
Natural gas with CCUS	-	-	-	0	0	0	-	0	0	n.a.	n.a.
Oil	11	9	8	3	3	2	3	1	0	-8.6	-6.2
Unabated coal	91	115	117	90	71	50	44	30	14	-2.3	-3.2
Coal with CCUS	-	0	0	0	0	0	0	0	0	33	17
Other energy sector	**50**	**67**	**69**	**75**	**76**	**83**	**100**	**100**	**100**	**0.7**	**0.7**
Biofuels conversion losses	-	6	7	9	9	11	100	100	100	2.6	2.0
Low-emissions hydrogen (offsite)											
Production inputs	-	0	0	2	3	6	100	100	100	n.a.	n.a.
Production outputs	-	0	0	1	2	4	100	100	100	54	26
For hydrogen-based fuels	-	-	0	0	1	2	9	40	51	76	34

Table A.2b: World total final consumption

				Stated Policies (EJ)			Shares (%)			CAAGR (%) 2024 to:	
	2010	2023	2024	2035	2040	2050	2024	2035	2050	2035	2050
Total final consumption	**378**	**444**	**453**	**504**	**516**	**541**	**100**	**100**	**100**	**1.0**	**0.7**
Electricity	64	91	95	130	144	169	21	26	31	2.9	2.2
Liquid fuels	154	178	180	186	184	184	40	37	34	0.3	0.1
Biofuels	2	5	5	7	8	9	1	1	2	3.1	2.4
Ammonia	-	-	-	0	0	0	-	0	0	n.a.	n.a.
Synthetic oil	-	-	-	0	0	1	-	0	0	n.a.	n.a.
Oil	152	173	175	179	176	174	39	35	32	0.2	-0.0
Gaseous fuels	57	71	73	85	87	91	16	17	17	1.4	0.8
Biomethane	0	0	0	1	2	5	0	0	1	13	11
Hydrogen	-	0	0	0	1	1	0	0	0	35	20
Synthetic methane	-	-	-	-	-	-	-	-	-	n.a.	n.a.
Natural gas	57	70	72	83	84	83	16	16	15	1.3	0.6
Solid fuels	90	87	87	81	79	75	19	16	14	-0.7	-0.6
Solid bioenergy	33	35	35	34	34	34	8	7	6	-0.3	-0.1
Coal	56	51	51	46	45	40	11	9	7	-0.9	-0.9
Heat	12	16	16	19	19	18	4	4	3	1.2	0.4
Industry	**142**	**170**	**174**	**197**	**203**	**210**	**100**	**100**	**100**	**1.2**	**0.7**
Electricity	27	39	40	51	53	58	23	26	28	2.1	1.4
Liquid fuels	29	33	34	40	42	43	19	20	20	1.5	0.9
Oil	29	33	34	40	41	43	19	20	20	1.5	0.9
Gaseous fuels	24	32	33	39	41	43	19	20	21	1.5	1.1
Biomethane	0	0	0	1	1	2	0	0	1	13	11
Hydrogen	-	-	0	0	0	0	0	0	0	36	17
Unabated natural gas	21	28	29	34	35	36	17	17	17	1.3	0.8
Natural gas with CCUS	0	0	0	0	0	0	0	0	0	10	5.9
Solid fuels	57	58	58	58	58	56	33	29	27	-0.0	-0.1
Modern solid bioenergy	8	11	11	14	15	17	7	7	8	1.9	1.6
Unabated coal	48	44	44	40	39	36	25	20	17	-0.7	-0.8
Coal with CCUS	-	0	0	0	0	0	0	0	0	12	5.2
Heat	5	9	9	10	10	10	5	5	5	1.0	0.3
Chemicals	37	50	52	61	64	65	30	31	31	1.6	0.9
Iron and steel	31	37	36	36	36	35	21	18	17	-0.2	-0.1
Cement	10	12	11	11	11	11	7	6	5	-0.0	-0.2
Aluminium	5	7	7	8	8	8	4	4	4	0.6	0.3

Table A.2b: World total final consumption (continued)

				Stated Policies (EJ)			Shares (%)			CAAGR (%) 2024 to:	
	2010	2023	2024	2035	2040	2050	2024	2035	2050	2035	2050
Transport	**102**	**123**	**125**	**135**	**137**	**144**	**100**	**100**	**100**	**0.8**	**0.6**
Electricity	1	2	2	8	12	18	2	6	11	13	8.7
Liquid fuels	97	116	117	118	115	115	94	84	70	0.1	-0.1
Biofuels	2	5	5	7	7	9	4	5	5	3.0	2.3
Oil	95	111	112	111	107	105	90	79	64	-0.1	-0.3
Gaseous fuels	4	5	5	9	10	12	4	7	7	4.9	2.9
Biomethane	0	0	0	0	1	2	0	0	1	12	11
Hydrogen	-	0	0	0	1	1	0	0	1	34	20
Natural gas	4	5	5	9	9	9	4	6	5	4.4	1.9
Road	76	93	93	97	97	100	75	70	61	0.4	0.3
Passenger cars	39	48	48	46	45	45	39	33	28	-0.4	-0.2
Heavy-duty trucks	23	29	29	35	37	41	24	25	25	1.6	1.3
Aviation	11	13	14	19	21	24	11	14	15	2.9	2.1
Shipping	10	11	11	13	13	14	9	9	8	1.2	0.8
Buildings	**112**	**124**	**127**	**140**	**143**	**154**	**100**	**100**	**100**	**0.9**	**0.7**
Electricity	35	47	49	66	73	86	38	45	50	2.8	2.2
Liquid fuels	13	13	13	10	9	8	10	7	5	-2.0	-1.6
Biofuels	-	-	-	0	0	0	-	0	0	n.a.	n.a.
Oil	13	13	13	10	9	8	10	7	5	-2.0	-1.6
Gaseous fuels	27	29	30	31	31	30	23	21	18	0.5	0.0
Biomethane	0	0	0	0	1	1	0	0	1	12	9.3
Hydrogen	-	-	-	0	0	0	-	0	0	n.a.	n.a.
Natural gas	26	29	29	30	30	28	23	21	16	0.3	-0.2
Solid fuels	31	27	26	20	19	17	21	14	10	-2.4	-1.8
Modern solid bioenergy	4	4	4	5	5	6	3	3	3	1.8	1.2
Traditional use of biomass	21	19	19	14	13	10	15	10	6	-2.7	-2.3
Coal	6	3	3	1	1	0	3	1	0	-8.8	-8.6
Heat	6	7	8	9	9	9	6	6	5	1.4	0.5
Residential	78	85	86	90	92	98	68	62	57	0.4	0.5
Services	34	39	40	50	52	56	32	34	33	1.9	1.3

Table A.3b: World electricity sector

				Stated Policies (TWh)			Shares (%)			CAAGR (%) 2024 to:	
	2010	2023	2024	2035	2040	2050	2024	2035	2050	2035	2050
Total generation	**21 519**	**29 975**	**31 229**	**44 274**	**49 114**	**58 081**	**100**	**100**	**100**	**3.2**	**2.4**
Renewables	4 207	9 011	9 935	23 603	29 880	40 107	32	53	69	8.2	5.5
Solar PV	32	1 605	2 073	10 113	14 007	20 374	7	23	35	15	9.2
Wind	342	2 333	2 533	6 917	8 609	10 991	8	16	19	9.6	5.8
Hydro	3 453	4 249	4 448	5 141	5 534	6 383	14	12	11	1.3	1.4
Bioenergy	310	709	760	1 147	1 278	1 575	2	3	3	3.8	2.8
of which BECCS	-	-	-	5	5	5	-	0	0	n.a.	n.a.
CSP	2	16	20	61	120	245	0	0	0	11	10
Geothermal	68	98	100	209	295	452	0	0	1	6.9	6.0
Marine	1	1	1	14	37	86	0	0	0	28	19
Nuclear	2 756	2 740	2 835	3 902	4 584	5 531	9	9	10	2.9	2.6
Hydrogen and ammonia	-	-	-	54	77	86	-	0	0	n.a.	n.a.
Fossil fuels with CCUS	-	1	1	19	46	53	0	0	0	33	17
Coal with CCUS	-	1	1	14	29	37	0	0	0	30	16
Natural gas with CCUS	-	-	-	5	17	16	-	0	0	n.a.	n.a.
Unabated fossil fuels	14 468	18 099	18 338	16 603	14 441	12 213	59	37	21	-0.9	-1.6
Coal	8 680	10 686	10 797	8 465	6 501	4 569	35	19	8	-2.2	-3.3
Natural gas	4 819	6 630	6 785	7 876	7 724	7 516	22	18	13	1.4	0.4
Oil	968	783	757	262	216	128	2	1	0	-9.2	-6.6

				Stated Policies (GW)			Shares (%)			CAAGR (%) 2024 to:	
	2010	2023	2024	2035	2040	2050	2024	2035	2050	2035	2050
Total capacity	**5 254**	**9 441**	**10 249**	**21 144**	**25 591**	**31 738**	**100**	**100**	**100**	**6.8**	**4.4**
Renewables	1 332	4 249	4 935	13 680	17 528	22 940	48	65	72	9.7	6.1
Solar PV	40	1 625	2 164	8 855	11 922	16 209	21	42	51	14	8.1
Wind	181	1 016	1 131	2 763	3 290	3 985	11	13	13	8.5	5.0
Hydro	1 026	1 410	1 437	1 746	1 924	2 236	14	8	7	1.8	1.7
Bioenergy	73	175	181	258	299	345	2	1	1	3.3	2.5
of which BECCS	-	-	-	1	1	1	-	0	0	n.a.	n.a.
CSP	1	7	8	20	35	67	0	0	0	9.4	8.8
Geothermal	10	15	15	32	43	64	0	0	0	6.8	5.7
Marine	0	1	1	6	15	33	0	0	0	25	17
Nuclear	401	415	420	574	663	784	4	3	2	2.9	2.4
Hydrogen and ammonia	-	-	-	16	26	30	-	0	0	n.a.	n.a.
Fossil fuels with CCUS	-	0	0	5	12	14	0	0	0	42	21
Coal with CCUS	-	0	0	4	8	10	0	0	0	38	19
Natural gas with CCUS	-	-	-	1	4	4	-	0	0	n.a.	n.a.
Unabated fossil fuels	3 509	4 669	4 708	5 205	5 025	4 580	46	25	14	0.9	-0.1
Coal	1 615	2 240	2 259	2 465	2 286	1 744	22	12	5	0.8	-1.0
Natural gas	1 467	2 024	2 049	2 472	2 515	2 702	20	12	9	1.7	1.1
Oil	426	406	401	268	225	135	4	1	0	-3.6	-4.1
Battery storage	1	89	166	1 652	2 327	3 380	2	8	11	23	12

Table A.4b: World CO_2 emissions

				Stated Policies (Mt CO_2)			CAAGR (%) 2024 to:	
	2010	2023	2024	2035	2040	2050	2035	2050
Total CO_2*	**32 854**	**37 820**	**38 153**	**35 244**	**32 764**	**29 629**	**-0.7**	**-1.0**
Combustion activities (+)	**30 619**	**34 871**	**35 233**	**32 266**	**29 717**	**26 599**	**-0.8**	**-1.1**
Coal	13 806	15 575	15 730	12 605	10 575	8 138	-2.0	-2.5
Oil	10 548	11 403	11 451	10 792	10 363	9 927	-0.5	-0.5
Natural gas	6 077	7 608	7 768	8 625	8 549	8 311	1.0	0.3
Bioenergy and waste	187	286	284	244	230	222	-1.3	-0.9
Other removals (-)**	**-**	**1**	**1**	**2**	**3**	**2**	**8.8**	**3.9**
Biofuels production	-	1	1	2	2	2	6.2	3.0
Direct air capture	-	0	0	1	1	1	44	17
Electricity and heat sectors	**12 525**	**15 311**	**15 588**	**12 783**	**10 751**	**8 449**	**-1.8**	**-2.3**
Coal	8 958	11 254	11 458	8 795	6 919	4 875	-2.4	-3.2
Oil	828	653	637	239	198	122	-8.5	-6.2
Natural gas	2 625	3 256	3 345	3 633	3 527	3 343	0.8	-0.0
Bioenergy and waste	115	148	148	116	107	109	-2.1	-1.2
Other energy sector**	**1 441**	**1 627**	**1 631**	**1 666**	**1 632**	**1 579**	**0.2**	**-0.1**
Final consumption**	**18 630**	**20 609**	**20 657**	**20 602**	**20 169**	**19 403**	**-0.0**	**-0.2**
Coal	4 646	4 218	4 171	3 717	3 569	3 186	-1.0	-1.0
Oil	9 086	10 144	10 223	9 999	9 631	9 310	-0.2	-0.4
Natural gas	2 867	3 543	3 604	4 110	4 149	4 101	1.2	0.5
Bioenergy and waste	72	136	136	128	124	113	-0.5	-0.7
Industry**	8 249	9 074	9 057	9 250	9 242	8 885	0.2	-0.1
Chemicals**	1 163	1 362	1 394	1 509	1 511	1 415	0.7	0.1
Iron and steel**	2 120	2 761	2 750	2 607	2 564	2 396	-0.5	-0.5
Cement**	1 980	2 409	2 324	2 347	2 359	2 290	0.1	-0.1
Aluminium**	176	241	251	264	263	260	0.5	0.1
Transport	7 022	8 278	8 358	8 451	8 201	7 989	0.1	-0.2
Road	5 219	6 219	6 232	5 979	5 667	5 370	-0.4	-0.6
Passenger cars	2 634	3 193	3 208	2 828	2 617	2 409	-1.1	-1.1
Heavy-duty trucks	1 586	1 956	1 968	2 169	2 199	2 303	0.9	0.6
Aviation	758	957	1 018	1 334	1 422	1 551	2.5	1.6
Shipping	798	825	847	895	872	833	0.5	-0.1
Buildings	2 917	2 812	2 802	2 492	2 332	2 167	-1.1	-1.0
Residential	1 960	1 921	1 911	1 696	1 596	1 489	-1.1	-1.0
Services	957	891	891	796	736	679	-1.0	-1.0
Total CO_2 removals**	**-**	**1**	**1**	**7**	**8**	**10**	**19**	**9.3**
Total CO_2 captured**	**16**	**44**	**43**	**158**	**217**	**305**	**12**	**7.8**

*Includes industrial process and flaring emissions.

**Includes industrial process emissions.

Table A.5b: World economic and activity indicators

				Stated Policies			CAAGR (%) 2024 to:	
	2010	2023	2024	2035	2040	2050	2035	2050
Indicators								
Population (million)	6 967	8 022	8 091	8 805	9 093	9 572	0.8	0.6
GDP (USD 2024 billion, PPP)	127 344	190 196	196 346	270 572	307 510	384 635	3.0	2.6
GDP per capita (USD 2024, PPP)	18 277	23 710	24 267	30 729	33 819	40 183	2.2	2.0
TES/GDP (GJ per USD 1 000, PPP)	4.2	3.4	3.3	2.6	2.3	1.9	-2.2	-2.1
TFC/GDP (GJ per USD 1 000, PPP)	2.8	2.2	2.2	1.8	1.6	1.4	-1.8	-1.8
CO_2 intensity of electricity generation (g CO_2 per kWh)	529	457	446	251	187	122	-5.1	-4.8
Industrial production (Mt)								
Primary chemicals	508	732	754	933	984	1 037	2.0	1.2
Steel	1 435	1 903	1 883	2 090	2 205	2 407	1.0	0.9
Cement	3 280	4 110	3 950	4 200	4 314	4 364	0.6	0.4
Aluminium	60	108	113	137	147	169	1.8	1.6
Transport								
Passenger cars (billion pkm)	16 342	25 096	25 835	34 339	38 890	46 781	2.6	2.3
Heavy-duty trucks (billion tkm)	25 614	34 657	35 104	47 020	52 561	62 691	2.7	2.3
Aviation (billion pkm)	5 157	8 408	9 323	14 097	16 193	20 526	3.8	3.1
Shipping (billion tkm)	80 106	115 314	121 712	140 795	149 880	173 495	1.3	1.4
Buildings								
Households (million)	1 836	2 256	2 284	2 595	2 728	2 967	1.2	1.0
Residential floor area (million m^2)	161 023	207 792	211 202	251 379	269 221	301 970	1.6	1.4
Services floor area (million m^2)	41 067	60 433	61 779	77 407	83 458	93 357	2.1	1.6

Table A.1c: World energy supply

				Net Zero Emissions by 2050 (EJ)			Shares (%)			CAAGR (%) 2024 to:	
	2010	2023	2024	2035	2040	2050	2024	2035	2050	2035	2050
Total energy supply	**536**	**641**	**654**	**571**	**551**	**570**	**100**	**100**	**100**	**-1.2**	**-0.5**
Renewables	43	78	83	224	298	401	13	39	70	9.5	6.3
Solar	1	8	9	66	101	148	1	12	26	19	11
Wind	1	8	9	43	60	84	1	8	15	15	8.9
Hydro	12	15	16	21	23	27	2	4	5	2.5	2.0
Modern solid bioenergy	23	35	37	60	67	75	6	11	13	4.7	2.8
Modern liquid bioenergy	2	5	5	11	12	12	1	2	2	7.2	3.5
Modern gaseous bioenergy	1	2	2	6	10	15	0	1	3	12	8.8
Traditional use of biomass	21	19	19	-	-	-	3	-	-	n.a.	n.a.
Nuclear	30	30	31	55	69	78	5	10	14	5.4	3.6
Natural gas	115	144	148	91	62	30	23	16	5	-4.3	-5.9
Unabated	109	136	139	75	41	7	21	13	1	-5.5	-11
With CCUS	0	1	1	8	13	16	0	1	3	28	14
Oil	174	192	193	129	92	45	30	23	8	-3.6	-5.4
Non-energy use	26	31	32	33	32	28	5	6	5	0.4	-0.5
Coal	153	176	178	70	29	15	27	12	3	-8.2	-9.0
Unabated	151	173	175	61	17	2	27	11	0	-9.2	-16
With CCUS	-	0	0	6	9	12	0	1	2	70	28
Electricity and heat sectors	**200**	**257**	**265**	**283**	**322**	**410**	**100**	**100**	**100**	**0.6**	**1.7**
Renewables	20	44	48	162	227	314	18	57	76	12	7.5
Solar PV	0	6	7	59	89	128	3	21	31	21	12
Wind	1	8	9	43	60	84	3	15	20	15	8.9
Hydro	12	15	16	21	23	27	6	7	6	2.5	2.0
Bioenergy	4	10	10	23	29	36	4	8	9	7.7	5.0
Hydrogen	-	-	-	2	4	5	-	1	1	n.a.	n.a.
Ammonia	-	-	-	2	2	2	-	1	0	n.a.	n.a.
Nuclear	30	30	31	55	69	78	12	20	19	5.4	3.6
Unabated natural gas	47	58	60	25	11	2	23	9	0	-7.7	-12
Natural gas with CCUS	-	-	-	1	2	3	-	0	1	n.a.	n.a.
Oil	11	9	8	1	0	0	3	0	0	-19	-27
Unabated coal	91	115	117	30	0	-	44	10	-	-12	n.a.
Coal with CCUS	-	0	0	5	6	7	0	2	2	80	30
Other energy sector	**50**	**67**	**69**	**79**	**94**	**129**	**100**	**100**	**100**	**1.1**	**2.4**
Biofuels conversion losses	-	6	7	14	16	15	100	100	100	7.4	3.1
Low-emissions hydrogen (offsite)											
Production inputs	-	0	0	17	29	48	100	100	100	n.a.	n.a.
Production outputs	-	0	0	12	21	35	100	100	100	88	36
For hydrogen-based fuels	-	-	0	6	10	18	9	50	52	120	46

Table A.2c: World total final consumption

				Net Zero Emissions by 2050 (EJ)			Shares (%)			CAAGR (%) 2024 to:	
	2010	2023	2024	2035	2040	2050	2024	2035	2050	2035	2050
Total final consumption	**378**	**444**	**453**	**408**	**380**	**352**	**100**	**100**	**100**	**-0.9**	**-1.0**
Electricity	64	91	95	133	156	192	21	33	55	3.1	2.8
Liquid fuels	154	178	180	135	104	65	40	33	19	-2.6	-3.8
Biofuels	2	5	5	11	12	12	1	3	3	7.2	3.5
Ammonia	-	-	-	1	2	3	-	0	1	n.a.	n.a.
Synthetic oil	-	-	-	1	2	6	-	0	2	n.a.	n.a.
Oil	152	173	175	121	87	43	39	30	12	-3.3	-5.2
Gaseous fuels	57	71	73	62	52	38	16	15	11	-1.4	-2.4
Biomethane	0	0	0	3	6	9	0	1	3	21	13
Hydrogen	-	0	0	3	6	11	0	1	3	65	30
Synthetic methane	-	-	-	0	0	0	-	0	0	n.a.	n.a.
Natural gas	57	70	72	55	39	16	16	13	4	-2.4	-5.7
Solid fuels	90	87	87	58	47	35	19	14	10	-3.7	-3.5
Solid bioenergy	33	35	35	24	25	27	8	6	8	-3.3	-1.0
Coal	56	51	51	33	22	7	11	8	2	-3.9	-7.1
Heat	12	16	16	15	13	9	4	4	3	-0.9	-2.1
Industry	**142**	**170**	**174**	**180**	**173**	**158**	**100**	**100**	**100**	**0.3**	**-0.4**
Electricity	27	39	40	58	67	78	23	32	50	3.4	2.6
Liquid fuels	29	33	34	33	30	24	19	18	15	-0.3	-1.4
Oil	29	33	34	32	29	22	19	18	14	-0.5	-1.7
Gaseous fuels	24	32	33	31	28	20	19	18	13	-0.4	-1.8
Biomethane	0	0	0	1	2	4	0	1	3	21	14
Hydrogen	-	-	0	1	3	4	0	1	3	91	38
Unabated natural gas	21	28	29	24	16	3	17	13	2	-1.9	-8.1
Natural gas with CCUS	0	0	0	1	3	5	0	1	3	41	22
Solid fuels	57	58	58	48	40	28	33	27	18	-1.7	-2.8
Modern solid bioenergy	8	11	11	17	19	21	7	9	14	3.5	2.4
Unabated coal	48	44	44	27	16	1	25	15	1	-4.1	-13
Coal with CCUS	-	0	0	2	3	5	0	1	3	56	26
Heat	5	9	9	7	6	3	5	4	2	-1.4	-3.5
Chemicals	37	50	52	55	55	50	30	31	32	0.6	-0.1
Iron and steel	31	37	36	32	29	25	21	18	16	-1.2	-1.5
Cement	10	12	11	11	11	9	7	6	6	-0.3	-0.7
Aluminium	5	7	7	7	6	5	4	4	3	-0.3	-1.1

Table A.2c: World total final consumption (continued)

	2010	2023	2024	Net Zero Emissions by 2050 (EJ) 2035	2040	2050	Shares (%) 2024	2035	2050	CAAGR (%) 2024 to: 2035	2050
Transport	**102**	**123**	**125**	**102**	**87**	**76**	**100**	**100**	**100**	**-1.8**	**-1.9**
Electricity	1	2	2	13	23	37	2	13	49	19	12
Liquid fuels	97	116	117	82	59	31	94	81	41	-3.1	-5.0
Biofuels	2	5	5	10	10	9	4	9	12	6.4	2.3
Oil	95	111	112	70	44	12	90	69	16	-4.2	-8.2
Gaseous fuels	4	5	5	6	6	8	4	6	10	1.4	1.3
Biomethane	0	0	0	1	1	1	0	1	1	21	6.4
Hydrogen	-	0	0	1	3	7	0	1	9	55	28
Natural gas	4	5	5	4	2	0	4	4	0	-2.4	-9.8
Road	76	93	93	71	57	47	75	70	62	-2.5	-2.6
Passenger cars	39	48	48	30	21	15	39	29	20	-4.2	-4.3
Heavy-duty trucks	23	29	29	29	27	24	24	29	32	0.0	-0.7
Aviation	11	13	14	17	17	16	11	17	20	1.7	0.4
Shipping	10	11	11	9	9	9	9	9	11	-2.1	-1.0
Buildings	**112**	**124**	**127**	**102**	**97**	**99**	**100**	**100**	**100**	**-2.0**	**-0.9**
Electricity	35	47	49	58	62	73	38	56	74	1.5	1.6
Liquid fuels	13	13	13	6	3	1	10	6	1	-6.4	-8.4
Biofuels	-	-	-	0	0	1	-	0	1	n.a.	n.a.
Oil	13	13	13	6	3	1	10	6	1	-6.5	-11
Gaseous fuels	27	29	30	20	14	6	23	19	6	-3.7	-5.8
Biomethane	0	0	0	1	2	4	0	1	4	20	15
Hydrogen	-	-	-	0	0	0	-	0	0	n.a.	n.a.
Natural gas	26	29	29	18	10	0	23	17	0	-4.5	-18
Solid fuels	31	27	26	7	5	5	21	7	5	-11	-6.1
Modern solid bioenergy	4	4	4	7	5	5	3	7	5	4.5	0.8
Traditional use of biomass	21	19	19	-	-	-	15	-	-	n.a.	n.a.
Coal	6	3	3	1	0	0	3	1	0	-15	-27
Heat	6	7	8	7	7	6	6	7	6	-0.3	-1.0
Residential	78	85	86	63	59	63	68	62	63	-2.9	-1.2
Services	34	39	40	39	38	37	32	38	37	-0.3	-0.4

Table A.3c: World electricity sector

	2010	2023	2024	Net Zero Emissions by 2050 (TWh) 2035	2040	2050	Shares (%) 2024	2035	2050	CAAGR (%) 2024 to: 2035	2050
Total generation	**21 519**	**29 975**	**31 229**	**48 118**	**60 301**	**80 175**	**100**	**100**	**100**	**4.0**	**3.7**
Renewables	4 207	9 011	9 935	36 615	51 450	71 220	32	76	89	13	7.9
Solar PV	32	1 605	2 073	16 415	24 796	35 509	7	34	44	21	12
Wind	342	2 333	2 533	11 898	16 607	23 250	8	25	29	15	8.9
Hydro	3 453	4 249	4 448	5 822	6 506	7 398	14	12	9	2.5	2.0
Bioenergy	310	709	760	1 802	2 315	2 917	2	4	4	8.2	5.3
of which BECCS	-	-	-	326	504	682	-	1	1	n.a.	n.a.
CSP	2	16	20	282	641	1 209	0	1	2	27	17
Geothermal	68	98	100	370	532	825	0	1	1	13	8.4
Marine	1	1	1	26	53	112	0	0	0	35	20
Nuclear	2 756	2 740	2 835	4 821	5 912	6 853	9	10	9	4.9	3.5
Hydrogen and ammonia	-	-	-	514	749	839	-	1	1	n.a.	n.a.
Fossil fuels with CCUS	-	1	1	584	870	986	0	1	1	82	31
Coal with CCUS	-	1	1	415	574	637	0	1	1	76	29
Natural gas with CCUS	-	-	-	169	296	349	-	0	0	n.a.	n.a.
Unabated fossil fuels	14 468	18 099	18 338	5 520	1 252	205	59	11	0	-10	-16
Coal	8 680	10 686	10 797	2 681	-	-	35	6	-	-12	n.a.
Natural gas	4 819	6 630	6 785	2 779	1 249	205	22	6	0	-7.8	-13
Oil	968	783	757	61	3	0	2	0	0	-20	-27

	2010	2023	2024	Net Zero Emissions by 2050 (GW) 2035	2040	2050	Shares (%) 2024	2035	2050	CAAGR (%) 2024 to: 2035	2050
Total capacity	**5 254**	**9 441**	**10 249**	**26 552**	**34 596**	**44 511**	**100**	**100**	**100**	**9.0**	**5.8**
Renewables	1 332	4 249	4 935	19 601	27 003	35 983	48	74	81	13	7.9
Solar PV	40	1 625	2 164	12 499	17 847	24 201	21	47	54	17	9.7
Wind	181	1 016	1 131	4 494	6 030	8 001	11	17	18	13	7.8
Hydro	1 026	1 410	1 437	2 037	2 317	2 616	14	8	6	3.2	2.3
Bioenergy	73	175	181	413	522	674	2	2	2	7.8	5.2
of which BECCS	-	-	-	63	91	118	-	0	0	n.a.	n.a.
CSP	1	7	8	91	186	329	0	0	1	25	16
Geothermal	10	15	15	57	80	120	0	0	0	13	8.2
Marine	0	1	1	11	21	43	0	0	0	31	18
Nuclear	401	415	420	714	892	1 079	4	3	2	4.9	3.7
Hydrogen and ammonia	-	-	-	258	344	420	-	1	1	n.a.	n.a.
Fossil fuels with CCUS	-	0	0	138	210	242	0	1	1	91	34
Coal with CCUS	-	0	0	99	138	154	0	0	0	86	32
Natural gas with CCUS	-	-	-	39	72	88	-	0	0	n.a.	n.a.
Unabated fossil fuels	3 509	4 669	4 708	2 948	2 020	1 066	46	11	2	-4.2	-5.6
Coal	1 615	2 240	2 259	1 238	714	227	22	5	1	-5.3	-8.5
Natural gas	1 467	2 024	2 049	1 546	1 216	808	20	6	2	-2.5	-3.5
Oil	426	406	401	165	91	31	4	1	0	-7.8	-9.4
Battery storage	1	89	166	2 885	4 120	5 716	2	11	13	30	15

Table A.4c: World CO_2 emissions

	2010	2023	2024	Net Zero Emissions by 2050 ($Mt\ CO_2$) 2035	2040	2050	CAAGR (%) 2024 to: 2035	2050
Total CO_2*	**32 854**	**37 820**	**38 153**	**17 606**	**8 137**	**-**	**-6.8**	**n.a.**
Combustion activities (+)	**30 619**	**34 871**	**35 233**	**16 059**	**7 494**	**991**	**-6.9**	**-13**
Coal	13 806	15 575	15 730	5 369	1 462	150	-9.3	-16
Oil	10 548	11 403	11 451	6 662	4 124	1 156	-4.8	-8.4
Natural gas	6 077	7 608	7 768	4 175	2 306	387	-5.5	-11
Bioenergy and waste	187	286	284	- 147	- 399	- 701	-194	n.a.
Other removals (-)**	**-**	**1**	**1**	**372**	**611**	**1 320**	**73**	**32**
Biofuels production	-	1	1	190	239	286	63	25
Direct air capture	-	0	0	182	372	1 034	144	56
Electricity and heat sectors	**12 525**	**15 311**	**15 588**	**4 173**	**406**	**- 278**	**-11**	**n.a.**
Coal	8 958	11 254	11 458	2 881	38	20	-12	-22
Oil	828	653	637	65	11	0	-19	-27
Natural gas	2 625	3 256	3 345	1 384	637	109	-7.7	-12
Bioenergy and waste	115	148	148	- 157	- 280	- 408	n.a.	n.a.
Other energy sector**	**1 441**	**1 627**	**1 631**	**404**	**134**	**- 107**	**-12**	**n.a.**
Final consumption**	**18 630**	**20 609**	**20 657**	**13 203**	**7 965**	**1 411**	**-4.0**	**-9.8**
Coal	4 646	4 218	4 171	2 462	1 409	117	-4.7	-13
Oil	9 086	10 144	10 223	6 264	3 872	1 017	-4.4	-8.5
Natural gas	2 867	3 543	3 604	2 553	1 543	189	-3.1	-11
Bioenergy and waste	72	136	136	12	- 109	- 233	-20	n.a.
Industry**	8 249	9 074	9 057	6 301	3 831	452	-3.2	-11
Chemicals**	1 163	1 362	1 394	1 022	661	78	-2.8	-10
Iron and steel**	2 120	2 761	2 750	1 923	1 224	216	-3.2	-9.3
Cement**	1 980	2 409	2 324	1 575	844	48	-3.5	-14
Aluminium**	176	241	251	211	135	12	-1.6	-11
Transport	7 022	8 278	8 358	5 245	3 254	893	-4.1	-8.2
Road	5 219	6 219	6 232	3 780	2 177	465	-4.4	-9.5
Passenger cars	2 634	3 193	3 208	1 588	769	118	-6.2	-12
Heavy-duty trucks	1 586	1 956	1 968	1 646	1 164	319	-1.6	-6.8
Aviation	758	957	1 018	1 018	808	316	-0.0	-4.4
Shipping	798	825	847	303	168	87	-8.9	-8.4
Buildings	2 917	2 812	2 802	1 437	745	50	-5.9	-14
Residential	1 960	1 921	1 911	967	487	35	-6.0	-14
Services	957	891	891	471	258	15	-5.6	-15
Total CO_2 removals**	**-**	**1**	**1**	**657**	**1 116**	**2 090**	**81**	**34**
Total CO_2 captured**	**16**	**44**	**43**	**2 261**	**3 889**	**6 052**	**43**	**21**

*Includes industrial process and flaring emissions.
**Includes industrial process emissions.

Table A.5c: World economic and activity indicators

	2010	2023	2024	Net Zero Emissions by 2050 2035	2040	2050	CAAGR (%) 2024 to: 2035	2050
Indicators								
Population (million)	6 967	8 022	8 091	8 805	9 093	9 572	0.8	0.6
GDP (USD 2024 billion, PPP)	127 344	190 196	196 346	270 572	307 510	384 635	3.0	2.6
GDP per capita (USD 2024, PPP)	18 277	23 710	24 267	30 729	33 819	40 183	2.2	2.0
TES/GDP (GJ per USD 1 000, PPP)	4.2	3.4	3.3	2.1	1.8	1.5	-4.1	-3.1
TFC/GDP (GJ per USD 1 000, PPP)	2.8	2.2	2.2	1.5	1.2	0.9	-3.7	-3.3
CO_2 intensity of electricity generation (g CO_2 per kWh)	529	457	446	72	4	- 4	-15	n.a.
Industrial production (Mt)								
Primary chemicals	508	732	754	875	891	851	1.4	0.5
Steel	1 435	1 903	1 883	1 946	1 944	1 917	0.3	0.1
Cement	3 280	4 110	3 950	3 881	3 755	3 535	-0.2	-0.4
Aluminium	60	108	113	138	146	159	1.8	1.3
Transport								
Passenger cars (billion pkm)	16 342	25 096	25 835	32 614	36 060	41 791	2.1	1.9
Heavy-duty trucks (billion tkm)	25 614	34 657	35 104	46 393	51 784	61 589	2.6	2.2
Aviation (billion pkm)	5 157	8 408	9 323	12 607	13 192	15 221	2.8	1.9
Shipping (billion tkm)	80 106	115 314	121 712	117 922	117 922	130 003	-0.3	0.3
Buildings								
Households (million)	1 836	2 256	2 284	2 595	2 728	2 967	1.2	1.0
Residential floor area (million m^2)	161 023	207 792	211 202	251 379	269 221	301 970	1.6	1.4
Services floor area (million m^2)	41 067	60 433	61 779	77 407	83 458	93 357	2.1	1.6

Table A.6: Total energy supply (EJ)

				Current Policies		Stated Policies	
	2010	2023	2024	2035	2050	2035	2050
World	**536.4**	**640.7**	**654.2**	**744.1**	**838.0**	**708.0**	**747.0**
North America	112.7	112.4	113.2	118.6	128.8	113.1	111.4
United States	94.1	92.0	93.0	98.3	106.3	93.3	91.0
Central and South America	26.7	30.1	30.4	36.6	46.5	35.3	41.8
Brazil	12.2	14.6	15.0	18.1	22.9	17.4	20.2
Europe	89.1	74.2	74.9	73.3	71.0	70.7	64.8
European Union	64.5	53.2	53.5	50.7	46.6	49.2	43.0
Africa	25.6	34.2	34.5	43.2	58.7	41.0	53.2
Middle East	26.1	36.5	37.2	48.0	62.8	45.2	55.3
Eurasia	35.8	41.4	42.3	44.2	46.7	43.4	44.5
Russia	29.1	33.2	33.9	34.1	34.0	33.5	32.5
Asia Pacific	205.4	295.6	304.5	358.1	396.3	337.8	352.3
China	107.0	169.6	174.5	196.4	191.8	181.9	169.8
India	27.7	46.2	48.4	67.0	89.5	64.0	77.5
Japan	20.9	15.8	15.7	14.8	13.8	14.0	12.3
Southeast Asia	21.3	32.5	34.0	45.1	59.8	44.1	54.9

Table A.7: Renewables energy supply (EJ)

				Current Policies		Stated Policies	
	2010	2023	2024	2035	2050	2035	2050
World	**43.0**	**77.8**	**82.7**	**142.3**	**217.2**	**148.9**	**233.4**
North America	8.8	13.1	13.6	18.1	25.1	19.1	26.3
United States	6.6	10.6	11.1	14.6	20.4	15.3	21.2
Central and South America	7.7	10.6	10.9	14.6	20.6	14.6	20.4
Brazil	5.6	7.6	7.8	10.2	13.5	10.1	12.6
Europe	9.9	15.1	15.7	23.8	30.1	25.1	31.2
European Union	7.8	11.2	11.6	18.0	22.4	18.9	23.0
Africa	3.7	5.9	6.1	10.2	16.8	10.1	17.0
Middle East	0.1	0.3	0.3	1.4	3.7	2.0	5.5
Eurasia	1.0	1.2	1.3	1.6	2.2	1.7	2.5
Russia	0.7	0.9	1.0	1.1	1.5	1.2	1.7
Asia Pacific	11.8	31.5	34.7	71.8	116.6	75.6	128.2
China	4.3	15.6	17.9	40.5	60.7	42.2	67.2
India	2.7	6.2	6.6	14.6	27.5	15.2	28.8
Japan	0.8	1.3	1.4	1.9	2.5	2.3	3.0
Southeast Asia	2.8	6.2	6.4	9.9	16.9	10.5	18.8

Table A.8: Oil production (mb/d)

	2010	2023	2024	Current Policies 2035	Current Policies 2050	Stated Policies 2035	Stated Policies 2050
World supply	**85.2**	**99.2**	**99.8**	**105.3**	**112.8**	**100.4**	**96.9**
Processing gains	2.1	2.4	2.4	2.6	3.4	2.6	2.9
World production	**83.2**	**96.9**	**97.5**	**102.7**	**109.4**	**97.7**	**93.9**
Conventional crude oil	66.7	62.6	61.7	61.0	66.3	57.4	56.8
Tight oil	0.7	9.2	9.8	11.8	11.9	11.2	11.2
Natural gas liquids	12.7	20.2	21.0	24.2	24.1	23.7	20.2
Extra-heavy oil & bitumen	2.6	3.9	4.1	4.5	5.7	4.2	4.5
Non-OPEC+	33.2	46.2	47.6	51.7	47.4	50.0	43.1
OPEC+	50.0	50.7	49.9	51.0	62.0	47.7	50.8
North America	14.0	27.5	28.4	29.3	27.4	28.8	24.8
Central and South America	7.4	7.1	7.4	10.1	11.1	9.3	9.5
Europe	4.4	3.4	3.3	2.4	1.3	2.2	1.2
European Union	0.7	0.5	0.4	0.4	0.3	0.3	0.2
Africa	10.3	7.3	7.2	7.1	6.9	6.6	6.0
Middle East	25.4	30.4	30.2	33.6	43.9	32.2	37.1
Eurasia	13.4	13.8	13.5	13.8	13.9	12.3	11.1
Asia Pacific	8.4	7.5	7.5	6.5	4.9	6.2	4.3
Southeast Asia	2.6	1.8	1.7	1.7	1.6	1.5	1.2

Table A.9: Oil demand (mb/d)

	2010	2023	2024	Current Policies 2035	Current Policies 2050	Stated Policies 2035	Stated Policies 2050
World	**87.6**	**99.2**	**100.0**	**105.3**	**112.8**	**100.4**	**96.9**
North America	22.2	22.1	22.0	21.9	21.7	20.7	17.5
United States	17.8	18.1	18.1	18.3	17.9	17.2	14.4
Central and South America	5.5	5.7	5.7	6.4	7.8	6.1	6.6
Brazil	2.2	2.5	2.5	2.7	3.2	2.6	2.7
Europe	13.8	12.2	12.2	9.4	6.0	9.1	5.1
European Union	10.6	9.0	9.0	6.6	3.3	6.4	2.9
Africa	3.3	4.5	4.5	5.8	8.6	5.7	7.8
Middle East	7.0	8.3	8.4	9.2	11.6	8.6	10.4
Eurasia	3.5	4.2	4.2	4.9	5.6	4.7	5.1
Russia	3.0	3.4	3.3	3.7	3.9	3.6	3.6
Asia Pacific	25.1	34.5	34.9	38.3	41.2	36.5	35.1
China	8.8	16.1	16.2	15.8	13.7	15.2	12.4
India	3.3	5.2	5.4	7.8	10.5	7.4	8.8
Japan	4.2	3.0	2.9	2.4	2.1	2.2	1.6
Southeast Asia	4.0	5.0	5.1	6.5	8.0	6.1	6.6
International bunkers	7.1	7.7	8.1	9.3	10.5	9.0	9.2

Table A.10: World liquids demand (mb/d)

	2023	2024	Current Policies 2035	Current Policies 2050	Stated Policies 2035	Stated Policies 2050
Total liquids	**101.6**	**102.5**	**108.9**	**119.1**	**104.0**	**102.1**
Biofuels	2.4	2.5	3.5	5.7	3.5	4.6
Hydrogen based fuels	-	-	0.1	0.6	0.1	0.6
Total oil	99.2	100.0	105.3	112.8	100.4	96.9
CTL, GTL and additives	0.9	0.9	1.2	1.3	1.1	1.2
Direct use of crude oil	0.9	0.9	0.3	0.2	0.2	0.2
Oil products	97.4	98.2	103.8	111.3	99.1	95.5
LPG and ethane	14.4	14.6	18.2	20.0	17.6	18.0
Naphtha	7.0	7.0	9.1	11.6	8.7	10.6
Gasoline	25.3	25.4	24.4	25.6	22.7	19.3
Kerosene	7.2	7.6	9.5	11.6	9.5	10.9
Diesel	27.4	27.2	28.2	29.2	26.7	24.7
Fuel oil	6.4	6.4	5.8	5.6	5.3	4.6
Other products	9.7	10.0	8.6	7.7	8.6	7.4
Products from NGLs	12.8	13.1	15.1	14.4	14.7	12.2
Refinery products	84.6	85.1	88.7	96.9	84.4	83.3
Refinery market share	*83%*	*83%*	*81%*	*81%*	*81%*	*82%*

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				
		CPS		STEPS			CPS		STEPS	
	2024	2035	2050	2035	2050	2024	2035	2050	2035	2050
North America	21.8	21.9	22.5	21.1	20.9	18.9	19.7	20.5	18.0	17.9
Europe	15.8	13.3	12.1	13.2	11.7	12.2	9.6	8.3	9.4	7.9
Asia Pacific	38.6	41.2	43.8	40.5	40.1	30.7	33.7	37.7	32.1	31.9
Japan and Korea	6.7	6.5	6.1	6.3	5.8	5.1	4.9	4.8	4.6	4.1
China	18.6	19.6	19.4	19.6	19.2	14.6	15.9	16.0	15.0	14.2
India	5.8	7.3	9.0	6.8	7.1	5.4	6.8	8.8	6.4	6.9
Southeast Asia	5.5	5.7	7.0	5.7	5.8	4.2	4.6	6.3	4.6	5.1
Middle East	11.5	13.2	14.6	13.0	13.0	9.8	11.1	12.7	10.6	10.7
Russia	7.0	6.7	6.7	6.5	6.4	4.7	4.1	4.5	3.8	3.6
Africa	3.7	4.5	4.9	4.5	4.5	1.8	2.9	4.2	2.8	3.4
Brazil	2.2	2.4	2.5	2.4	2.4	2.0	2.1	2.4	2.1	2.2
World	**105.6**	**108.2**	**112.3**	**106.1**	**103.9**	**82.6**	**86.0**	**93.5**	**81.6**	**80.5**
Atlantic Basin	55.3	53.5	53.7	52.3	50.7	42.1	41.1	43.0	38.7	37.8
East of Suez	50.3	54.7	58.6	53.7	53.3	40.5	44.9	50.5	42.8	42.7

Table A.12: Natural gas production (bcm)

				Current Policies		Stated Policies	
	2010	2023	2024	2035	2050	2035	2050
World	3 293	4 222	4 282	5 044	5 596	4 770	4 645
Conventional gas	2 792	2 912	2 955	3 350	3 782	3 162	3 136
Tight gas	268	316	319	383	294	373	220
Shale gas	155	895	897	1 201	1 414	1 130	1 194
Coalbed methane	77	84	93	85	81	81	70
North America	815	1 322	1 324	1 563	1 588	1 489	1 301
Central and South America	163	158	159	183	223	171	177
Europe	341	240	247	216	166	198	150
European Union	148	39	37	41	32	36	29
Africa	210	252	240	272	389	259	281
Middle East	464	707	717	1 092	1 393	1 012	1 166
Eurasia	814	837	877	933	997	894	894
Asia Pacific	487	705	717	785	840	748	676
Southeast Asia	215	204	209	185	202	176	140

Table A.13: Natural gas demand (bcm)

				Current Policies		Stated Policies	
	2010	2023	2024	2035	2050	2035	2050
World	3 317	4 138	4 254	5 044	5 596	4 770	4 645
North America	838	1 158	1 179	1 253	1 192	1 198	950
United States	678	925	942	1 022	943	975	733
Central and South America	151	154	157	188	222	177	177
Brazil	29	30	32	38	51	33	31
Europe	697	504	507	477	426	411	304
European Union	446	328	329	296	244	256	166
Africa	107	174	172	214	323	199	260
Middle East	370	582	596	837	1 077	773	870
Eurasia	578	633	660	693	713	690	684
Russia	467	503	526	529	507	529	490
Asia Pacific	575	931	982	1 330	1 565	1 274	1 345
China	110	397	428	632	724	584	606
India	64	68	75	137	209	139	187
Japan	95	90	91	97	93	87	67
Southeast Asia	149	176	184	238	285	244	272

Table A.14: Coal production (Mtce)

	2010	2023	2024	Current Policies 2035	Current Policies 2050	Stated Policies 2035	Stated Policies 2050
World	**5 250**	**6 314**	**6 404**	**5 617**	**4 725**	**4 920**	**3 297**
Steam coal	4 082	5 084	5 184	4 619	3 805	3 991	2 531
Coking coal	867	1 004	1 002	874	813	825	692
Lignite and peat	300	226	218	125	107	104	74
North America	818	447	402	316	250	230	111
Central and South America	81	67	62	32	27	20	11
Europe	331	167	155	71	43	50	19
European Union	220	113	101	35	18	21	7
Africa	210	214	217	199	181	177	144
Middle East	1	3	2	3	3	3	2
Eurasia	309	419	421	356	313	333	272
Asia Pacific	3 500	4 997	5 145	4 640	3 907	4 107	2 738
Southeast Asia	325	628	671	568	564	506	465

Table A.15: Coal demand (Mtce)

	2010	2023	2024	Current Policies 2035	Current Policies 2050	Stated Policies 2035	Stated Policies 2050
World	**5 208**	**6 018**	**6 089**	**5 617**	**4 724**	**4 894**	**3 258**
North America	769	316	305	226	170	151	42
United States	717	289	280	217	161	143	35
Central and South America	38	40	41	41	47	39	41
Brazil	21	20	21	24	28	22	25
Europe	539	291	268	171	148	138	109
European Union	361	185	168	78	57	56	34
Africa	156	148	153	128	115	119	93
Middle East	3	7	7	9	9	8	8
Eurasia	203	265	266	228	202	212	181
Russia	151	204	203	166	138	153	120
Asia Pacific	3 501	4 952	5 050	4 813	4 032	4 226	2 784
China	2 565	3 515	3 562	3 200	2 276	2 745	1 476
India	392	728	765	901	977	840	706
Japan	165	142	137	76	54	63	47
Southeast Asia	112	312	336	456	562	417	427

Table A.16: Electricity demand (TWh)

				Current Policies		Stated Policies	
	2010	2023	2024	2035	2050	2035	2050
World	**18 494**	**26 179**	**27 290**	**37 819**	**50 667**	**37 766**	**49 657**
North America	4 632	4 883	4 998	5 910	6 841	5 937	6 990
United States	3 880	4 007	4 102	4 854	5 472	4 887	5 647
Central and South America	924	1 178	1 221	1 645	2 404	1 612	2 320
Brazil	451	603	637	835	1 170	797	1 066
Europe	3 559	3 419	3 487	4 560	5 950	4 595	5 907
European Union	2 571	2 398	2 437	3 209	4 235	3 230	4 178
Africa	565	731	753	1 196	2 195	1 202	2 197
Middle East	693	1 174	1 205	1 775	2 789	1 762	2 726
Eurasia	985	1 195	1 230	1 438	1 708	1 430	1 679
Russia	828	945	969	1 093	1 225	1 078	1 176
Asia Pacific	7 136	13 600	14 395	21 294	28 772	21 222	27 819
China	3 659	8 535	9 102	13 416	16 871	13 276	16 131
India	715	1 549	1 644	2 941	4 990	2 959	4 803
Japan	1 071	898	913	991	1 027	978	1 015
Southeast Asia	614	1 233	1 317	2 105	3 275	2 110	3 197

Table A.17: Electricity generation (TWh)

				Current Policies		Stated Policies	
	2010	2023	2024	2035	2050	2035	2050
World	**21 519**	**29 975**	**31 229**	**45 109**	**59 426**	**44 274**	**58 081**
North America	5 233	5 444	5 581	6 683	7 742	6 623	7 763
United States	4 354	4 430	4 564	5 480	6 179	5 420	6 237
Central and South America	1 129	1 416	1 462	1 949	2 832	1 911	2 723
Brazil	516	708	748	970	1 362	925	1 240
Europe	4 119	3 896	3 971	5 335	6 740	5 412	6 764
European Union	2 955	2 718	2 772	3 797	4 792	3 847	4 816
Africa	687	912	939	1 446	2 562	1 449	2 560
Middle East	829	1 426	1 461	2 140	3 323	2 122	3 245
Eurasia	1 251	1 468	1 511	1 712	2 001	1 701	1 967
Russia	1 036	1 159	1 188	1 297	1 431	1 279	1 374
Asia Pacific	8 270	15 414	16 304	25 844	34 227	25 055	33 058
China	4 236	9 530	10 170	16 791	20 583	15 854	19 696
India	972	1 987	2 090	3 597	6 022	3 687	5 805
Japan	1 164	993	1 009	1 106	1 156	1 082	1 105
Southeast Asia	692	1 365	1 457	2 329	3 618	2 334	3 525

Table A.18: Renewables generation (TWh)

				Current Policies		Stated Policies	
	2010	2023	2024	2035	2050	2035	2050
World	**4 207**	**9 011**	**9 935**	**21 940**	**35 441**	**23 603**	**40 107**
North America	857	1 453	1 535	2 501	3 384	2 800	4 419
United States	441	963	1 054	1 788	2 418	2 046	3 396
Central and South America	752	1 051	1 086	1 516	2 357	1 508	2 411
Brazil	437	630	655	849	1 176	824	1 146
Europe	954	1 784	1 925	3 734	5 206	4 042	5 501
European Union	653	1 228	1 338	2 766	3 827	2 940	3 982
Africa	116	221	234	621	1 409	714	1 724
Middle East	18	49	63	324	820	463	1 271
Eurasia	226	278	300	349	431	370	482
Russia	167	208	219	242	287	247	306
Asia Pacific	1 285	4 175	4 791	12 895	21 834	13 705	24 298
China	782	2 904	3 433	9 275	14 230	9 654	15 723
India	161	395	416	1 684	3 951	1 834	4 259
Japan	106	226	244	346	451	411	538
Southeast Asia	105	349	370	740	1 542	825	1 841

Table A.19: Solar PV generation (TWh)

				Current Policies		Stated Policies	
	2010	2023	2024	2035	2050	2035	2050
World	**32**	**1 605**	**2 073**	**9 068**	**17 015**	**10 113**	**20 374**
North America	3	245	311	856	1 280	1 081	2 209
United States	3	214	279	761	1 110	961	2 004
Central and South America	0	81	108	275	497	282	534
Brazil	0	51	74	168	258	165	260
Europe	23	302	360	1 106	1 487	1 214	1 631
European Union	22	247	297	926	1 207	976	1 294
Africa	0	17	24	205	524	275	718
Middle East	0	24	31	237	587	356	976
Eurasia	0	6	7	19	27	31	44
Russia	0	3	3	6	9	6	10
Asia Pacific	6	930	1 232	6 371	12 613	6 876	14 261
China	1	584	851	4 722	8 809	5 002	10 042
India	0	119	136	987	2 454	1 081	2 604
Japan	4	96	99	161	210	204	260
Southeast Asia	0	42	44	177	451	198	542

Table A.20: Wind generation (TWh)

				Current Policies		Stated Policies	
	2010	2023	2024	2035	2050	2035	2050
World	342	2 333	2 533	6 327	9 855	6 917	10 991
North America	105	487	526	809	1 108	882	1 210
United States	95	426	459	661	834	718	914
Central and South America	3	134	151	305	634	306	676
Brazil	2	96	108	198	383	194	396
Europe	154	614	630	1 562	2 398	1 774	2 556
European Union	140	479	489	1 234	1 894	1 362	1 961
Africa	2	29	30	112	284	128	343
Middle East	0	4	6	44	120	63	179
Eurasia	0	9	13	29	66	36	88
Russia	0	5	6	14	39	16	51
Asia Pacific	77	1 056	1 178	3 466	5 244	3 729	5 939
China	45	886	997	2 735	3 398	2 830	3 649
India	20	93	93	309	907	363	1 066
Japan	4	10	11	38	67	56	85
Southeast Asia	0	17	18	139	385	174	523

Table A.21: Nuclear generation (TWh)

				Current Policies		Stated Policies	
	2010	2023	2024	2035	2050	2035	2050
World	2 756	2 740	2 835	3 856	5 192	3 902	5 531
North America	935	910	912	952	1 601	949	1 711
United States	839	808	815	834	1 450	838	1 573
Central and South America	22	24	26	49	65	47	57
Brazil	15	15	15	37	45	36	37
Europe	1 032	748	806	838	930	839	914
European Union	854	620	651	659	729	657	719
Africa	12	9	9	48	78	48	78
Middle East	0	39	40	70	94	78	105
Eurasia	173	220	217	261	333	261	333
Russia	170	217	215	256	327	256	327
Asia Pacific	582	791	825	1 637	2 090	1 679	2 332
China	74	435	451	937	1 257	977	1 408
India	26	48	54	184	276	193	337
Japan	288	84	91	212	210	205	208
Southeast Asia	0	0	0	0	12	0	44

Table A.22: Natural gas generation (TWh)

				Current Policies		Stated Policies	
	2010	2023	2024	2035	2050	2035	2050
World	**4 819**	**6 630**	**6 785**	**8 519**	**9 961**	**7 880**	**7 532**
North America	1 217	2 192	2 282	2 625	2 314	2 490	1 558
United States	1 018	1 864	1 929	2 268	1 875	2 168	1 202
Central and South America	170	202	211	292	353	264	201
Brazil	36	38	51	66	131	50	49
Europe	946	724	672	485	404	321	206
European Union	589	450	422	275	191	200	107
Africa	235	382	388	550	949	478	661
Middle East	524	972	995	1 613	2 354	1 511	1 844
Eurasia	603	667	684	814	967	809	902
Russia	521	511	525	597	639	599	585
Asia Pacific	1 125	1 491	1 552	2 141	2 621	2 007	2 161
China	92	306	329	571	696	470	570
India	107	59	62	76	153	107	164
Japan	332	331	332	383	374	335	250
Southeast Asia	335	361	379	607	828	612	745

Table A.23: Coal generation (TWh)

				Current Policies		Stated Policies	
	2010	2023	2024	2035	2050	2035	2050
World	**8 680**	**10 687**	**10 797**	**10 321**	**8 495**	**8 479**	**4 606**
North America	2 106	798	768	572	422	352	55
United States	1 994	742	717	567	421	347	54
Central and South America	41	50	53	32	23	31	19
Brazil	11	14	15	12	8	10	4
Europe	1 068	550	485	241	185	174	129
European Union	755	346	295	70	37	24	1
Africa	259	226	236	169	83	151	57
Middle East	0	4	4	7	7	5	4
Eurasia	235	288	294	284	268	258	248
Russia	166	211	216	198	176	174	154
Asia Pacific	4 971	8 771	8 957	9 016	7 506	7 509	4 094
China	3 263	5 869	5 940	5 985	4 364	4 730	1 958
India	658	1 479	1 552	1 648	1 638	1 548	1 041
Japan	317	284	278	117	63	82	51
Southeast Asia	192	635	691	974	1 225	887	886

Table A.24: Total final consumption (EJ)

	2010	2023	2024	Current Policies 2035	Current Policies 2050	Stated Policies 2035	Stated Policies 2050
World	**377.8**	**444.3**	**452.7**	**522.8**	**599.4**	**503.7**	**541.0**
North America	76.7	78.4	78.7	82.8	87.4	79.4	76.2
United States	63.8	65.3	65.6	69.4	72.6	66.5	62.9
Central and South America	19.2	21.9	22.2	26.6	33.8	25.5	30.2
Brazil	9.1	10.7	11.0	12.9	16.2	12.2	14.3
Europe	63.1	55.3	55.8	54.8	52.1	53.0	47.0
European Union	46.0	39.9	40.2	38.0	33.8	36.9	30.8
Africa	17.8	23.8	24.0	30.5	41.8	29.4	38.6
Middle East	18.3	25.0	25.4	33.3	43.9	32.1	39.8
Eurasia	24.1	28.4	29.0	31.5	33.7	30.9	32.1
Russia	19.6	22.9	23.4	24.2	24.4	23.7	23.2
Asia Pacific	143.6	195.1	200.4	241.0	278.5	231.7	252.4
China	76.0	110.1	113.0	127.4	131.3	123.1	121.5
India	18.9	31.6	33.1	48.6	68.1	45.8	59.5
Japan	14.2	11.2	11.0	10.4	9.9	10.0	8.8
Southeast Asia	14.4	20.3	21.0	28.7	37.9	27.7	34.2

Table A.25: Industry consumption (EJ)

	2010	2023	2024	Current Policies 2035	Current Policies 2050	Stated Policies 2035	Stated Policies 2050
World	**142.2**	**170.5**	**174.1**	**204.6**	**229.1**	**197.4**	**209.9**
North America	17.8	19.2	19.3	21.4	22.5	20.5	20.1
United States	14.1	15.3	15.4	17.0	17.6	16.3	15.5
Central and South America	7.3	7.3	7.4	8.6	10.2	8.4	9.6
Brazil	4.0	4.1	4.2	4.8	5.7	4.7	5.3
Europe	19.6	16.1	16.5	17.1	18.0	16.4	16.1
European Union	14.3	12.0	12.4	12.3	12.4	11.7	11.0
Africa	4.0	4.8	4.8	6.3	8.7	6.1	8.1
Middle East	7.5	9.8	10.1	13.2	16.7	12.7	15.3
Eurasia	8.6	9.9	10.0	10.7	11.1	10.4	10.5
Russia	7.0	8.3	8.4	8.7	8.5	8.5	8.1
Asia Pacific	77.4	103.3	105.9	127.3	141.8	123.0	130.3
China	49.0	66.3	67.5	75.3	74.5	72.8	68.6
India	7.8	14.5	15.4	24.2	34.2	23.3	31.2
Japan	6.1	4.7	4.6	4.4	4.2	4.2	3.9
Southeast Asia	5.8	8.7	9.1	12.7	16.2	12.3	14.9

Table A.26: Transport consumption (EJ)

				Current Policies		Stated Policies	
	2010	2023	2024	2035	2050	2035	2050
World	**101.8**	**122.8**	**124.5**	**139.8**	**163.2**	**135.3**	**143.7**
North America	29.6	30.1	30.2	30.4	32.4	28.7	26.0
United States	25.0	25.5	25.5	26.1	27.8	24.6	22.1
Central and South America	6.1	7.8	8.0	10.0	13.4	9.7	12.0
Brazil	2.9	3.9	4.1	4.8	6.1	4.6	5.4
Europe	15.6	16.2	16.2	13.6	10.0	13.5	9.4
European Union	11.7	11.7	11.7	9.3	5.6	9.3	5.4
Africa	3.7	5.5	5.5	7.6	11.9	7.4	11.1
Middle East	4.9	6.3	6.3	8.2	11.1	7.9	10.1
Eurasia	4.7	5.7	5.8	6.4	7.5	6.4	7.2
Russia	4.0	4.5	4.5	4.7	5.0	4.7	4.9
Asia Pacific	22.1	34.9	35.4	41.3	48.5	40.1	43.2
China	8.2	15.8	15.9	15.7	14.8	15.6	14.4
India	2.7	5.2	5.5	8.9	13.1	8.5	11.1
Japan	3.3	2.7	2.6	2.2	2.0	2.1	1.6
Southeast Asia	3.7	6.2	6.3	8.3	10.7	8.0	9.4

Table A.27: Buildings consumption (EJ)

				Current Policies		Stated Policies	
	2010	2023	2024	2035	2050	2035	2050
World	**111.9**	**124.4**	**126.8**	**146.0**	**171.1**	**139.6**	**153.8**
North America	23.7	23.8	23.9	25.4	26.8	24.7	24.6
United States	20.5	20.4	20.5	21.7	22.5	21.1	20.8
Central and South America	4.4	5.3	5.4	6.2	8.0	5.7	6.7
Brazil	1.4	1.9	1.9	2.3	3.3	2.0	2.7
Europe	24.3	19.8	19.9	20.7	20.9	20.0	18.7
European Union	17.6	14.0	13.9	14.3	13.9	13.8	12.4
Africa	9.3	12.6	12.7	15.3	19.2	14.6	17.6
Middle East	5.1	7.5	7.6	9.9	13.3	9.7	12.1
Eurasia	8.4	10.1	10.4	11.0	11.4	10.8	10.9
Russia	6.2	7.5	7.7	7.7	7.6	7.5	7.2
Asia Pacific	36.8	45.4	46.9	57.4	71.5	54.2	63.2
China	15.6	21.9	22.9	28.9	34.7	27.7	32.0
India	6.9	9.1	9.4	11.3	15.0	9.9	11.5
Japan	4.3	3.5	3.5	3.4	3.4	3.3	3.0
Southeast Asia	3.9	4.3	4.5	6.3	9.4	6.0	8.2

Table A.28: Hydrogen demand (PJ)

			Current Policies		Stated Policies	
	2023	2024	2035	2050	2035	2050
World	**11 708**	**11 965**	**14 760**	**18 240**	**14 919**	**18 542**
North America	1 933	1 943	2 126	2 293	2 172	2 481
United States	1 608	1 611	1 707	1 815	1 749	1 986
Central and South America	372	369	550	850	535	864
Brazil	51	55	103	141	86	104
Europe	869	868	975	1 547	1 006	1 610
European Union	694	707	782	1 342	821	1 412
Africa	374	391	587	1 065	578	986
Middle East	1 625	1 719	2 439	3 139	2 425	3 102
Eurasia	803	794	844	851	849	869
Russia	721	715	745	732	751	748
Asia Pacific	5 734	5 881	7 424	8 705	7 580	8 883
China	3 438	3 512	3 915	4 079	3 944	4 103
India	1 123	1 173	1 777	2 289	1 781	2 236
Japan	227	219	217	216	226	261
Southeast Asia	441	451	624	745	637	795
International bunkers	-	-	13	61	20	81

Table A.29: Low-emissions hydrogen balance (Mt H_2 equivalent)

		Current Policies		Stated Policies		Net Zero Emissions by 2050	
	2024	2035	2050	2035	2050	2035	2050
Low-emissions hydrogen production	0.7	11	33	13	39	123	376
Water electrolysis	0.1	8	29	10	33	92	304
Fossil fuels with CCUS	0.5	3	5	3	6	30	71
Bioenergy and other	0.0	0	0	0	0	0	1
Transformation of hydrogen	0.3	8	25	8	25	80	199
To power generation	-	2	2	2	2	21	39
To hydrogen-based fuels	0.0	4	18	4	18	49	151
In oil refining	0.3	2	3	2	4	8	5
To biofuels	0.0	0	1	0	1	3	4
Hydrogen demand for end-use sectors	0.4	3	8	5	14	41	170
Low-emissions hydrogen-based fuels	-	4	18	4	17	46	151
Total final consumption	-	2	15	2	14	32	131
Power generation	-	1	3	1	3	15	19
Trade	0.0	6	22	7	22	27	68
Trade as share of demand	0%	61%	65%	50%	56%	22%	18%

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Table A.30: Total CO_2 emissions* (Mt CO_2)

				Current Policies		Stated Policies	
	2010	2023	2024	2035	2050	2035	2050
World	32 854	37 820	38 153	38 503	37 779	35 244	29 629
North America	6 488	5 589	5 560	5 395	5 133	4 916	3 782
United States	5 469	4 546	4 521	4 447	4 127	4 012	2 929
Central and South America	1 151	1 204	1 204	1 358	1 612	1 290	1 356
Brazil	412	455	459	501	596	472	491
Europe	4 723	3 586	3 501	2 693	2 014	2 423	1 518
European Union	3 315	2 449	2 385	1 643	995	1 482	710
Africa	1 179	1 452	1 460	1 658	2 244	1 573	1 961
Middle East	1 641	2 257	2 291	2 673	3 302	2 466	2 736
Eurasia	2 138	2 408	2 446	2 454	2 493	2 378	2 320
Russia	1 680	1 854	1 881	1 803	1 699	1 745	1 581
Asia Pacific	14 408	20 125	20 423	20 730	19 220	18 712	14 438
China	8 772	12 572	12 660	11 977	9 256	10 515	6 567
India	1 668	2 964	3 113	3 883	4 495	3 645	3 428
Japan	1 189	985	958	705	581	629	452
Southeast Asia	1 129	1 881	1 969	2 551	3 132	2 411	2 563

*Includes industrial process and flaring emissions.

Table A.31: Electricity and heat sectors CO_2 emissions (Mt CO_2)

				Current Policies		Stated Policies	
	2010	2023	2024	2035	2050	2035	2050
World	12 525	15 311	15 588	14 794	12 809	12 783	8 449
North America	2 596	1 727	1 730	1 568	1 267	1 318	648
United States	2 346	1 490	1 490	1 415	1 099	1 177	509
Central and South America	234	212	219	200	184	189	126
Brazil	46	47	55	47	61	39	29
Europe	1 731	1 008	916	523	386	394	258
European Union	1 188	646	579	236	131	166	66
Africa	421	467	479	426	462	386	332
Middle East	548	779	788	816	987	705	727
Eurasia	1 034	1 075	1 105	1 065	1 025	1 038	976
Russia	892	853	875	820	734	799	688
Asia Pacific	5 960	10 043	10 350	10 196	8 499	8 754	5 382
China	3 509	6 509	6 688	6 658	4 894	5 451	2 777
India	785	1 485	1 558	1 556	1 502	1 478	977
Japan	499	446	441	260	186	209	132
Southeast Asia	405	830	893	1 201	1 480	1 132	1 159

Table A.32: Total final consumption CO_2 emissions* (Mt CO_2)

				Current Policies		Stated Policies	
	2010	2023	2024	2035	2050	2035	2050
World	**18 630**	**20 609**	**20 657**	**21 776**	**22 991**	**20 602**	**19 403**
North America	3 472	3 403	3 353	3 330	3 336	3 107	2 664
United States	2 863	2 785	2 740	2 726	2 702	2 539	2 131
Central and South America	805	896	900	1 071	1 332	1 020	1 145
Brazil	342	387	392	440	526	419	449
Europe	2 817	2 431	2 448	2 062	1 548	1 924	1 185
European Union	2 014	1 703	1 707	1 333	811	1 243	594
Africa	572	810	808	1 076	1 613	1 039	1 459
Middle East	930	1 203	1 222	1 516	1 899	1 453	1 668
Eurasia	911	1 199	1 204	1 251	1 331	1 217	1 228
Russia	665	902	904	882	870	860	816
Asia Pacific	7 996	9 466	9 454	9 928	10 172	9 357	8 538
China	5 000	5 703	5 608	4 969	4 064	4 713	3 502
India	849	1 400	1 473	2 225	2 887	2 066	2 351
Japan	662	521	501	433	386	408	311
Southeast Asia	647	960	982	1 273	1 585	1 205	1 342

* Includes industrial process emissions.

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Design of the scenarios

This annex provides an overview of the design of the *World Energy Outlook 2025 (WEO-2025)* scenarios and a summary of key underlying assumptions. The following sections and tables outline assumptions related to population, gross domestic product, fossil fuel resources, electricity generation technology costs, other key technology costs, CO_2 prices, and policies. Each table indicates which scenarios the assumptions apply to; unless otherwise specified, the assumptions apply to all scenarios.

The WEO-2025 examines the outlook for the energy system through an updated set of scenarios. The first two, the Current Policies Scenario (CPS) and the Stated Policies Scenario (STEPS) do not target a specific endpoint or objective but rather establish different sets of starting conditions and explore where they may lead.

- The **Current Policies Scenario** (CPS) returns in this *Outlook*, setting out a pathway for the future of the energy system in which no change in energy-related policies is assumed beyond what is already in place. The CPS therefore builds on a narrow reading of today's policy settings, only considering those that are adopted in legislation and regulation, and assuming no change, even where governments have indicated their intention to do so. Where existing policies target a range of outcomes, it is assumed that the lower end of the range is achieved. In the CPS, policies that are time-bound or that target specific years are not strengthened after they expire. Alongside this view of the policy landscape, the CPS also offers a generally cautious perspective on the speed at which new energy technologies are deployed and integrated into the energy system. It tends to project slower growth in the adoption of new technologies in the energy system than seen in recent years, or than projected in the STEPS.

- The **Stated Policies Scenario** (STEPS) builds on a broader reading of the policy landscape than the CPS, also taking account of those policies that have been formally tabled but not yet adopted as well as other official strategy documents that indicate the direction of travel. These could include, for example, development plans for the power sector that aim to achieve a certain mix of generation assets by a specific date; or plans to reform the regulatory framework for part of the transport sector or to achieve a certain level of efficiency for new or retrofitted buildings. Such targets are not automatically assumed to be met; the prospects and timing for their realisation are subject to an assessment of relevant market, infrastructure and financial constraints.

  Another difference with the CPS relates to time-bound policies. Whereas the CPS assumes no further change in a policy once it expires, the STEPS assumes that time-bound policies are prolonged into the future and retain a similar pace of change. In addition, the STEPS offers a more dynamic perspective on energy technology and market trends, and it allows for a slightly more rapid introduction of new energy technologies than the CPS. However, like the CPS, the STEPS does not assume that aspirational goals, such as those included in the Paris Agreement, are achieved.

In addition, the *Outlook* includes scenarios that have normative elements relating to energy access or the achievement of various goals related to emissions. This means that these scenarios work toward a defined outcome and map out a way to achieve it.

- The **Net Zero Emissions by 2050** (NZE) **Scenario** maps out a pragmatic but ambitious global pathway for the energy sector to achieve net zero CO_2 emissions by 2050 and is consistent with a long-term goal of limiting the rise in global average temperatures to 1.5 °C (with a 50% probability). In contrast with previous editions of the *WEO*, the NZE Scenario is no longer a limited-overshoot scenario, as warming peaks above 1.6 °C and exceeds 1.5 °C for several decades before returning below 1.5 °C by 2100. These changes in the scenario trajectory reflect the reality of persistently high emissions in recent years and slow or uneven momentum behind the deployment of some policies and technologies. In addition to very rapid progress with the transformation of the energy sector, bringing the temperature rise back down below 1.5 °C by 2100 also requires widespread deployment of CO_2 removal technologies that are currently unproven at large scale.

The *WEO-2025* also includes an additional scenario — the **Accelerating Clean Cooking and Electricity Services Scenario (ACCESS)** — which presents a data-driven pathway to achieve universal access to electricity by 2035 and to clean cooking by 2040. The ACCESS scenario applies the same prevailing technology cost and fuel price assumptions as the STEPS. Therefore, its specific assumptions are not listed separately in the following tables.

B.1 Population

Table B.1 ▷ Population assumptions by region

	Compound average annual growth rate (%)			Population (million)			Urbanisation (share of population, %)		
	2000-24	2024-35	2024-50	2024	2035	2050	2024	2035	2050
North America	0.9	0.5	0.4	513	543	571	83	86	89
United States	0.7	0.4	0.4	340	357	374	84	86	89
C & S America	1.0	0.5	0.3	537	567	586	82	85	88
Brazil	0.9	0.3	0.1	217	224	223	88	90	92
Europe	0.3	-0.1	-0.1	692	687	668	76	80	84
European Union	0.2	-0.2	-0.3	448	438	420	76	79	84
Africa	2.5	2.1	1.9	1 494	1 884	2 434	45	51	59
Middle East	2.1	1.5	1.3	274	323	380	73	76	81
Eurasia	0.4	0.3	0.3	241	250	264	65	68	73
Russia	-0.1	-0.3	-0.2	143	138	135	76	79	83
Asia Pacific	1.0	0.4	0.3	4 340	4 549	4 670	52	57	64
China	0.5	-0.3	-0.5	1 415	1 369	1 256	66	74	80
India	1.3	0.8	0.6	1 441	1 568	1 669	37	43	53
Japan	-0.1	-0.6	-0.6	124	116	105	92	93	95
Southeast Asia	1.2	0.6	0.4	690	736	769	52	59	66
World	**1.2**	**0.8**	**0.6**	**8 091**	**8 805**	**9 572**	**58**	**62**	**68**

Notes: C & S America = Central and South America. See Annex C for composition of regional groupings.

Sources: OECD (2025); UN DESA (2018, 2024); World Bank (2025a); 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 9.6 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 fifth 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 1.5 billion increase in global population over the period is added to cities and towns.

B.2 Gross domestic product

Table B.2 ▻ GDP average growth assumptions by region

	Compound average annual growth rate			
	2010-24	2024-35	2035-50	2024-50
North America	2.3%	2.0%	1.8%	1.9%
United States	2.3%	2.0%	1.8%	1.9%
Central and South America	1.4%	2.6%	2.1%	2.3%
Brazil	1.3%	2.3%	2.1%	2.2%
Europe	1.7%	1.6%	1.3%	1.4%
European Union	1.4%	1.3%	1.0%	1.1%
Africa	3.1%	4.2%	3.9%	4.0%
South Africa	1.1%	1.8%	2.6%	2.2%
Middle East	2.5%	2.9%	2.7%	2.8%
Eurasia	2.2%	1.8%	1.4%	1.6%
Russia	1.8%	1.0%	0.5%	0.7%
Asia Pacific	4.9%	3.9%	2.8%	3.3%
China	6.3%	3.5%	2.2%	2.7%
India	6.0%	6.1%	4.0%	4.9%
Japan	0.6%	0.6%	0.7%	0.6%
Southeast Asia	4.3%	4.1%	3.0%	3.5%
World	**3.1%**	**3.0%**	**2.4%**	**2.6%**

Note: Calculated based on GDP expressed in year-2024 US dollars at purchasing power parity terms.
Sources: IEA analysis based on IMF (2025c) and Oxford Economics (2025).

- The global economy is assumed to grow by 2.6% on average annually to 2050 across all scenarios. Out to 2030, our GDP assumptions at a country and regional level are based on the IMF World Economic Outlook (April 2025), with global GDP projected to grow by 3% annually over this period (IMF, 2025c). This projection is similar to the rate of growth in the IMF October 2025 assessment (IMF, 2025a).
- After 2030, GDP growth assumptions are based on Oxford Economics forecasts (Oxford Economics, 2025) and the application of the Solow growth model (World Bank, 2022). The Solow model estimates future GDP on a country and regional basis by accounting for labour supply, capital stock, and total factor productivity (TFP). TFP growth reflects catch-up dynamics in lower income countries and convergence towards advanced economy levels. Economic assumptions are held constant across the various scenarios to facilitate comparisons between them, although we recognise that decisions taken by policy makers in the energy sector have broader economic implications.

B.3 Fossil fuel resources

Table B.3 ▷ Remaining technically recoverable fossil fuel resources, 2024

Oil (billion barrels)	Proven reserves	Resources	Conventional crude oil	Tight oil	NGLs	EHOB	Kerogen oil
North America	222	2 410	231	233	150	795	1 000
Central and South America	296	848	247	57	49	492	3
Europe	14	109	54	19	28	3	6
Africa	124	445	306	54	82	2	-
Middle East	902	1 139	861	29	206	14	30
Eurasia	146	940	227	85	57	552	18
Asia Pacific	51	270	115	72	64	3	16
World	**1 756**	**6 161**	**2 042**	**549**	**636**	**1 862**	**1 073**

Natural gas (trillion cubic metres)	Proven reserves	Resources	Conventional gas	Tight gas	Shale gas	Coalbed methane
North America	19	143	49	9	78	7
Central and South America	9	84	28	15	41	-
Europe	5	45	18	5	18	5
Africa	19	100	50	10	40	0
Middle East	84	119	99	9	11	-
Eurasia	69	165	127	11	10	17
Asia Pacific	19	136	42	21	53	20
World	**224**	**792**	**413**	**80**	**250**	**49**

Coal (billion tonnes)	Proven reserves	Resources	Coking coal	Steam coal	Lignite
North America	257	8 387	1 032	5 837	1 519
Central and South America	14	60	3	32	25
Europe	137	980	164	415	402
Africa	15	343	43	299	-
Middle East	1	41	36	5	-
Eurasia	191	2 015	391	992	632
Asia Pacific	460	8 950	1 712	5 824	1 413
World	**1 074**	**20 776**	**3 380**	**13 405**	**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 (2024); CEDIGAZ (2025); Energy Institute (2024); OGJ (2024); US EIA (2025); 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 2024*. All fuels are at a level 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 210 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.

B.4 Electricity generation technology costs

General note to the tables

- All cost components, LCOE and VALCOE figures are expressed in year-2024 US dollars and rounded.
- 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 next-generation geothermal, 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, 2025), 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. Lower values for VALCOE indicate improved competitiveness.
- 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 2024).
- Solar PV and wind costs do not include the cost of energy storage technologies, such as utility-scale batteries.
- 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 system costs reflect total electricity supply costs, including grids, per unit of electricity generation.
- Abbreviations/acronyms used in the tables include: USD = United States dollar; kW = kilowatt; MWh = megawatt-hour; O&M = operation and maintenance; LCOE = levelised cost of electricity; VALCOE = value-adjusted LCOE; CCGT = combined-cycle gas turbine; PV = photovoltaics; n.a. = not applicable.

Table B.4a ▷ Technology costs in selected regions in the Current Policies Scenario

	Capital costs (USD/kW)			Capacity factor (%)			Fuel, CO_2, O&M (USD/MWh)			LCOE (USD/MWh)			VALCOE (USD/MWh)		
	2024	2035	2050	2024	2035	2050	2024	2035	2050	2024	2035	2050	2024	2035	2050
United States															
Nuclear	5 000	4 700	4 500	90	90	90	30	30	30	110	110	105	110	110	105
Coal	2 100	2 100	2 100	45	40	35	30	30	30	95	100	110	95	95	105
Gas CCGT	1 000	1 100	1 100	65	60	50	30	40	40	50	65	70	50	60	65
Geothermal*	15 000	9 000	6 600	75	75	80	50	25	20	330	195	135	330	195	135
Solar PV	1 060	680	570	20	23	23	10	10	10	55	35	30	65	50	50
Wind onshore	1 570	1 510	1 470	42	44	44	10	10	10	40	40	35	45	45	40
Wind offshore	4 060	2 940	2 420	41	46	49	35	30	25	125	85	70	130	90	75
Electricity generation costs										65	65	70			
European Union															
Nuclear	6 600	5 000	4 500	75	75	80	35	35	35	165	130	120	160	115	105
Coal	2 000	2 000	2 000	25	25	n.a.	115	110	n.a.	235	230	n.a.	200	190	n.a.
Gas CCGT	1 000	1 000	1 000	15	10	10	115	110	115	205	230	290	150	150	150
Geothermal*	21 630	18 130	16 730	75	75	80	55	45	45	455	380	330	450	365	315
Solar PV	760	480	410	14	14	14	10	10	10	50	35	30	60	65	70
Wind onshore	1 620	1 540	1 510	29	30	30	15	15	15	60	55	55	70	75	75
Wind offshore	3 460	2 360	2 020	50	54	55	15	10	10	75	50	40	75	65	60
Electricity generation costs										125	105	85			
China															
Nuclear	2 800	2 700	2 500	75	70	70	25	25	25	70	75	70	70	75	70
Coal	800	800	800	50	40	40	45	40	40	65	65	65	60	60	55
Gas CCGT	560	560	560	30	20	20	80	75	80	100	105	110	90	85	80
Geothermal*	16 050	11 050	9 050	75	75	80	55	30	25	320	215	165	320	215	165
Solar PV	590	360	290	12	12	12	10	10	10	45	30	25	65	60	65
Wind onshore	860	810	790	23	24	24	10	10	10	40	35	35	45	45	50
Wind offshore	1 520	1 060	900	30	32	32	15	10	10	60	40	35	65	50	50
Electricity generation costs										75	80	80			
India															
Nuclear	2 800	2 800	2 800	80	85	90	30	30	30	75	70	70	75	70	70
Coal	1 200	1 200	1 200	75	85	90	40	40	40	60	55	55	60	55	50
Gas CCGT	700	700	700	30	35	45	55	60	65	85	85	85	80	75	70
Geothermal*	19 500	15 000	13 200	75	75	80	75	55	45	400	305	250	400	305	250
Solar PV	530	320	260	20	21	22	5	5	5	30	20	15	35	35	50
Wind onshore	1 110	1 050	1 020	27	29	30	15	10	10	55	45	45	60	50	55
Wind offshore	2 620	1 800	1 500	34	38	39	25	15	15	110	70	60	110	75	70
Electricity generation costs										75	65	50			

*Next-generation geothermal.

Sources: IEA analysis; IRENA (2025).

Table B.4b ▷ 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)		
	2024	2035	2050	2024	2035	2050	2024	2035	2050	2024	2035	2050	2024	2035	2050
United States															
Nuclear	5 000	4 700	4 500	90	90	90	30	30	30	110	110	105	110	110	105
Coal	2 100	2 100	2 100	40	30	20	30	25	25	100	120	190	100	110	180
Gas CCGT	1 000	1 100	1 100	65	55	35	30	35	40	50	60	80	50	55	70
Geothermal*	15 000	9 000	6 600	75	75	80	50	25	20	330	195	135	330	195	135
Solar PV	1 060	660	530	20	23	23	10	10	10	55	35	25	65	50	50
Wind onshore	1 570	1 510	1 460	42	44	44	10	10	10	40	40	35	45	45	40
Wind offshore	4 060	2 860	2 340	41	46	49	35	30	25	125	85	65	130	90	70
Electricity generation costs										65	65	70			
European Union															
Nuclear	6 600	5 000	4 500	75	75	80	35	35	35	165	135	120	160	120	105
Coal	2 000	2 000	2 000	20	n.a.	n.a.	120	n.a.	n.a.	280	n.a.	n.a.	235	n.a.	n.a.
Gas CCGT	1 000	1 000	1 000	15	10	10	110	110	135	200	230	290	145	150	150
Geothermal*	21 630	18 130	16 730	75	75	80	55	45	45	455	380	330	450	365	325
Solar PV	760	470	390	14	14	14	10	10	10	50	35	30	60	65	70
Wind onshore	1 620	1 540	1 510	29	30	30	15	15	15	60	55	55	70	75	75
Wind offshore	3 460	2 300	1 980	50	54	55	15	10	10	75	50	40	75	65	60
Electricity generation costs										125	100	85			
China															
Nuclear	2 800	2 700	2 500	75	70	70	25	25	25	70	75	70	70	75	70
Coal	800	800	800	50	25	20	40	35	35	65	80	90	60	70	70
Gas CCGT	560	560	560	25	15	15	70	65	70	100	115	125	90	90	95
Geothermal*	16 050	11 050	9 050	75	75	80	55	30	25	320	215	165	320	215	165
Solar PV	590	350	280	12	12	12	10	10	10	45	30	25	65	65	70
Wind onshore	860	800	790	23	24	24	10	10	10	40	35	35	45	45	55
Wind offshore	1 520	1 020	880	30	32	32	15	10	10	60	40	35	65	50	55
Electricity generation costs										75	75	80			
India															
Nuclear	2 800	2 800	2 800	80	85	90	30	30	30	75	70	70	75	70	70
Coal	1 200	1 200	1 200	70	70	65	40	45	50	60	65	70	60	65	65
Gas CCGT	700	700	700	30	35	45	60	70	75	90	95	95	85	90	85
Geothermal*	19 500	15 000	13 200	75	75	80	75	55	45	400	305	250	400	305	250
Solar PV	530	310	250	20	21	22	5	5	5	30	20	15	35	30	45
Wind onshore	1 110	1 040	1 010	27	29	30	15	10	10	55	45	45	60	50	55
Wind offshore	2 620	1 760	1 460	34	38	39	25	15	15	110	70	55	110	75	65
Electricity generation costs										75	65	50			

*Next-generation geothermal.

Sources: IEA analysis; IRENA (2025).

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, O&M (USD/MWh)			LCOE (USD/MWh)		
	2024	2035	2050	2024	2035	2050	2024	2035	2050	2024	2035	2050
United States												
Nuclear	5 000	4 700	4 500	90	85	85	30	30	30	110	115	115
Coal	2 100	2 100	2 100	25	n.a.	n.a.	95	n.a.	n.a.	210	n.a.	n.a.
Gas CCGT	1 000	1 100	1 100	40	10	n.a.	55	90	n.a.	85	265	n.a.
Geothermal*	15 000	6 600	3 560	75	75	80	50	20	10	330	140	70
Solar PV	1 060	590	480	20	23	23	10	10	10	55	30	25
Wind onshore	1 570	1 450	1 400	42	44	44	10	10	10	40	35	35
Wind offshore	4 060	2 380	1 980	41	46	49	35	20	15	125	70	55
Electricity generation costs										65	80	70
European Union												
Nuclear	6 600	5 000	4 500	75	70	65	35	35	35	165	140	135
Coal	2 000	2 000	2 000	15	n.a.	n.a.	150	n.a.	n.a.	330	n.a.	n.a.
Gas CCGT	1 000	1 000	1 000	15	n.a.	n.a.	115	n.a.	n.a.	215	n.a.	n.a.
Geothermal*	21 630	16 030	14 000	75	75	80	55	40	35	455	335	280
Solar PV	760	440	370	14	14	14	10	10	10	50	35	30
Wind onshore	1 620	1 510	1 460	29	30	30	15	15	15	60	55	50
Wind offshore	3 460	2 180	1 800	50	54	55	15	10	10	75	45	35
Electricity generation costs										125	95	80
China												
Nuclear	2 800	2 700	2 500	80	75	75	25	25	25	70	70	70
Coal	800	800	800	40	n.a.	n.a.	80	n.a.	n.a.	105	n.a.	n.a.
Gas CCGT	560	560	560	40	30	n.a.	85	100	n.a.	100	120	n.a.
Geothermal*	16 050	8 050	5 150	75	75	80	55	25	15	320	160	95
Solar PV	590	320	260	12	12	12	10	10	5	45	30	25
Wind onshore	860	780	750	23	24	24	10	10	10	40	35	35
Wind offshore	1 520	900	760	30	32	32	15	10	10	60	35	30
Electricity generation costs										75	80	75
India												
Nuclear	2 800	2 800	2 800	80	85	85	30	30	30	75	70	70
Coal	1 200	1 200	1 200	60	25	n.a.	35	135	n.a.	60	195	n.a.
Gas CCGT	700	700	700	30	30	n.a.	50	80	n.a.	80	110	n.a.
Geothermal*	19 500	12 300	9 690	75	75	80	75	45	35	400	250	185
Solar PV	530	290	220	20	21	22	5	5	5	30	15	15
Wind onshore	1 110	1 020	970	26	29	29	15	10	10	55	45	45
Wind offshore	2 620	1 600	1 280	34	38	39	25	15	10	110	65	50
Electricity generation costs										75	75	40

*Next-generation geothermal.
Sources: IEA analysis; IRENA (2025).

B.5 Other key technology costs

Table B.5 ▷ Costs for selected technologies by scenario

		Current Policies Scenario		Stated Policies Scenario		Net Zero Emissions by 2050 Scenario	
	2024	2035	2050	2035	2050	2035	2050
Levelised cost of iron-based steel production (USD/t)							
Conventional							
Lower range	470	460	460	450	450	560	690
Upper range	570	570	620	530	530	780	810
Innovative							
Lower range	N/A	790	750	710	690	700	700
Upper range	N/A	870	810	850	840	810	850
Vehicles (USD/vehicle)							
Hybrid cars	17 800	16 300	16 200	16 200	16 200	16 000	15 900
Battery electric cars	19 500	16 200	15 500	16 000	15 100	15 500	14 700
Batteries and hydrogen							
Hydrogen electrolysers							
Lower range (USD/kW)	600	440	390	420	390	330	310
Upper range (USD/kW)	2 600	1 680	1 460	1 650	1 450	1 310	1 180
Fuel cells							
Trucks (USD/kW)	370	230	190	210	190	150	80
Utility-scale stationary batteries (USD/kWh)	150	100	90	100	90	100	80

Notes: t = tonnes; kW = kilowatt; kWh = kilowatt-hour. All values are in USD (2024).

Sources: IEA analysis; BNEF (2025); Cole et al. (2021); Financial Times (2020); JATO (2021); S&P Global Mobility (2024); 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 is 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. They represent a global average, evolving in line with the regions' roles in the global market and their respective production costs.
- 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 heavy-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.

B.6 CO_2 prices

Table B.6 ▷ CO_2 prices for electricity in selected regions by scenario

USD (2024, MER) per tonne of CO_2	2035	2040	2050
Current Policies Scenario			
Canada	70	70	70
China	14	14	14
European Union	87	87	87
Japan	2	2	2
Korea	13	13	13
Stated Policies Scenario			
Canada	126	126	126
China	22	26	34
European Union	89	92	174
Japan	39	61	105
Korea	52	62	75
Net Zero Emissions by 2050 Scenario			
Advanced economies with net zero emissions pledges	180	205	250
Selected emerging markets and developing economies*	125	160	200
Other emerging market and developing economies	25-50	35-85	55-180

*Includes Brazil, China, India, Indonesia and South Africa.

Notes: USD = United States dollar; MER = market exchange rate. Values are rounded.

- There are 113 direct carbon pricing instruments in place today, covering 55 countries and 44 sub-national jurisdictions. Global carbon pricing revenues in 2024 slightly decreased by 2.4% from 2023 levels, to around USD 102 billion (World Bank, 2025b).
- The CPS only considers implemented and enforced carbon pricing mechanisms in place as of 2025. It does not consider planned carbon pricing policies or extensions/expansions of existing schemes that have a stated end date. Existing and scheduled CO_2 pricing schemes are reflected in the STEPS. In the NZE Scenario, CO_2 prices cover all regions and rise over time. Prices are generally higher in advanced economies and lower prices in developing regions.

B.7 Policies

- The policy actions taken by governments are key inputs in the *World Energy Outlook*. An overview of the policies, measures and targets considered in the various scenarios is included in Tables B.7 to B.11. The tables do not include all policies and measures but rather highlight the latest, prominent policies shaping global and regional energy demand today. A more complete policy dataset that can be accessed through the publicly available IEA Global Energy Policies Hub.
- The policies are additive: measures listed under the Stated Policies Scenario (STEPS) are supplemental to the policies in the Current Policies Scenario (CPS). The tables begin with cross-cutting and energy supply policy frameworks, followed by detailed policies by sector: electricity generation, industry, buildings and transport. Table B.12 provides a list of key industry and intergovernmental-led initiatives considered fully or partially implemented in the CPS, STEPS and Net Zero Emissions by 2050 (NZE) Scenario. In the NZE Scenario, these initiatives are often met globally, not just by current signatories.

Table B.7 ▷ Selected cross-cutting and energy supply policy as modelled by scenario and regions/countries

Region/ country	Scenario	Policies and targets
United States	CPS	• Unleashing American Energy: Executive Order Establishing a National Energy Emergency (2025). • One Big Beautiful Bill Act (2025).
Canada	CPS	• Regulation Respecting Reduction in the Release of Methane and Certain Volatile Organic Compounds (2018).
	STEPS	• Strategic Innovation Fund (2017); Investing in Canada Infrastructure Programme (2016). • 2023 proposed amendments to the Regulation Respecting Reduction in the Release of Methane and Certain Volatile Organic Compounds (2018).
Latin America and the Caribbean	CPS	• Brazil: Regulations to reduce flaring and extraordinary methane emissions. • Colombia: Requirements to undertake leak detection and repair, control flaring and reduce methane emissions.
	STEPS	• Brazil: Energy Transition Acceleration Programme (2025); Nova Indústria Brazil (2024); New Growth Acceleration Programme (2023). • Colombia: National Strategy for Mitigation of Short-Lived Climate Pollutants (2018). • Chile: Energy Efficiency Law (2021).
Japan	CPS	• Energy demand and supply mix specified in alternative scenarios of the 7th Strategic Energy Plan on Safety, Energy Security, Economic Efficiency and Environment (2025).
	STEPS	• Energy demand and supply mix of the 7th Strategic Energy Plan (2025) • Green Transformation basic policy (2023); Act on Carbon Dioxide Storage Business (2024).
Korea	STEPS	• 11th Basic Electricity Supply and Demand Plan.
Australia and New Zealand	STEPS	• Australia: Future Made in Australia (2024); Long-Term Emissions Reduction Plan (2022).

Table B.7 ▷ Selected cross-cutting and energy supply policy as modelled by scenario and regions/countries (continued)

Region/ country	Scenario	Policies and targets
European Union	CPS	• Regulation on methane emissions reduction in the energy sector, with less stringent import requirements (2024).
	STEPS	• Regulation on methane emissions reduction in the energy sector, with more stringent import requirements (2024). • Clean Industrial Deal (2025). • Ban of imports of Russian LNG into the European Union from January 2027 for long-term contracts (2025). • EU Recovery and Resilience Facility (2021); European Green Deal (2019).
Other Europe	CPS	• United Kingdom: Energy Act on energy production and security (2023). • Norway: Measurement regulations and taxes on flaring and methane emissions (2012); Green Conversion Package (2020).
	STEPS	• United Kingdom: North Sea Transition Deal (2021); Ten Point Plan for a Green Industrial Revolution (2020).
Eurasia	CPS	• Kazakhstan: Tax code on combustion of natural gas flaring (2017). • Uzbekistan: Tax on methane emissions and other environmental pollutants (2021).
China	CPS	• China Energy Law (2025), including promoting renewable energy through minimum consumption targets for utilities, consumers and captive power plants, and setting renewable energy quotas for provinces. • National Economic and Social Development Plan, with energy consumption per unit of GDP to decline by around 2.5% within the year (2024). • Targets for 20% non-fossil share of the energy mix by 2025 contained in the 14th Five-Year Plan. • Emissions standard for coal mine methane (2008).
	STEPS	• China Energy Law and its mid-to-long-term energy development strategy (2024).
India	CPS	• Amendments to the Energy Conservation Act (2022).
Southeast Asia	CPS	• Indonesia: 17-19% share of renewable energy in primary energy supply by 2025.
	STEPS	• Singapore: Future Energy Fund (2024); Green Plan 2030 (2021).
Africa	CPS	• South Africa: Energy Action Plan (2022); New amendments to the 2008 National Energy Act. • Nigeria: National Development Plan 2021-2025; methane regulations.
	STEPS	• 63 access programmes for clean cooking and 56 for electricity implemented since 2024.
Middle East	CPS	• United Arab Emirates: Conservation of Petroleum Resources Law, including flaring or venting methane restrictions.
	STEPS	• Saudi Arabia: Saudi Vision 2030 (2016).

Note: CPS = Current Policies Scenario; STEPS = Stated Policies Scenario; GDP= gross domestic product.

Table B.8 ⊳ Selected electricity sector policies and measures as modelled by scenario for selected regions/countries

Region/ country	Scenario	Policies and targets
United States	CPS	• The One Big Beautiful Bill Act (2025), including accelerated phase out schedule for tax credits for wind and solar, and stricter ownership and sourcing rules. • Reinvigorating Nuclear Industrial Base Executive Order. • Repeal in progress of Environmental Protection Agency Clean Power Plan 2.0 and the Mercury and Air Toxics Standards Rule. • State-level renewable and clean energy mandates in law, including 20 states and District of Columbia with 100% targets within the 2032 to 2050 period, and 4 states with targets often ranging between 8% and 60% with various expiration dates after 2025.
	STEPS	• State-level renewable and clean energy targets extended and strengthened beyond current expiration dates.
Canada	CPS	• A Healthy Environment and a Healthy Economy including to reach nearly 90% non-emitting electricity generation by 2030. • Phase out conventional coal-fired plants by 2030 under the Canadian Environmental Protection Act.
Latin America and the Caribbean	CPS	• Brazil: Ten-year Energy Expansion Plan 2034. • Chile: Phase out unabated coal use by 2040 under the Decarbonisation Plan. National Energy Policy target for 80% of total national electricity generation to come from renewable sources by 2030. • Colombia: 6 GW Plus Plan to reduce bottlenecks for solar and wind projects. • A total of 16 of 33 countries in the region have targets to expand renewables electricity in their national energy policies.
	STEPS	• Argentina: National Energy Transition Plan to 2030 including at least 50% electricity from renewable sources, of which 1 GW is distributed solar PV capacity by 2030. • An additional 9 of 33 countries in the region have targets to expand renewables electricity in their transition and expansion plans.
Japan	CPS	• Alternative generation mix aligned with the 7th Strategic Energy Plan. • Restart nuclear power plants aligned with the 7th Strategic Energy Plan and the Green Transformation policy initiative.
	STEPS	• Reference electricity generation mix in the 7th Strategic Energy Plan, targeting 40-50% renewable energy and 20% nuclear by 2040.
Korea	CPS	• The 11th Basic Plan for Long-term Electricity Supply and Demand including 35% electricity generation from nuclear, and along with renewables, reaching over 70% electricity generation from low-emissions sources by 2038.
	STEPS	• Extension of higher targets of low-emissions electricity generation under the 11th Basic Plan for Long-term Electricity Supply and Demand beyond 2038.
Australia and New Zealand	STEPS	• Australia: Progress towards reaching 82% renewables electricity generation target by 2030.
European Union	CPS	• Coal phase out commitments as specified by 15 member states. Eleven EU member states are already coal free or did not use coal in power generation. • National Energy and Climate Plans (2023-2025) submitted by member states. • Updated development plans for nuclear in Belgium, Slovak Republic, Poland and Czech Republic.
	STEPS	• Coal phase out commitments fulfilled at earliest time announced by member states.

Table B.8 ⊳ Selected electricity sector policies and measures as modelled by scenario for selected regions/countries (continued)

Region/ country	Scenario	Policies and targets
Other Europe	STEPS	• Türkiye: Emissions trading system to start its full compliance period in 2027. • United Kingdom: Clean Power 2030 Action Plan sets targets to expand offshore wind, solar PV and nuclear power. Long duration electricity storage investment support measure.
China	CPS	• China Energy Law (2025), including promoting renewable energy through minimum consumption targets for utilities, consumers and captive power plants, and setting renewable energy quotas for provinces. • Wind and solar capacity target of 3 600 GW by 2035. • Pumped hydro storage capacity target to exceed 62 GW by 2025 and 120 GW by 2030. • Power market reform to reduce curtailment and promote spot markets, including Market-oriented Reform of New Energy Feed-in Tariffs in 2025.
	STEPS	• Extension of provincial and national non-fossil fuel generation targets beyond the current expiration dates. • Further expansion of power market reforms to additional provinces and enhancement of interprovincial exchanges (improving integration of renewables).
India	CPS	• National Electricity Plan (2024) including targets of 500 GW of non-fossil fuel capacity, 50% of electricity generation from renewables by 2030. It also includes targets of 47 GW of battery storage and 27 GW of pumped hydro, expansion of regional grid interconnections by 2032. • Government target of 22 GW of nuclear capacity by 2032.
	STEPS	• Expanded R&D funding to develop small modular reactors under the 2025 India Nuclear Energy Mission. • Carbon Credit Trading Scheme with compliance period starting in 2026. • Beyond 2030, extension and strengthening of targets for non-fossil fuel generation capacity.
Southeast Asia	CPS	• Indonesia: Electricity Supply Business Plan 2025-2034 aims to add 42 GW of renewables along with IDR 400 trillion (USD 25 billion) investment for transmission networks. • Viet Nam: Progress towards reaching targets under Adjusted Power Development Plan 8 to install over 45 GW of solar PV and 20-38 GW of onshore wind by 2030 and phasing out coal-fired generation by 2050.
	STEPS	• Cambodia: Power Development Plan 2022-2040 targets 3.2 GW of solar capacity and 3 GW of hydropower by 2040.
Africa	CPS	• Egypt: El Dabaa nuclear plant reaching full capacity by 2030. • South Africa: Increased renewables capacity and reduced coal-fired capacity under the 2023 Integrated Resource Plan.
	STEPS	• Libya: National Strategy for Renewable Energy & Efficiency 2023-2025 aims to increase the share of renewables to 20% by 2035. • Morocco: Long-term strategy target of increasing the share of renewables to 52% of electrical capacity by 2030. • Tunisia: Target of increasing the share of renewables to 30% in its electricity mix. • Tanzania: Power System Master Plan 2025.

Table B.8 ▻ Selected electricity sector policies and measures as modelled by scenario for selected regions/countries (continued)

Region/ country	Scenario	Policies and targets
Middle East	CPS	• Jordan: Energy Strategy 2020-2030, including 31% renewables share in electricity generation. • Lebanon: Policy Statement, including at least 30% of generation capacity from renewable sources by 2030.
	STEPS	• Qatar: National Renewable Energy Strategy to increase the share of renewable energy to 18% in electricity generation mix by 2030. • Saudi Arabia: Saudi Vision 2030 aims to phase out oil use in power and provide 50% of electricity generation from renewables by 2030.

Note: CPS = Current Policies Scenario; STEPS = Stated Policies Scenario; TWh = terawatt-hour; GW = gigawatt; MW = megawatt; IDR = Indonesian rupiah.

Table B.9 ▷ Selected industry sector policies and measures as modelled by scenario for selected regions/countries

Region/ country	Scenario	Policies and targets
United States	CPS	• Declaration of National Emergency to Increase Competitive Edge, Protect Sovereignty, and Strengthen National and Economic Security (2025).
Canada	CPS	• Disbursement of clean industry packages and provisions to promote clean industry, as part of Building Canada's Clean Industrial Advantage, only for projects under construction.
	STEPS	• Full disbursement of clean industry provisions, extended beyond current budget allocations. • Beyond current expiration dates, extension and strengthening of existing efficiency and decarbonisation regulations in accordance with latest available standards.
Latin America and the Caribbean	CPS	• Brazil: energy efficiency guarantee fund. • Colombia: Tax break on energy efficiency investment (2014).
	STEPS	• Brazil: Greenhouse Gas Emissions Trading System; 2024 Brazil Industry Decarbonization investment programme. • 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. • Beyond current expiration dates, extension and strengthening of existing efficiency and decarbonisation regulations in accordance with latest available standards.
Japan	CPS	• Disbursement of the Green Innovation Fund (USD 13 billion R&D funding for transportation and manufacturing-related industries until 2030), only for projects under construction.
	STEPS	• Green Innovation Fund, extended support for transportation and manufacturing-related industries beyond 2030. • Beyond current expiration dates, extension and upgrading of existing efficiency and decarbonisation regulations in accordance with latest available standards.
Korea	CPS	• Disbursement of the Green Infrastructure Overseas Export Support Fund, only for projects under construction, including its second round of funding in 2025.
	STEPS	• Beyond current expiration dates, extension and strengthening of existing efficiency and decarbonisation regulations in accordance with latest available standards.
Australia and New Zealand	CPS	• Australia: Disbursement of the Industrial Transformation Stream (USD 260 million) and National Industrial Transformation Programme (USD 26 million), only for projects under construction.
	STEPS	• Australia: Safeguard Mechanism for large greenhouse gas emitters. • Australia: Full disbursement of the Industrial Transformation Stream and National Industrial Transformation Programme. • New Zealand: Ban on new coal boilers in industries as well as phase out of existing ones by 2037. • Beyond current expiration dates, extension and strengthening of existing efficiency and decarbonisation regulations in accordance with latest available standards.

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Table B.9 ⊳ Selected industry sector policies and measures as modelled by scenario and regions/countries (continued)

Region/ country	Scenario	Policies and targets
European Union	CPS	• Disbursement of the EU Innovation Fund support for renewables, energy-intensive industries, storage and CCUS, only for projects under construction. • France: Disbursement of the Green Industry Bill to create new green industries and accelerate the decarbonisation of existing ones, only for projects under construction. • Germany: Disbursement of the Federal Fund for Industry and Climate Action, only for projects under construction.
	STEPS	• EU Clean Industrial Deal. • European Union Emissions Trading System (EU ETS), including phasing out of some industry free allowances with the implementation of the Carbon Border Adjustment Mechanism from 2026. • Energy efficiency and decarbonisation provisions, extended support for renewables, energy-intensive industries, storage and CCUS beyond currently announced funds through the Industrial Decarbonisation Bank. • Beyond current expiration dates, extension and strengthening of existing efficiency and decarbonisation regulations in accordance with latest available standards.
Other Europe	CPS	• United Kingdom: Disbursement of the Industrial Decarbonisation Challenge, funding for low-emissions industrial clusters and Industrial Energy Transformation Fund funding for energy efficiency, only for projects under construction. Disbursement of the Zero Growth Plan and Industrial Energy Transformation Fund (with total grant funding of up to USD 640 million until 2028), only for projects under construction.
	STEPS	• United Kingdom: Energy efficiency and decarbonisation provisions, extended support for low-emissions industrial clusters beyond 2028. Emissions trading system phasing out of some industry free allowances with the implementation of the Carbon Border Adjustment Mechanism from 2027. • Türkiye: Emissions trading system to start its full compliance period in 2027. • Beyond current expiration dates, extension and strengthening of existing efficiency and decarbonisation regulations in accordance with latest available standards.
Eurasia	CPS	• Russia: Mandatory carbon reporting for companies emitting 150 000 tonnes of carbon or more per year, and between 50 000 to 150 000 tonnes of carbon starting 2023 and 2025 respectively.
	STEPS	• Beyond current expiration dates, extension and strengthening of existing efficiency and decarbonisation regulations in accordance with latest available standards.
China	CPS	• China Green Electricity Certificate, with mandatory proportion of green power consumption for data centres, iron and steel, non-ferrous metals, building materials, petrochemicals and chemical industries (2025). • 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.
	STEPS	• Implementation Plan for Accelerating the Application of Clean and Low-Carbon Hydrogen in the Industrial Sector by 2027. • China emissions trading system expansion to cement, steel and aluminium (2025). • Beyond current expiration dates, extension and strengthening of existing efficiency and decarbonisation regulations in accordance with latest available standards.

Table B.9 ▷ Selected industry sector policies and measures as modelled by scenario and regions/countries (continued)

Region/ country	Scenario	Policies and targets
India	CPS	• Perform, Achieve and Trade Scheme to trade energy saving credits. • Disbursement of the Make in India programme, only for projects under construction. • Disbursement of the Production Linked Incentives programme (subsidies related to new manufacturing capacity for solar PV and modern batteries), only for projects under construction. • Mandatory energy audits under Energy Conservation Act. • Disbursement of USD 50 million in Green Hydrogen in steel sector until 2029-2030, only for projects under construction.
	STEPS	• Manufacturing provisions, extended support for advanced manufacturing programmes beyond 2029. • National Mission on Enhanced Energy Efficiency. • India Carbon Credit Trading Scheme to start in 2026. • National steel policy 2030. • Steel Scrap Recycling Policy 2030. • Beyond current expiration dates, extension and strengthening of existing efficiency and decarbonisation regulations in accordance with latest available standards.
Africa	CPS	• Nigeria: Value-added tax exemption for energy-related goods and services including steel and bars for LNG processing (2025). • Morocco: Updated MEPS for industrial motors (2025).
	STEPS	• Beyond current expiration dates, extension and strengthening of existing efficiency and decarbonisation regulations in accordance with latest available standards.
Middle East	CPS	• Saudi Arabia: International Efficiency (IE) 3 MEPS for electric motors. • United Arab Emirates: Industrial plan to raise contribution of industrial sector to GDP from USD 36 to USD 82 billion (2024).
	STEPS	• Beyond current expiration dates, extension and strengthening of existing efficiency and decarbonisation regulations in accordance with latest available standards.

Note: CPS = Current Policies Scenario; STEPS = Stated Policies Scenario; CCUS = carbon capture, utilisation and storage; R&D = research and development; LNG = liquefied natural gas; MEPS = minimum energy performance standards.

Table B.10 ⊳ Selected buildings sector policies and measures as modelled by scenario and regions/countries

Region/ country	Scenario	Policies and targets
United States	CPS	• State-level building codes related to energy for new buildings, including 11 states with revised and updated energy codes (2021 International Energy Conservation Code).
	STEPS	• Beyond current expiration dates, extension and strengthening of existing state-level support for efficient space and water heating, and building envelope improvements.
Canada	CPS	• Updated National Energy Code of Canada for Buildings (2022).
	STEPS	• Oil to Heat Pump Affordability Programme and extended support for appliances. • Beyond current expiration dates, extension and strengthening of existing efficiency regulations for appliances and buildings.
Latin America and the Caribbean	CPS	• Brazil: Updated MEPS for air conditioners (2022). • Chile: Revision of minimum energy performance standards for indoor lighting, effectively banning the sale of less efficient technologies (2025). • Colombia: Mandatory building energy codes applied to new construction covered under Resolution 0549 (2015). • Peru: Updated building energy codes for new buildings (2021). • Common regulation on MEPS (2022) for air conditioners in El Salvador, Honduras, Nicaragua, Costa Rica, Guatemala and Panama.
	STEPS	• Colombia: Subsidies for household purchases of efficient lighting, refrigeration and cooking equipment established in partnership with the Inter-American Development Bank (2023). • Beyond current expiration dates, extension and strengthening of existing efficiency regulations for appliances and buildings.
Japan	CPS	• Strengthened MEPS for air conditioners, water heaters, glazing and televisions, introduced as part of the changes to the Top Runner Programme for 2025-2027. • Revised mandatory building energy codes applied to all new construction covered under the Act on the Improvement of Energy Consumption Performance of Buildings (2022).
	STEPS	• Subsidies for retrofits and efficient water heaters introduced as part of the Residential Energy Conservation Campaign (2024). • Beyond current expiration dates, extension and strengthening of existing efficiency regulations for appliances and buildings.
Korea	CPS	• Updated energy saving design standards for new buildings (2023).
	STEPS	• KEPCO Programme: Subsidies for highly energy efficient appliances distributed via on-bill rebates. • Korean New Deal: Increased funding to improve the efficiency of schools, public housing and recreational and healthcare facilities. • Beyond current expiration dates, extension and strengthening of existing efficiency regulations for appliances and buildings.
Australia and New Zealand	CPS	• Australia: Updated energy efficiency standards for new homes (2022). Updated MEPS for air conditioners and heat pumps (2022). • New Zealand: Replacement of all coal-fired boilers in schools with electric or renewable biomass alternatives by 2025.
	STEPS	• Beyond current expiration dates, extension and strengthening of existing efficiency regulations for appliances and buildings.

Table B.10 ⊳ Selected buildings sector policies and measures as modelled by scenario and regions/countries (continued)

Region/ country	Scenario	Policies and targets
European Union	CPS	• Mandatory nearly zero-energy building requirements applied to all new construction as of 2021. • 2018 Energy Efficiency Directive: Requirement 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).
	STEPS	• EU Recovery and Resilience Facility: Funding national government incentives and investment in buildings energy efficiency and appliance upgrades. • Carbon pricing for buildings introduced from 2027 onwards via the EU Emissions Trading System II. • Beyond current expiration dates, extension and strengthening of existing efficiency regulations for appliances and buildings.
Other Europe	CPS	• Türkiye: Updated building energy codes for all new buildings and large existing buildings, and all new public buildings to be nearly zero-energy buildings (2023). • United Kingdom: Updated building energy codes for new and existing buildings (2023).
	STEPS	• United Kingdom: Low-Carbon Heat Scheme and Green Heat Network Fund; Warm Homes Plan; Clean Heat Market Mechanism. Financial incentives to purchase clean household technologies. Extended support for efficient appliances and retrofits. • Ukraine: Voluntary certification for nearly zero-energy buildings (2025). • Beyond current expiration dates, extension and strengthening of existing efficiency regulations for appliances and buildings.
Eurasia	CPS	• Russia: Revised Building Thermal Performance of Buildings Code sets mandatory requirements for the construction of new apartment and commercial buildings (2018). • Kyrgyzstan: Requirements for public bodies to purchase highly efficient energy-consuming appliances and equipment (2025). • Uzbekistan: Tax exemptions for producers of renewable energy equipment and customers of off-grid renewable installations in residential buildings (2019).
	STEPS	• Georgia: Law on Energy Efficiency for Buildings to require all new construction after 30 September 2029 to meet the requirements for nearly zero-energy building. • Kyrgyzstan: Extension of loans and grants for energy saving technologies provided by the Kyrgyz Sustainable Energy Financing Facility. • Beyond current expiration dates, extension and strengthening of existing efficiency regulations for appliances and buildings.
China	CPS	• Green building incentives and subsidies in various provinces. • Updated MEPS for air conditioners and heat pumps (2024). • General Code for Building Energy Efficiency and Renewable Energy Utilisation (2022).
	STEPS	• 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). • Extension of province-level equipment replacement and consumer goods trade-in policies. • Beyond current expiration dates, extension and strengthening of existing efficiency regulations for appliances and buildings.

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Table B.10 ▷ Selected buildings sector policies and measures as modelled by scenario and regions/countries (continued)

Region/ country	Scenario	Policies and targets
India	CPS	• Energy Conservation and Sustainable Building Code applied to new commercial buildings (2024). • Revised MEPS for refrigerators, air conditioners and fans (2021-2022). • Partial disbursement of the subsidy scheme for residential rooftop PV systems (2024).
	STEPS	• Bachat Lamp Yojana Lighting Programme (2009) and full disbursement of the subsidy scheme for residential rooftop PV systems (2024). • Beyond current expiration dates, extension and strengthening of existing efficiency regulations for appliances and buildings.
Southeast Asia	CPS	• Singapore: Revised mandatory building energy codes applied to new large construction (2025). • Indonesia: Updated MEPS for air conditioners (2021). • Vietnam: Mandatory building energy codes applied to new large construction (2022).
	STEPS	• Singapore: Extension of subsidies for retrofits provided as part of the GMIS Programme (2022). • Beyond current expiration dates, extension and strengthening of existing efficiency regulations for appliances and buildings.
Africa	CPS	• South Africa: Mandatory building energy code for new construction (2021). • Nigeria: National building energy code for new construction (2017). • Kenya: Revised building energy code for new construction (2022). • MEPS for lighting (South Africa, 2022), air conditioners and refrigerators (Egypt, 2022); air conditioners, refrigerators, water heaters and lighting (Ghana, 2022).
	STEPS	• Mozambique: Replacement of 2.5 million incandescent lamps with efficient lamps for all domestic consumers in the country. • Beyond current expiration dates, extension and strengthening of existing efficiency regulations for appliances and buildings.
Middle East	CPS	• Qatar: The Energy & Water Conservation Code sets minimum efficiencies for HVAC (2023). • Saudi Arabia: Green Energy Code (2025); updated MEPS for air conditioners (2021). • United Arab Emirates: MEPS for air conditioners (2019).
	STEPS	• Saudi Arabia: Extension of energy efficiency project grants provided under the Public Investment Fund Green Finance Framework. • United Arab Emirates: Extension of the smart meter roll out programme in Dubai. • Beyond current expiration dates, extension and strengthening of existing efficiency regulations for appliances and buildings.

Note: CPS = Current Policies Scenario; STEPS = Stated Policies Scenario; MEPS = minimum energy performance standards; HVAC = heating, ventilation and air conditioning.

Table B.11 ▷ Selected transport sector policies and measures as modelled by scenario and regions/countries

Region/ country	Scenario	Policies and targets
United States	CPS	• One Big Beautiful Bill Act (2025): Includes the phase-out of EV tax credits available through September 2025 and eliminates penalties for automakers that fail to meet fuel economy standards for passenger cars and light trucks. • Renewable Fuel Standard for biofuel volumes across all transport modes to 2025.
	STEPS	• Clean fuel production credits to December 2029.
Canada	CPS	• Electric Vehicle Availability Standard regulates annual zero emissions light-duty vehicle sales targets to 2035 and waives the mandate for 2026. • CO_2 emissions standards for heavy commercial vehicles to reduce emissions by 5% to 27% in 2027, compared to 2017. • British Colombia: Low-Carbon Fuels Act mandates renewable jet fuel share of 1% in 2028, 2% in 2029 and 3% in 2030.
	STEPS	• Fuel economy improvements of heavy commercial vehicles beyond 2027.
Latin America and the Caribbean	CPS	• Mexico: Revised CO_2 emission standards in 2024 with stricter emission limits on new light-duty vehicles up to model year 2027. • Chile: Partial implementation of fuel economy standards for light-duty vehicles to reduce level to around 3.5 litres/100 km by 2030. • Brazil: Reduction of at least 1% of CO_2 emission in domestic aviation with use of sustainable fuel from 2027. Partial implementation of 20% biodiesel blending mandate across all transport modes by 2030.
	STEPS	• Mexico: Fuel economy improvements of light-duty vehicles beyond 2027. • Chile: Fuel economy improvements of light-duty vehicles beyond 2030.
Japan	CPS	• Fuel economy standard for light-duty vehicles to improve fuel efficiency by 32% to 2030 relative to 2016 levels.
	STEPS	• Subsidies for the purchase of clean energy vehicles toward the realisation of the green transformation (GX) policy in the automobile sector. • Fuel economy improvements in light-duty vehicles beyond 2030.
Korea	CPS	• 2021 GHG standard reaching 70 g/km and fuel economy standard of 33.1 km/litre by 2030 for new passenger cars.
	STEPS	• Grants available for the purchase of private and commercial light-duty EVs and subsidies for electric buses. • Fuel economy improvements in passenger cars beyond 2030.
Australia and New Zealand	**CPS**	• Australia: New Vehicle Efficiency Standard Bill to reduce emissions of new passenger and light commercial vehicles by 2029 to 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 Vehicle Standard to reduce emissions of new passenger and light commercial vehicles by 2029 to 65 g CO_2/km and 131 g CO_2/km. The CO_2 targets are adjusted as a function of vehicle weight.
	STEPS	• Fuel economy improvements in light-duty vehicles beyond 2029. • Australia: Future Fuels Fund. • New Zealand: Low Emissions Heavy Vehicle Fund.

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Table B.11 ▷ Selected transport sector policies and measures as modelled by scenario and regions/countries (continued)

Region/ country	Scenario	Policies and targets
European Union	CPS	• CO_2 standards for both new cars and vans for 2030 and 2035, including a recent amendment for the 2025-2027 period. • 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. • ReFuelEU Aviation initiative 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. • Alternative Fuels Infrastructure Regulation to accelerate the roll-out of recharging infrastructure for EVs and hydrogen refuelling stations. Developing electricity infrastructure for maritime ports and airports. • Inclusion of the maritime sector in the EU Emissions Trading System (EU ETS) since January 2024.
	STEPS	• EU ETS II for transport fuels to become operational in 2027.
Other Europe	CPS	• United Kingdom: ZEV mandate for new cars and vans by 2035, including compliance flexibilities introduced that are in effect to 2029. CO_2 emissions reduction regulation for heavy-duty vehicles reducing by 30% CO_2 emissions in 2030 relative to 2019. • Switzerland: CO_2 emissions reduction regulation for light-duty vehicles.
	STEPS	• United Kingdom: Fuel economy improvements of heavy-duty vehicles beyond 2030. • Türkiye: High Technology Investment Programme with provisions for USD 4.5 billion incentive for battery production and USD 5 billion incentive to increase EV production.
Eurasia	CPS	• Georgia: VAT exemptions and reduced import taxes for EVs.
	STEPS	• Russia: Production support scheme for Russian automakers and battery producers to establish manufacturing plants.
China	CPS	• Extension of tax exemption for new energy vehicles to 2027. • Trade-in subsidy scheme for replacing fossil fuel-powered vehicles with new energy or fuel-efficient vehicles renewed for 2025. • Subsidy for new energy city buses and battery replacement. • 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. Stage 4 fuel consumption standards for light commercial and heavy-duty commercial vehicles. • National railway energy intensity target of 10% reduction by 2030 compared to 2020.
	STEPS	• Energy efficiency improvement of national railway beyond 2030.
India	CPS	• 20% bioethanol blending target for gasoline by 2026 and partial implementation of 5% biodiesel target by 2030.
	STEPS	• PM Electric Drive Revolution in Innovative Vehicle Enhancement (PM E-DRIVE) and PM e-Bus Sewa-Payment Security Mechanism (PM e-Bus Sewa-PSM) schemes to incentivise the uptake of electric two/three-wheelers, buses and freight vehicles.

Table B.11 ⊳ Selected transport sector policies and measures as modelled by scenario and regions/countries (continued)

Region/ country	Scenario	Policies and targets
Southeast Asia	CPS	• Indonesia: Tax incentives provided for EVs until the end of 2025. Waiver on EV import duties for original equipment manufacturers committing to produce locally until the end of 2025. Subsidy for purchase of electric motorcycles. Biodiesel blending mandate (40%) and partial implementation of ethanol blending mandate (20%).
	STEPS	• Singapore: Vehicle emissions, including tax rebates and surcharges based on CO_2 and local pollutant emissions of newly registered cars until the end of 2027. • Thailand: EV3.5 scheme which promotes EV adoption through purchase subsidies, tax breaks and import duty reductions. • Philippines: Excise tax and import duty exemptions for battery electric vehicles until the end of 2028. • Viet Nam: Registration fee and reduced special consumption tax for battery electric vehicles through 2027. • Malaysia: Grants related to the installation, rental or subscription of EV charging facilities at home.
Africa	CPS	• Morocco: Adopted the Euro 6 standard for passenger cars. Customs duties and VAT exemption for EVs. Removal of the circulating tax for hybrid and electric vehicles. • Tunisia: Exemption of customs duties and VAT and purchase subsidy for EVs. • Egypt: Custom duty exemption for EVs.
	STEPS	• South Africa Automotive Production Development Programme to produce electric and hydrogen-powered vehicles.
Middle East	CPS	• Saudi Arabia: 2024-2028 Saudi Arabia Corporate Average Fuel Economy standards.
	STEPS	• Saudi Arabia: Fuel economy improvements beyond 2028.

Notes: CPS = Current Policies Scenario; STEPS = Stated Policies Scenario. IMO = International Maritime Organization; GHG = greenhouse gases; km = kilometre; ICE = internal combustion engine; EVs = electric vehicles; FCEVs = fuel cell electric vehicle; VAT = value-added tax; ZEV = zero emissions vehicle; 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.12 ▷ Selected industry and intergovernmental-led initiatives and manufacturing targets by scenario

Initiatives	Pledge type	Signatories pledge	Achievement in:		
			CPS	STEPS	NZE
Buildings					
Buildings Breakthrough	Emissions reduction	Make near zero emissions and resilient buildings the norm for new buildings by 2030.	Not met	Not met	Fully met
Steel					
First Mover Coalition	Procurement	10% of low-carbon steel by 2030.	Not met	Not met	Fully met
Net Zero Steel Initiative	Technology deployment	Bring zero carbon primary steel production technologies to market by 2030.	Not met	Not met	Fully met
Glasgow Breakthrough	Procurement	Near zero emissions steel to be preferred for every member of the coalition.	Not met	Not met	Fully met
Cement					
Concrete Action for Climate	Emissions reduction	Achieve net zero carbon emissions from operations by 2050.	Not met	Not met	Fully met
Rail					
UIC Railway Climate Responsibility Pledge	Emissions reduction	Align CO_2 emissions reduction to achieve carbon neutrality by 2050.	Not met	Not met	Fully met
Aviation					
ICAO long-term aspirational goal	Emissions reduction	Net zero emissions from international aviation by 2050.	Not met	Not met	Fully met
ICAO initiative (CORSIA)	Emissions reduction	Offset CO_2 emissions of international aviation above 85% of 2019 levels (2024-2035).	Not met	Not met	Fully met
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.	Not met	Not met	Fully met

Notes: CPS = Current Policies Scenario; STEPS = Stated Policies Scenario; NZE = Net Zero Emissions by 2050 Scenario. UIC = International Union of Railways; ICAO = International Civil Aviation Organization; CORSIA = Carbon Offsetting and Reduction Scheme for International Aviation; MoU = memorandum of understanding; MHDVs = medium- and heavy-duty vehicles.

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 kilometres
	Mha	million hectares
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	MJ	megajoule (1 joule x 10^6)
	GJ	gigajoule (1 joule x 10^9)
	TJ	terajoule (1 joule x 10^{12})
	PJ	petajoule (1 joule x 10^{15})
	EJ	exajoule (1 joule x 10^{18})
	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})
	kWh	kilowatt-hour
	MWh	megawatt-hour
	GWh	gigawatt-hour
	TWh	terawatt-hour
	MBtu	million British thermal units
Energy density	Wh/kg	watt hours per kilogramme
Energy equivalence	boe	barrel of oil equivalent
	mboe/d	million barrels of oil equivalent per day
	toe	tonne of oil equivalent
	ktoe	thousand tonnes of oil equivalent
	Mtoe	million tonnes of oil equivalent
	Lge	litre of gasoline equivalent
	bcme	billion cubic metres of natural gas equivalent
	Mtce	million tonnes of coal equivalent (equals 0.7 Mtoe)
	btce	billion tonnes of coal equivalent

Mass	kg	kilogramme
	t	tonne (1 tonne = 1 000 kg)
	kt	kilotonne (1 tonne x 10^3)
	Mt	million tonnes (1 tonne x 10^6)
	Gt	gigatonne (1 tonne x 10^9)
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
Volumetric	bcm	billion cubic metres
	tcm	trillion cubic metres
	barrel	one barrel of crude oil
	kb/d	thousand barrels per day
	mb/d	million barrels per day

General conversion factors for energy

		Multiplier to convert to:					
		EJ	**Mtoe**	**MBtu**	**bcme**	**Mtce**	**TWh**
Convert from:	**EJ**	1	23.88	9.478×10^8	27.78	34.12	277.8
	Mtoe	0.04187	1	3.968×10^7	1.163	1.429	11.63
	MBtu	1.0551×10^{-9}	2.520×10^{-8}	1	2.931×10^{-8}	3.60×10^{-8}	2.931×10^{-7}
	bcme	0.036	0.860	3.412×10^7	1	1.228	10
	Mtce	0.02931	0.700	2.778×10^7	0.8141	1	8.141
	TWh	0.0036	0.086	$3\ 412 \times 10^6$	0.1	0.1228	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. 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 International Energy Agency (IEA) balances due to the use of country-specific energy densities. Lower heating values (LHV) are used throughout.

Currency conversions

Exchange rates *(2024 annual average)*	**1 US dollar (USD) equals:**
British Pound	0.78
Chinese Yuan Renminbi	7.20
Euro	0.92
Indian Rupee	83.67
Japanese Yen	151.37

Source: World Bank Data: Official exchange rate (Local Currency Units per USD, period average), https://data.worldbank.org/indicator/PA.NUS.FCRF, accessed September 2025.

Definitions

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, resulting in substantial carbon dioxide (CO_2) emissions from the use of fossil fuel inputs to generate the input hydrogen. With properties similar to liquefied petroleum gas, 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.

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 used as a substitute for 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. It also includes energy used by data centres and desalination plants.

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, coal or kerosene. It refers to improved cook 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 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.

Critical minerals: A wide range of minerals and metals that are essential for key energy, digital and other modern technologies, but whose supply chains are vulnerable to disruption. While definitions and criteria vary across countries, they typically include chromium, cobalt, copper, gallium, germanium, graphite, lithium, manganese, molybdenum, nickel, platinum group metals, zinc, and rare earth elements.

Data centres: Facilities that house information technology (IT) equipment, such as servers, storage systems and networking equipment, and are equipped with cooling and other auxiliary systems to keep the IT equipment operating under optimal conditions.

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.

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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 include 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 and before curtailment. 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.

End-use sectors: Include industry, transport, buildings and other, i.e. 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 oxide (N_2O) emissions from the energy and industry sectors.

Energy services: A personal or societal gain from the use of energy. Includes, *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*, 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: Coal, oil and natural gas. Total fossil fuel use is equal to unabated fossil fuels plus fossil fuels with CCUS and 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 resistance heating or heat pumps which can extract heat 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 both medium freight trucks (gross weight 3.5 to 15 tonnes), heavy freight trucks (gross weight >15 tonnes) 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: Includes 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. It excludes output from pumped storage and marine (e.g. tidal and wave technologies).

Improved cook stoves: Intermediate and advanced improved biomass cook stoves (ISO tier > 1). It excludes basic improved stoves (ISO tier 0-1).

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 pulp and paper. 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. For many countries this incorrectly excludes fuels used by domestically owned carriers for their international departures.

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: Energy investment is the capital expenditure in fuel supply, the power sector, energy efficiency and other end-use. Fuel supply investment includes the production, transformation and transport of oil, gas, coal, low-emissions fuels and direct air capture. 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 equipment for the direct use of renewables and other low-emissions fuels, electric vehicles, electrification in buildings, industry and international marine transport, and CCUS in industry. Data and projections reflect capital expenditure over the lifetime of projects and are presented in real terms in year-2024 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. 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.

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 that is produced through water electrolysis with electricity generated from a low-emissions source, e.g. solar, wind and nuclear power. Hydrogen produced from biomass or from fossil fuels with 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.

Modern renewables: Include all renewables with the exception of the traditional use of solid biomass.

Modern solid bioenergy: Includes all solid bioenergy products except the traditional use of biomass. It also includes the use of solid bioenergy in intermediate and advanced improved biomass cook stoves (ISO tier > 1), requiring fuel to be cut into small pieces or often using processed biomass such as pellets.

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. Natural gas liquids, manufactured gas (i.e. produced from municipal or industrial waste, or sewage) and quantities vented or flared are not included. 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 vaporisation 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.

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.

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. Note that for biofuels, only the amounts specifically used for energy purposes, a small part of the total, are included in energy statistics. Therefore, the non-energy use of biomass is not taken into consideration and the quantities are null by definition.

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 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. Light commercial vehicles, motor coaches, urban buses and mini-buses/mini-coaches are excluded.

Peat: A solid formed from the partial decomposition of dead vegetation under conditions of high humidity and limited air access, i.e. 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. In the *World Energy Outlook*, peat is included under data for lignite.

Plastic collection rate: Proportion of plastic 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, i.e. 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, for example. freight, could be considered as productive, but is treated separately.

Primary chemicals: Include ethylene, propylene, benzene, toluene, mixed xylenes, ammonia and methanol.

Rare earth elements (REEs)**:** A group of seventeen chemical elements in the periodic table, specifically the fifteen lanthanides plus scandium and yttrium. REEs are vital inputs for key energy technologies, including wind turbines, electric vehicle motors and electrolysers.

Renewables: Include bioenergy, geothermal, hydropower, solar photovoltaics, concentrating solar power, wind and marine (tidal and wave) energy for electricity and heat generation.

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, i.e. 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 such as schools, hospitals and public offices. Energy use in services includes space heating and cooling, water heating, lighting, appliances, cooking, data centres 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 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, i.e. 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. Although all SHS are included in the IEA access to electricity definition and historic counting, only solar home systems from 25 Wp in rural areas and 50 Wp in urban areas are deployed in the IEA scenarios for population gaining access. It excludes solar systems smaller than 10 Wp, i.e. multi light systems and solar lanterns.

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 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).

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 0-2), 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.

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 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, i.e. battery electric, plug-in hybrids and fuel cell vehicles.

Regional and country groupings

Advanced economies: Organisation for Economic Co-operation and Development (OECD) 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.

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[6], Montenegro, North Macedonia, Norway, Republic of Moldova, Serbia, Switzerland, Türkiye, Ukraine and United Kingdom.

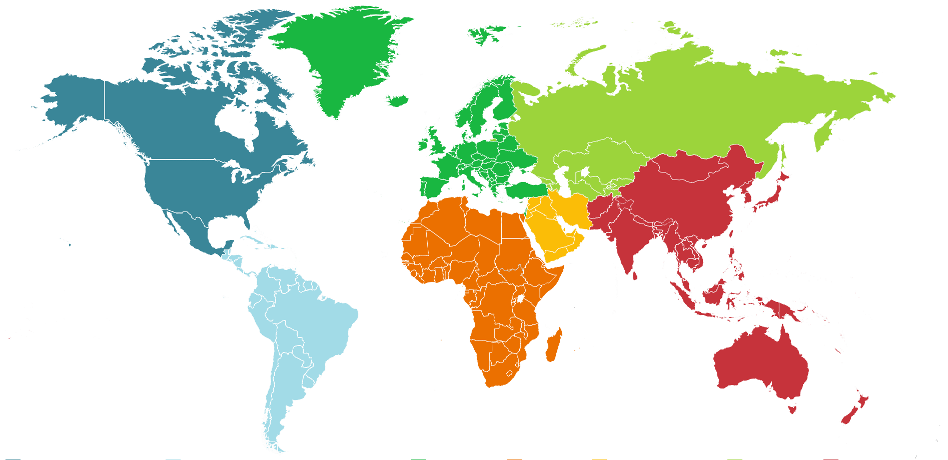
European Union: Austria, Belgium, Bulgaria, Croatia, Cyprus[1,2], Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain and Sweden.

IEA (International Energy Agency)**:** Australia, Austria, Belgium, Canada, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Mexico, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, The Netherlands, 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.

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.

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.

OECD (Organisation for Economic Co-operation and Development)**:** IEA grouping plus Chile, Colombia, Costa Rica, Iceland, Israel, Latvia and Slovenia.

OPEC (Organization of the Petroleum Exporting Countries)**:** Algeria, Angola, 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, 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). Timor-Leste joined ASEAN on 26 October 2025 and is excluded from this *WEO* grouping for this publication, but is included in aggregate within the overarching Asia Pacific group.

Sub-Saharan Africa: Angola, Benin, Botswana, Cameroon, Côte d'Ivoire, Democratic Republic of the Congo (DRC), 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.[7]

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] This designation is without prejudice to positions on status, and is in line with United Nations Security Council Resolution 1244/99 and the Advisory Opinion of the International Court of Justice on Kosovo's declaration of independence.

[7] 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.

Abbreviations and acronyms

AC	alternating current
ACCESS	Accelerating Clean Cooking and Electricity Services Scenario
AFOLU	agriculture, forestry and other land use
APEC	Asia-Pacific Economic Cooperation
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
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 the Parties (UNFCCC)
CPS	Current Policies Scenario
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
EIT	energy-intensive industry
EMDE	emerging market and developing economies
EOR	enhanced oil recovery
EPA	Environmental Protection Agency (United States)
ETS	emissions trading system
EU	European Union
EU ETS	European Union Emissions Trading System
EV	electric vehicle
FAO	Food and Agriculture Organization of the United Nations
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

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
IT	Information technology
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
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
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
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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Unless otherwise indicated, all material presented in figures and tables is derived from IEA data and analysis.

IEA Publications
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World Energy Outlook 2025

The IEA's flagship *World Energy Outlook (WEO)* is the most authoritative source of global energy analysis and projections. Updated annually to reflect the latest energy data, technology and market trends, and government policies, it explores a range of possible energy futures and their implications for energy security, access and emissions.

The *WEO* covers the whole energy system, using a scenario-based approach to highlight the central choices, consequences and contingencies that lie ahead. It includes exploratory scenarios that flow from different assumptions about existing policies, as well as normative pathways that achieve energy and emissions goals in full. The multi-scenario approach illustrates how the course of the energy system might be affected by changing key variables, including the energy policies adopted by governments around the world.

This year's edition comes amid major shifts in global energy policies and markets, and acute geopolitical strains. Governments are reaching different conclusions about the best ways to tackle concerns about energy security, affordability and sustainability. As always, the *World Energy Outlook* provides unrivalled insights into the consequences of different energy policy and investment choices. An important theme in this year's *WEO* is security of supply of critical minerals.

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